Q13: What length of open pipe will produce a frequency of 1200Hz as its first overtone on a day when the speed of sound is 340ms⁻¹? (28·3cm)

Solution: **Given data:** Speed of sound = $v = 340m/sec$

First overtone = $f_2 = 1200Hz$

Required:

Length of open pipe = L ?

Calculation:

In case of 1st overtone, we have,

$$f_2 = 2\left(\frac{v}{2L}\right) \Rightarrow f_2 = \frac{v}{L} \Rightarrow L = \frac{v}{f_2} \quad \text{------(1)}$$

Putting the values in equation (1), we get,

$$L = \left(\frac{340}{1200}\right) m = 0{\cdot}283m$$

$\Rightarrow L = (0{\cdot}283 \times 100)cm$ $\boxed{100cm = 1m}$

$\Rightarrow \boxed{L = 28{\cdot}3cm}$

Ans. $\boxed{\text{Length of open pipe} = L = 28{\cdot}3cm}$

+++

- رسول اللہ ﷺ نے ارشاد فرمایا: اللہ تعالیٰ نے تمہاری شفا حرام چیز میں نہیں رکھی۔
- رسول اللہ ﷺ نے ارشاد فرمایا: جس شخص کے جسم سے روح اس حال میں نکلی کہ وہ تین چیزوں سے بری تھا تو وہ جنت میں داخل ہوگا: تکبر، قرض اور خیانت۔
- ہم تکلیف کے جس مقام پر بھی ہوں، ہم سے آگے ضرور کچھ لوگ ہوتے ہیں۔ انہیں دیکھ کر ہمیں شکر کی لاٹھی تھام لینی چاہیے تاکہ راستہ سہولت سے کٹ سکے۔
- اگر تم اس وقت مسکرا سکتے ہو جب تم پوری طرح ٹوٹ چکے ہو تو یقین جانو کہ دنیا میں تمہیں کبھی کوئی توڑ نہیں سکتا۔
- خوبصورتی تو ختم اور تبدیل ہو جاتی ہے لیکن سیرت نہ تو ختم ہوتی ہے نہ تبدیل۔
- مشکلوں سے لڑنا نہیں بلکہ سنبھل کر گزرنا سیکھو ورنہ آپ کی شخصیت تباہ ہو جائے گی۔
- حضرت عثمان غنیؓ کا قول ہے "محبوبین کی کمائیں بھی دل کی طرح نرم ہو جاتی ہیں۔ ان کے رونگٹے کھڑے ہو جاتے ہیں۔ ان کے دل اور جلد نرم ہو جاتے ہیں اور یاد خدا سے ان کو راحت ہوتی ہے۔

CHAPTER 09 PHYSICAL OPTICS

Q1: What is meant by the dual nature of light? Discuss the history about the nature of light in detail.

Ans. **Dual Nature of Light:**

Light is a form of energy with the help of which we can see objects in our surrounding. The light shows dual nature i.e. in some cases, it behaves like a wave and in some cases it behaves like a particle.

In case of Compton effect, photoelectric and pair production phenomenon's, the light behaves like a particle. While in case of interference, polarization, reflection, diffraction, the light behaves like a wave. Thus the light shows dual nature.

History about the Nature of Light:

As the light shows dual nature, so in the beginning it was a great problem for the scientists to explain its real nature. The scientists gave their ideas about light in the form of following theories:

1. Newton's Corpuscular Theory of Light:

The corpuscular theory of light was put forward by Newton. It is also known as particle theory of light. According to Newton, light travels from one place to another in the form of extremely small particles known as carpuscles. On the basis of this theory, Newton was able to explain the phenomenon of reflection and refraction of light.

2. Wave Theory of Light:

This theory was put forward by Huygen. According to this theory, light travels from one place to another in the form of waves. This theory was able to explain reflection and refraction. However, this theory was failed to explain the phenomenon of polarization, diffraction and interference of light.

3. Maxwell's Theory of Light:

This theory was put forward by Maxwell in 1873. According to

Maxwell, light is electromagnetic in nature. It consists of both electric vector "$\vec{E}$" and magnetic vector "$\vec{H}$" and both are oscillating perpendicularly to the direction of propagation of the waves. The speed of light is $3 \times 10^8 m/sec$. This theory tells us that light waves needs no material medium for their propagation.

Beside it, "Thomas Young" performed an experiment on the basis of which he explained the diffraction of light.

In 1901, "Plank" introduced the "Quantum theory" of light. According to this theory, light travels from one place to another in the form of pockets or bundles of energy which are known as Quantas or photons. The energy of photon is equal to "hf". The rest mass of photon is zero.

The Quantum theory was able to explain the phenomenon of photoelectric effect, Compton effect and pair production.

Q2: (a) What is wave front? What is the difference between spherical and plane wave fronts? (b) State and explain Huygens principle.

Ans. (a) **Wavefront:**

The locus of points in a medium with same phase of vibration is known as wave front.

Explanation:

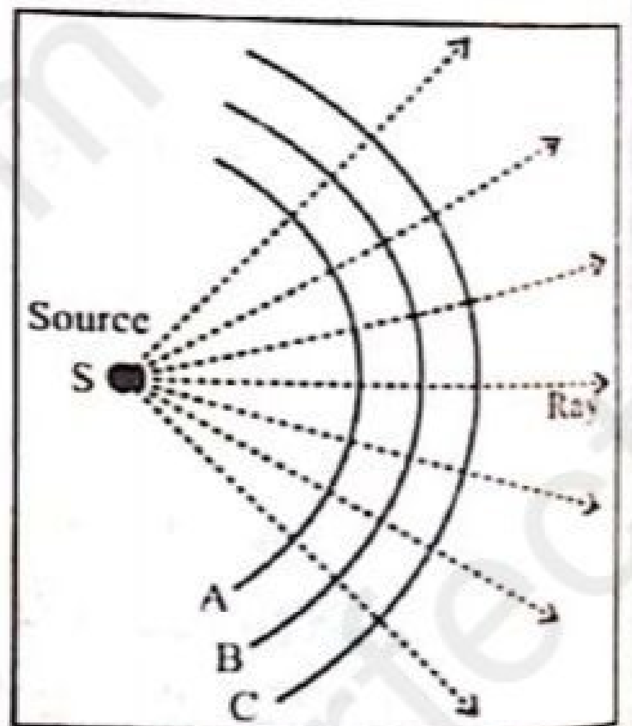
When we throw a piece of stone into a pond of water, then circular waves are produced. Now the crest produced here is a wave front, because all the points on the crest will have same phase of vibrations.

Types of Wavefront:

There are two types of wave fronts which are given below:

(i) Spherical Wave Front:

A wave front which have concentric sphere with centre at its source is known as spherical wave front, as shown in the figure.



In case of spherical wave front, the energy of the wave is transmitted equally in all directions as the wave propagates. The direction in which the energy travel is known as the ray.

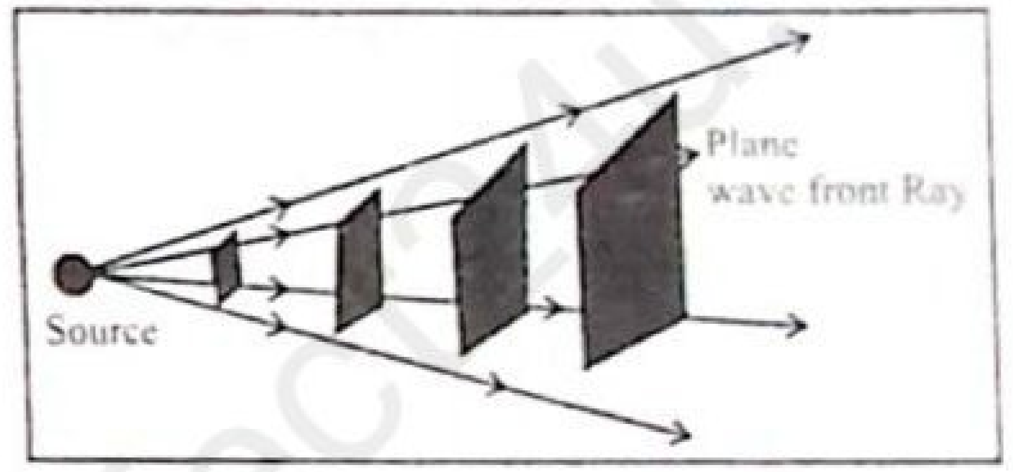
(ii) Plane Wavefront:

At very large distance, some portion of spherical wavefront appears as plane. Such straight portion of the wavefront is known as plane wavefront.

The plane surfaces are parallel to each other. The rays are perpendicular to the plane surfaces.

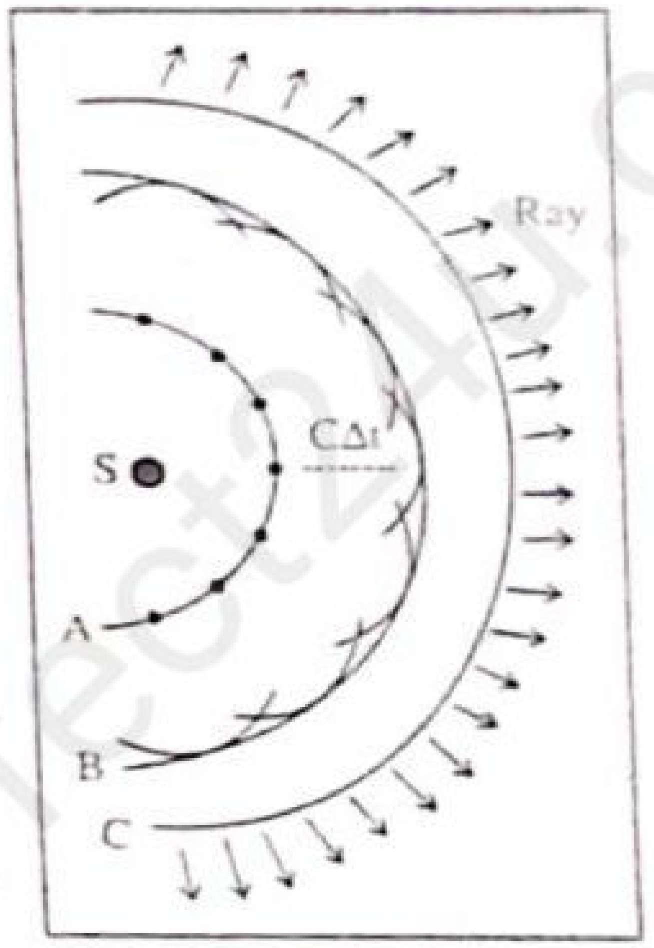
(b) Huygen's Principle:

According to this principles, "all points on a spherical wavefront acts as point sources for the production of secondary spherical wave which are known as wavelets.



Explanation:

Consider a source "S" which produces a wavefront "A" as shown in the figure. Let us take several points in the form of dots on the wavefront "A", as shown in the figure. These dots act as secondary sources and each produces spherical wave, as shown in the figure. Thus using these points as secondary sources, we can draw spherical circles each having radius "$C\Delta t$", where "C" is the velocity of light and "Δt" represents the time interval during which a wave propagates from one wavefront to another.



Thus the wavefront "A" give rises to another wavefront "B" as shown in the figure. Similarly, the wavefront "B" will give rise to another wavefront "C" and so on. This phenomena also occurs in case of plane wavefront. Such principle is known as Huygen's principle.

Q3: What is meant by coherent and incoherent sources of light? Explain how coherent sources can be produced?

Ans. (i) **Coherent Sources:**

Two sources of light are said to be coherent, if there is a constant phase relationship between the waves produced by them.

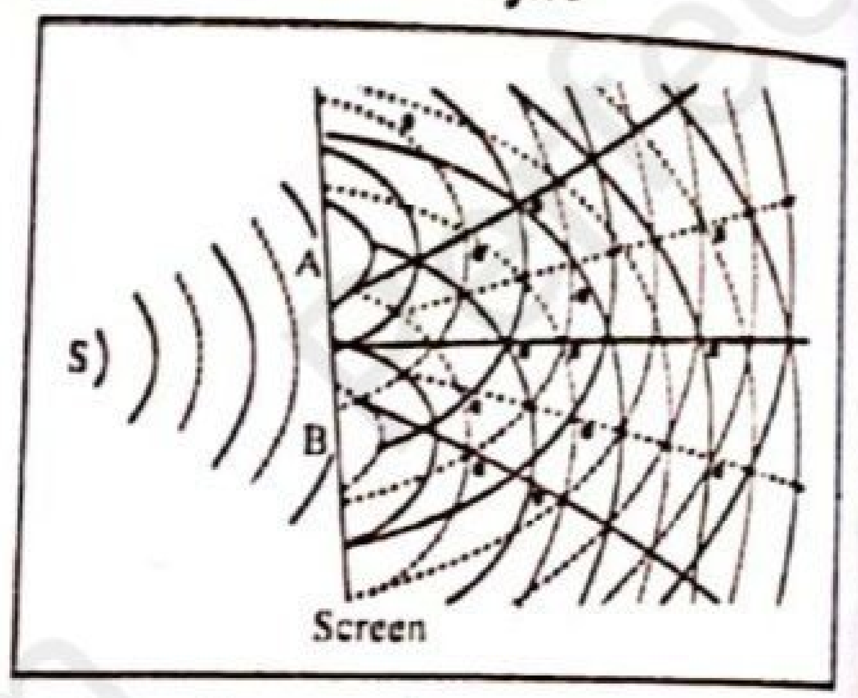
(ii) Incoherent Sources:

Two sources of light are said to be incoherent sources, if there is no constant phase relationship between the waves produced by them.

Production of Coherent Sources:

When light from a single source "S" is allowed to fall on a screen having two narrow openings, then the light which emerges out through the narrow openings becomes coherent. Thus the openings or slits of the screen behaves as coherent sources of light.

Examples:



1. The two vibrating spheres that produce the water waves are coherent sources because the spheres vibrate up and down together.
2. The two slits in Young's double slit experiment are coherent sources because the light from these sources originates from the same primary source.

Q4: (a) What is interference of light? (b) Discuss the types of interference. (c) Discuss the conditions for interference

---

Ans. (a) **Interference of Light:** (ETEA 2012-2…)

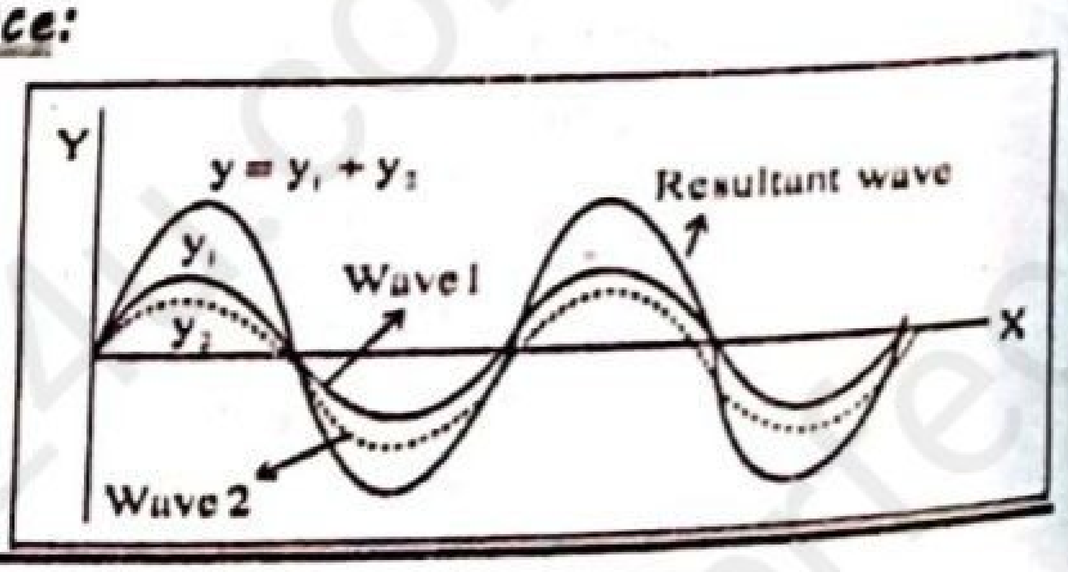
The superposition of two coherent light waves travelling along the same medium is known as interference of light.

(b) Types of Interference of Light:

There are two types of interference which are given below:

(i) Constructive Interference:

Waves are said to be interfere constructively when they reinforce the effect of each other.

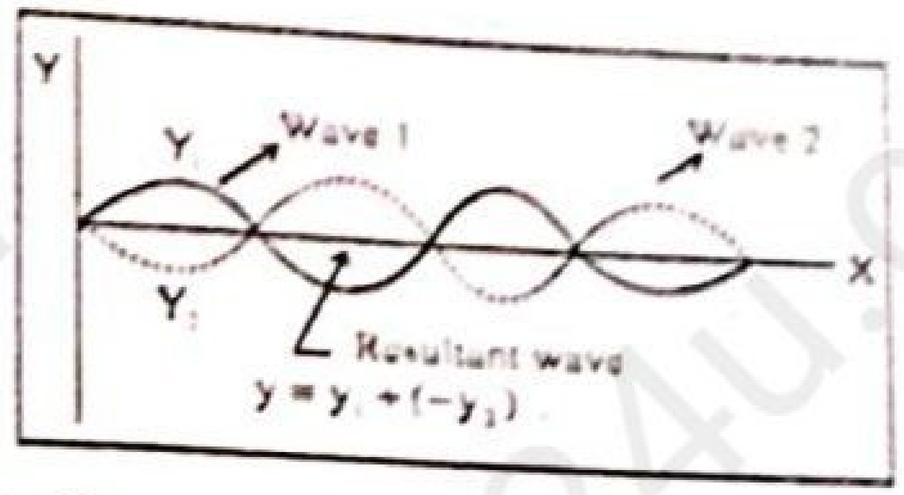


Due to constructive interference, the resultant in-

tensity of light increases and as a result bright bands [fringes] can be seen on the screen.

For constructive interference, the crest of one wave should coincide the trough of the other wave.

(ii) Destructive Interference:



Waves are said to be interfere destructively, if they cancel the effect of each other. Due to destructive interference, the intensity of light decreases and as a result dark bands [fringes] are produced on the screen. In case of destructive interference, the amplitude of the resultant wave will be less than either of the individual waves. For destructive interference, the crest of one wave coincide the trough of the other wave.

(c) Conditions for Interference: (ETEA 2006-2008)

1. The waves having same wavelength and period should be emitted continuously from the two sources.
2. The distance between the sources should be minimum.
3. The amplitude of the two waves should be the same.
4. Both light sources should be narrow.
5. For constructive interference, the path difference between the two waves is an integral multiple of the wavelength i.e.

$$\boxed{P.d = m\lambda} \quad \text{\_\_\_\_\_\_\_\_(1)}$$

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

And $\lambda =$ wavelength of light coming from the sources.

6. For destructive interference, the path difference between the two waves is an odd integral multiple of half of wavelength i.e.

$$\boxed{P.d = \left(m + \frac{1}{2}\right)\lambda} \quad \text{\_\_\_\_\_\_\_\_(2)}$$

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

And $\lambda =$ wavelength of light

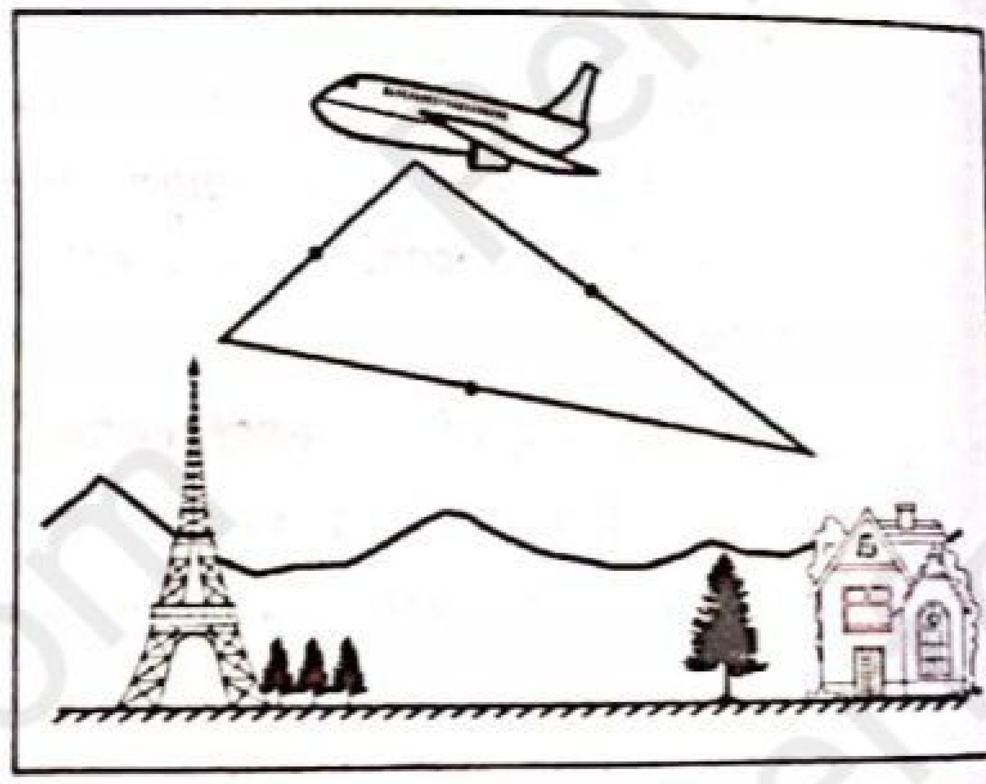
Do you know!

Different colors can be seen on the soap bubble whenever the light of the sun is falling on its surface. It is because the colors seen in a soap bubble arise from interference of light reflecting from the front and lack surfaces of the thin soap film.

For your information:

Distortion of the picture on a television receiver:

This occurs when an aircraft passes low overhead. The waves traveling directly from the transmitting antenna to the receiving aerial, interferes with the waves reflected from the aircraft. Usually the reflected wave is much weaker and so the interference is never completely destructive as a result the distortion of the picture on television screen takes place.



Q5: Describe the experimental arrangement for the production of interference fringes by Young's double slits method, and get an expression for the fringes space.

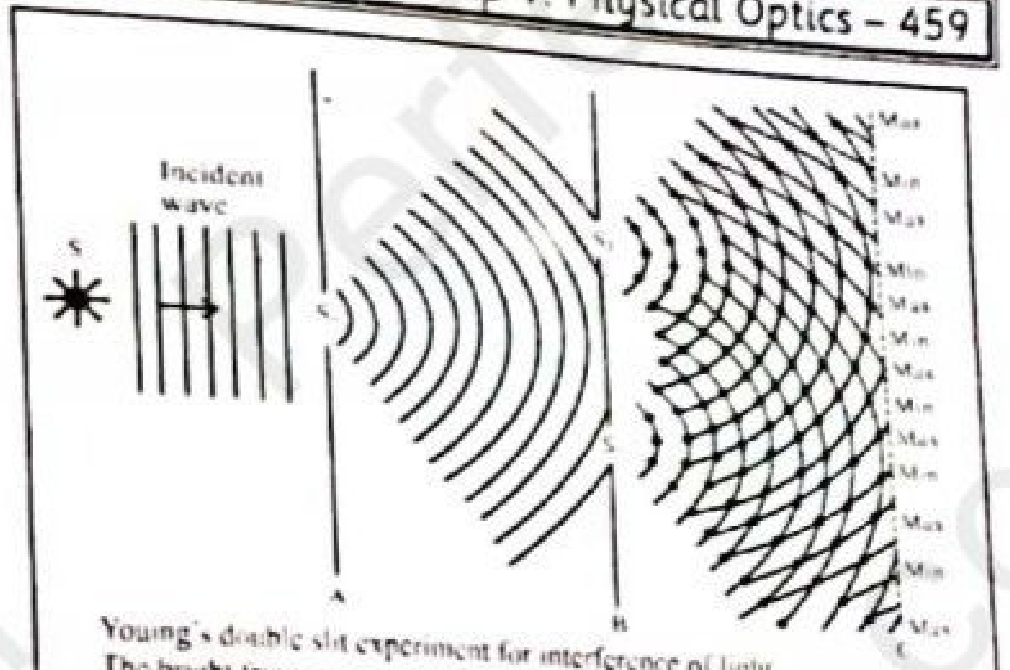
ETEA 2009, 2016, BISE Mardan 2019

Ans. The Young's double slits experiment gives the experimental verification of wave theory of light. This experiment was performed by Thomas Young in 1801 for studying the interference phenomenon of light.

Experimental Arrangement:

The experimental arrangement consists of light source "S", two slits "S_1" and "S_2" and a screen as shown in the figure.

A point "P" on the screen is situated at a distance "r_1" and at a distance "r_2" from slit "S_2" respectively. While the separation between the two slits is represented by "d". There is another narrow slit "S_o" placed closer to the source of monochromatic light, as shown in the figure.

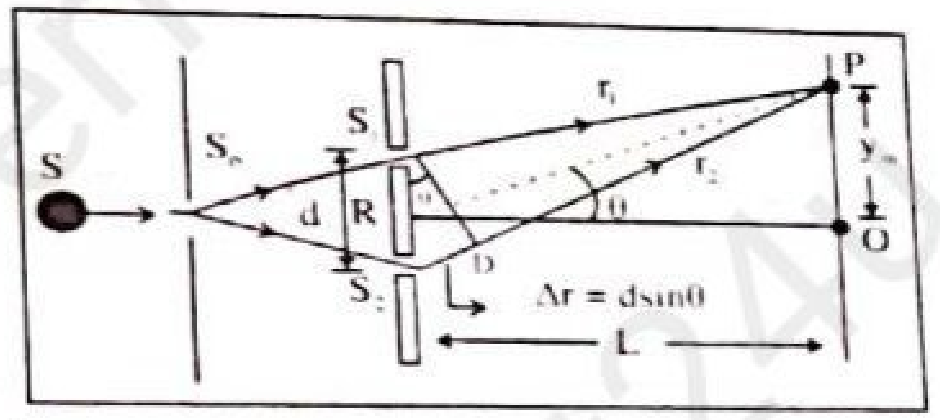


Young's double slit experiment for interference of light. The bright fringes are termed as maxima and dark fringes as minima

Now in the given arrangement, a beam of monochromatic light is allowed to pass through the narrow slit "S_o" and then through slits "S_1" and "S_2", as shown in the figure. The waves passes through "S_1" and "S_2" produce interference at point "P" on the screen.

Path Difference: (ETEA 2013,2016)

From the figure, we see that, $r_2 > r_1$. The difference between them is known as the path difference. To find the path difference, we draw a perpendicular from "S_1" on "r_2", as shown in the figure. Now in "ΔS_1DS_2", we have,



$$\sin\theta = \frac{\Delta r}{d} \Rightarrow \Delta r = d\sin\theta \quad \text{\_\_\_\_\_\_\_\_(1)}$$

Equation (1) represents the path difference. Now there will be constructive interference, if

$$\boxed{\Delta r = d\sin\theta = m\lambda} \quad \text{\_\_\_\_\_\_\_\_(2)}$$

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

And $\lambda =$ wavelength

Now there will be destructive interference if

$$\boxed{\Delta r = d\sin\theta = (m + \frac{1}{2})\lambda} \quad \text{\_\_\_\_\_\_\_\_(3)}$$

Position of Bright Fringes [Band] and Dark Fringes on the Screen:

In order to find out the position of bright band [fringes] or dark fringes on the screen we use the triangle "ΔROP", in which,

$\tan\theta = \frac{y_m}{L} \Rightarrow y_m = L\tan\theta$ ________ (4)

Now if $L >> d$ and point "P" is very close to point "O", we put $\tan\theta = \sin\theta$ so equation (4) becomes,

$y_m = L\sin\theta$ ________ (5)

Now for constructive interference, we have,

$d\sin\theta = m\lambda$

$\Rightarrow \sin\theta = \frac{m\lambda}{d}$ ________ (6)

Putting equation (6) n equation (5), we get,

$y_m = L\frac{m\lambda}{d} \Rightarrow \boxed{y_m = \frac{L}{d}m\lambda}$ ________ (7)

Equation (7) represents the position of mth bright fringe on the screen. Now for destructive interference, we have,

$d\sin\theta = \left(m+\frac{1}{2}\right)\lambda \Rightarrow \sin\theta = \frac{1}{d}\left(m+\frac{1}{2}\right)\lambda$ ________ (8)

Putting equation (8) in equation (5), we get,

$\boxed{y_m = \frac{L}{d}\left(m+\frac{1}{2}\right)\lambda}$ ________ (9)

Equation (9) represents the position of mth dark fringe on the screen.

Fringe Width: (ETEA 2014)

The distance between two consecutive bright fringes is known as fringe width or fringe spacing.

Now for finding the fringe spacing for dark fringe, we subtract 1st order dark fringe from 2nd order dark fringe i.e.

Fringe spacing $= y_2 - y_1$

$\Rightarrow [\text{Fringe spacing}]_{Dark} = \frac{5L\lambda}{2d} - \frac{3L\lambda}{2d}$

$\Rightarrow \boxed{(\text{Fringe spacing})_{Dark} = \frac{L\lambda}{d}}$ ________ (10)

> $y_m = \frac{L}{d}\left(m+\frac{1}{2}\right)\lambda$
>
> For 1st order we put $m = 1$
>
> So $y_1 = \frac{3}{2}\frac{L\lambda}{d}$
>
> For $m = 2$
>
> $y_2 = \frac{5}{2}\frac{L\lambda}{d}$

Similarly for bright fringes, we have,

$(\text{Fringe spacing})_{Bright} = y_2 - y_1$

$\Rightarrow (\text{Fringe spacing})_{Bright} = \frac{2L\lambda}{d} - \frac{L\lambda}{d}$

$\Rightarrow \boxed{(\text{Fringe spacing})_{Bright} = \frac{L\lambda}{d}}$ ________ (11)

Uses of Young's Double Slits Experiments:

1. It gives us the experimental verification of wave theory of light.
2. It can be used to study the phenomenon of interference.
3. It is used for the determination of fringe width.
4. It can be used for finding the wavelength of light.

> $y_m = \frac{L}{d}m\lambda$
>
> For $m = 1$
>
> $y_1 = \frac{L}{d}\lambda$
>
> For $m = 2$
>
> $y_2 = \frac{2L}{d}\lambda$

> **Quiz:**
>
> Young's double slit experiment breaks a single light beam into two sources. Would the same pattern be obtained for two independent sources of light, such as the headlights of a distant car?
>
> Ans. No, two independent light sources do not have coherent phase.

Q6: Explain the interference effect produced by thin film.

Ans. **Thin Film:**

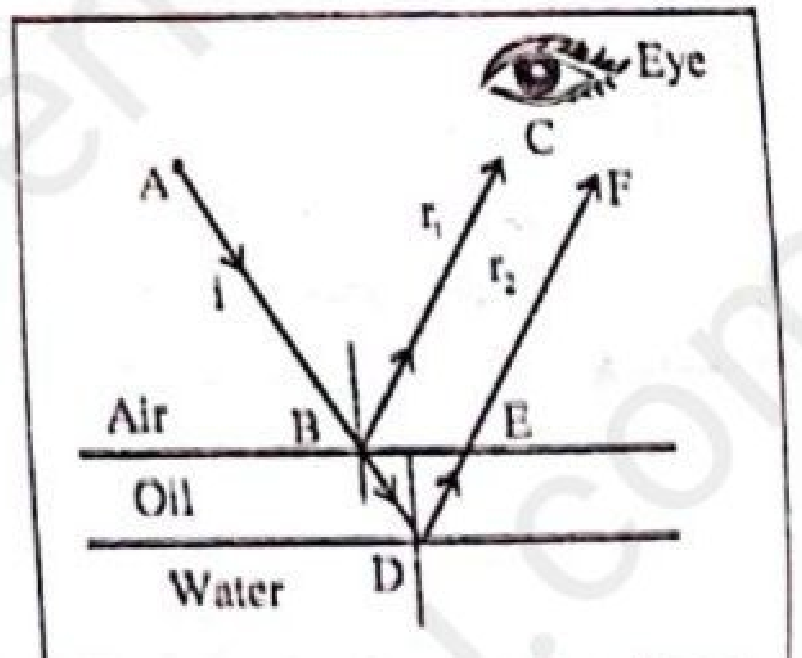
A layer of extremely small thickness of certain transparent medium is known as thin film.

Examples of Thin Film:

Surface of soap bubbles, a thin layer of oil on the surface of water, cracks in glass plate etc are the examples of thin film in which phenomenon of interference takes place.

Explanation:

Consider a thin film of a refracting medium, as shown in the figure. Let a beam "AB" of monochromatic light is allowed to fall on the upper surface of the film. At point "B" the incident ray is divided into two parts. One part is reflected in the form of beam "BC", while the other part is refracted in the form of beam "BD" as shown in the figure.



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

Now at "D" the ray "BD" is divided into two parts. One part is refracted and the other part is reflected in the form of beam "DE". At "E" the beam is refracted in the form of ray "EF" as shown in the figure. As the beam "BC" and "EF" are the parts of the same primary beam "AB", so both beams are phase coherent. As the film is thin, so the separation between the beam "BC" and "EF" will be very small. Thus both beams superpose each other and as a result, interference takes place which can be observed with eye, as shown in the figure.

Now if the two beams reinforce each other, then constructive interference will take place and the film will be appear as bright.

And if the two beams cancel each other, then destructive interference will take place and the film will be appear as dark.

Film of Irregular Thickness:

If we allowed a white light to fall on a film of irregular thickness at all possible angles, then the interference can be observed 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 white light.

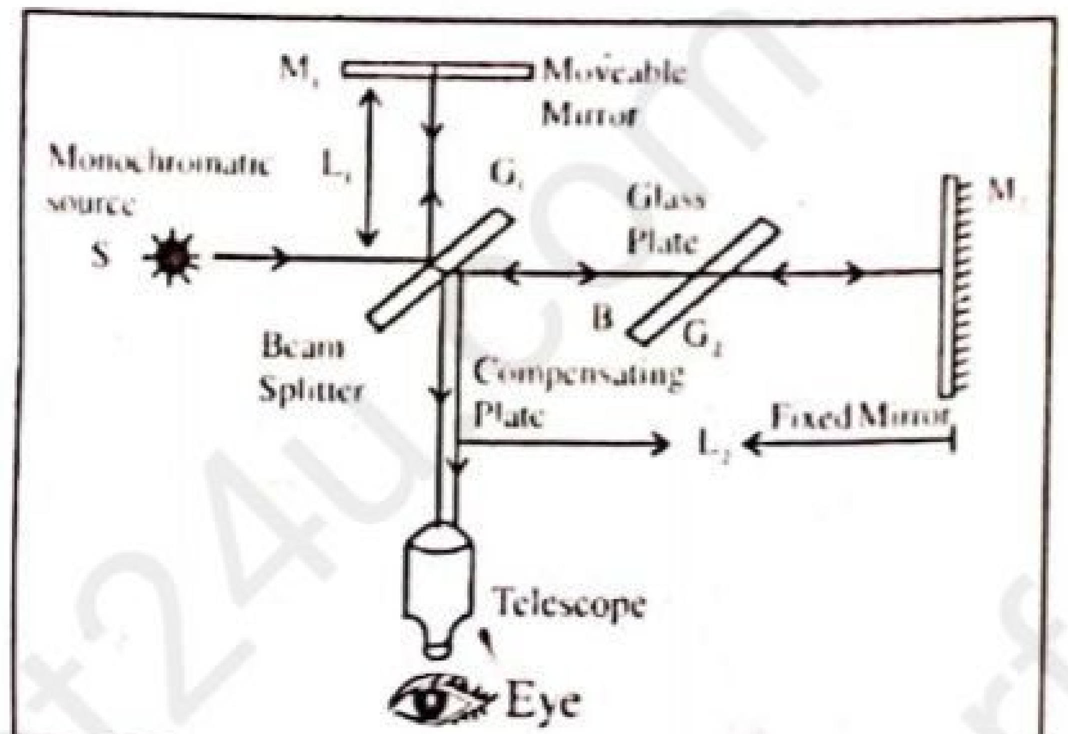
Q7: Describe the construction and working of Michelson's interferometer.

ETEA 2006, 2010

Ans. Michelson's interferometer is an optical instrument which is used to study the interference of light waves and find its wavelength.

Principle:

It splits a light beam into two parts and then recombines them to form an interference pattern after they have travelled over different paths.



Construction:

It consists of the following parts:

1. Source of monochromatic light.
2. Two plane mirrors M_1 and M_2.
3. Half silvered glass plate "G_1".
4. Glass plate [compensator plate] "G_2".

Working:

In the given arrangement, a beam of monochromatic light originates from the source "S" as shown in the figure. This beam of light is then allowed to fall on a glass plate "G_1" which divides this ray into two parts. One of these rays is directed towards the mirror "M_1" and the other is directed towards the mirror "M_2". These rays are reflected from the mirrors and travels back towards the glass plate "G_1". Both rays transmit through "G_1" and enter the eye through telescope. Both waves superpose each other and thus the phenomenon of interference takes place.

Now if the paths "L_1" and "L_2" are the same, then we will observe constructive interference. As a result bright fringes will be produced which can be seen with the help of telescope, as shown in the figure. We can change the length of path "L_1" by moving the mirror "M_1" and as a result, we will observe both constructive and destructive interference.

Alternate Bright and Dark Fringes:

If the mirror "M_1" is moved through a distance "$\frac{\lambda}{4}$" backward, then the path difference between the two beams will be equal to "$\frac{\lambda}{2}$" and destructive interference will take place and thus we will observe dark fringe.

If the mirror "M_1" is further moved through a distance "$\frac{\lambda}{4}$" then the path difference will become $\left[\frac{\lambda}{2}+\frac{\lambda}{2}=\lambda\right]$ "λ" and as a result constructive interference will take place. So we will observe bright fringe.

In this way, if we move the mirror "M_1" slowly through distance "$\frac{\lambda}{4}$" each time, then bright and dark fringes will be appear alternately.

Determination of Wavelength:

To determine the wavelength "λ" of the given light, let "m" be the total number of observed fringes. Now if the mirror "M_1" is moved backward through distance "$\frac{\lambda}{4}$" each time, then the total distance "p" is given by,

$$p = m\left(\frac{\lambda}{4}+\frac{\lambda}{4}\right) \Rightarrow p = \frac{m\lambda}{2} \Rightarrow \boxed{\lambda = \frac{2p}{m}} \text{ ——— (1)}$$

Using equation (1), we can calculate the wavelength of given light for given values of "p" and "m".

Uses of Michelson Interferometer:

1. It is used to observe the interference of light.
2. It is used to calculate the wavelength of light.

Q8: Define and explain the diffraction of light.

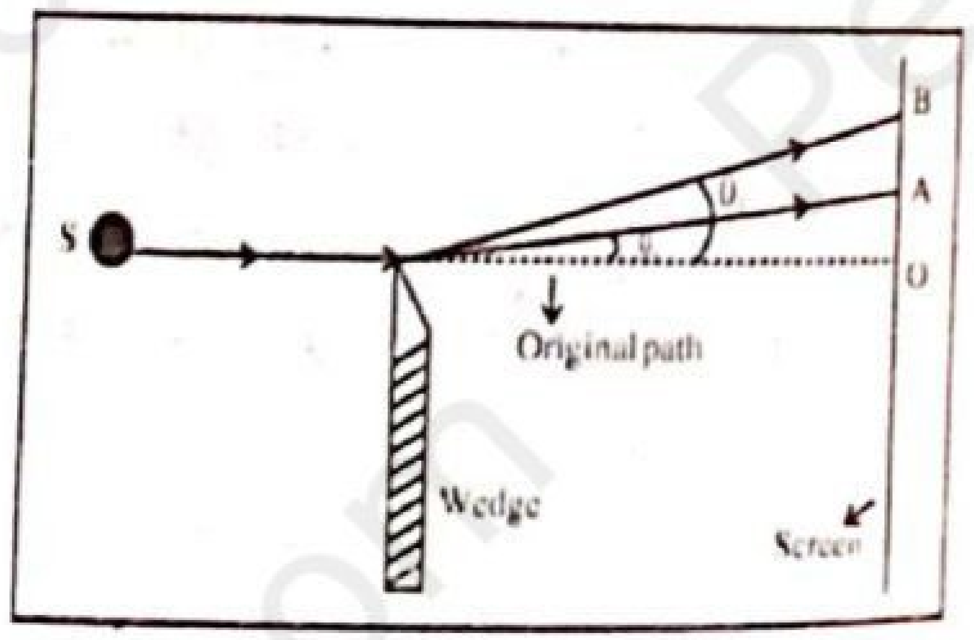
ETEA 2005, 2013

Ans. **Diffraction of Light:**

The spreading of light waves round the edges of a narrow opening is known as diffraction. (OR)

The spreading of light into the region behind an obstacle is known as diffraction. (OR)

The deviation of light from its original path is known as diffraction.



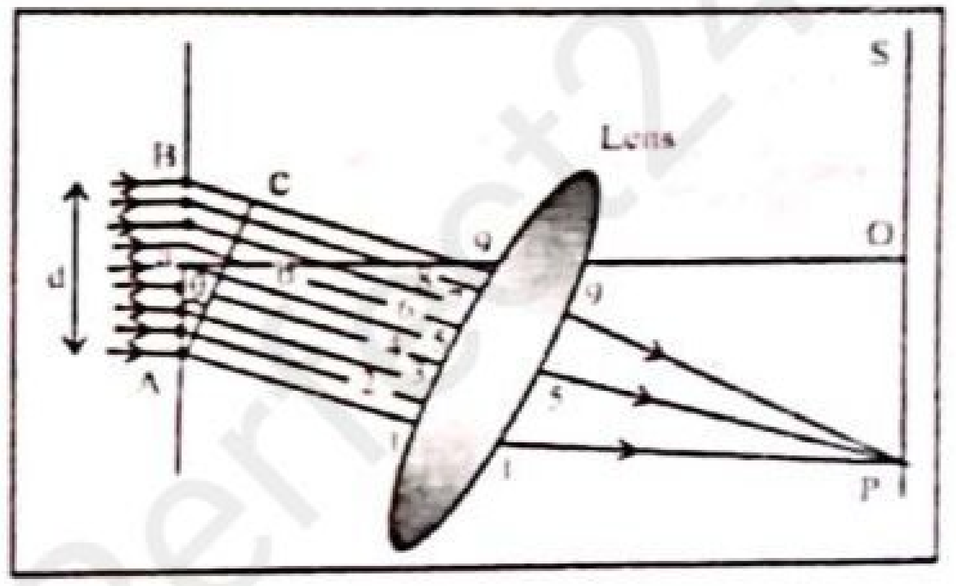
Explanation:

Consider a wedge placed in the path of a beam of light coming from its source "S" as shown in the figure. When the beam of light strikes the wedge, it deviates from its path through an angle θ_1, θ_2 etc as shown in the figure. As a result, the original position "O" on the screen will appear dark and we will observe the diffraction fringes at points "A" and "B" above the central point "O". Such deviation of light from its original path is known as diffraction of light.

Q9: Discuss Fraunhofer diffraction at a single slit. (OR) Discuss the diffraction due to a narrow slit.

BISE Mardan 2019

Ans. Consider a beam of monochromatic light of wavelength "λ" falls on a slit AB having width "d" as shown in the figure. In order to observe the diffraction pattern, a screen "S" is placed parallel to the slit "AB"; the rays [wavelets] are focused on the screen with the help of a convex lens. 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.



The wavelets interfere to produce the diffraction pattern on the screen. Now let the waves "1" and "5" are in phase. When these waves reach the wavefront "AC", wave "5" would have a path difference "ab".

If $ab = \frac{\lambda}{2}$, then the two rays will reach the point "p" on the screen and destructive interference will takes place. Similarly, each pair 2 and 6, 3 and 7, 4 and 8, differ in path by $\frac{\lambda}{2}$ and hence they will also interfere destructively.

Now to find the value of path difference "ab", we use the ΔabA, in which we have,

$$\sin\theta = \frac{ab}{\left(\frac{AB}{2}\right)} \qquad \left[\sin\theta = \frac{perp}{hyp}\right]$$

$$\Rightarrow ab = \frac{AB}{2}\sin\theta \Rightarrow ab = \frac{d}{2}\sin\theta \text{ ——— (1)} \quad [AB = d]$$

For destructive interference, we have,

$ab = \frac{\lambda}{2}$ So equation (1)

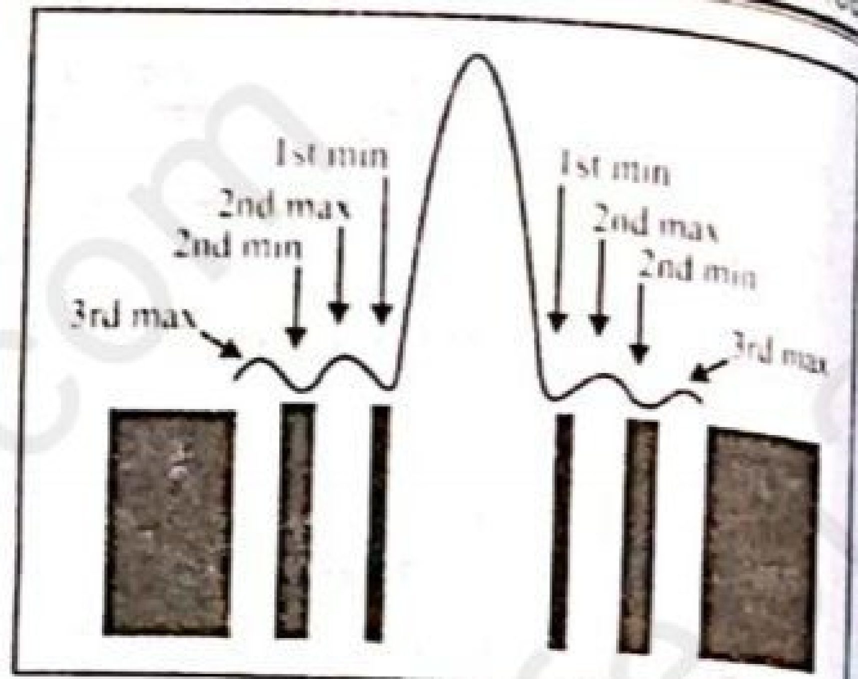
$$\Rightarrow \frac{\lambda}{2} = \frac{d}{2}\sin\theta \Rightarrow \boxed{d\sin\theta = \lambda} \text{ ——— (2)}$$

Equation (2) represents the first order minimum [dark]. In general, equation (2) can be written as,

$\boxed{d\sin\theta = m\lambda}$ ________ (3)

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

The region between any two consecutive minima will be maxima [bright]. Thus a series of bright and dark [maxima and minima] regions are observed on the screen. The first bright region is situated at the centre of the pattern, as shown in the figure.



Q10: Discuss the difference between interference and diffraction.

INTERFERENCE	DIFFRACTION
1. Interference is the superposition of two waves.	1. Diffraction is the bending of waves around an obstacle.
2. Two separate wave fronts originating from two coherent sources produce interference.	2. Secondary wavelets originating from different parts of the same wave front cause diffraction.
3. The region of minimum intensity is perfectly dark in interference.	3. In diffraction they are not perfectly dark.
4. The width of the fringes is equal in interference.	4. In diffraction the width of the fringes is never equal.
5. The intensity of all positions of maxima are of the same intensity in interference.	5. In diffraction, only zeroth order maxima has maximum intensity while all other maxima are of lower intensity than the zeroth order maxima.

Q11: (a) What is diffraction grating? (b) What is grating element? (c) How can the wavelength of a beam of light be measured with diffraction grating?

BISE Kohat 2017, 2019, BISE DI Khan 2019, BISE Bannu 2017

Ans. (a) Diffraction Grating:

A glass plate having large number of close parallel equidistant slits mechanically ruled on it is known as diffraction grating. (OR)

A diffraction grating is a device that can separate a beam of light into its constituent colurs or wavelengths.

(b) Grating Element:

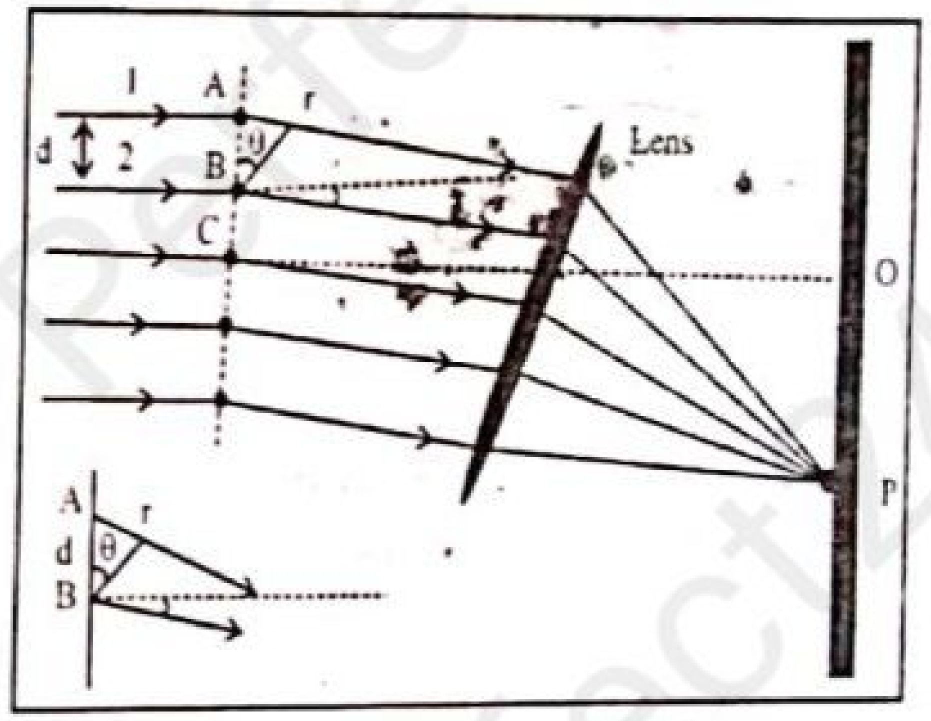
The separation between two slits is known as grating element. It is represented by "d". Its value can be obtained by dividing the unit length of grating by the total number of lines ruled on it. i.e.

$$d = \frac{\text{unit length of grating}}{\text{total number of lines ruled on it}} \Rightarrow \boxed{d = \frac{1}{N}}$$

(c) Grating Equation for Measuring Wavelength of Light:

Consider a grating plate which consists of a number of parallel slits, as shown in the figure. Let parallel rays of light are allowed to pass through this diffraction grating, as shown in the figure.

The diffraction grating diffracts the rays towards a convex lens which converges these rays to a single point "O" on the screen as shown in the figure.



Now consider rays "1" and "2", we see that ray "1" covers longer distance than ray "2". So for finding their path difference, we draw a perpendicular "Br" from ray "2" on ray "1". Thus "Ar" represents path difference between the two waves.

Now in "ΔABr", we have,

$$\sin\theta = \frac{Ar}{AB} \Rightarrow Ar = AB\sin\theta \text{ ________ (1)}$$

In equation (1), Ar = path difference, $AB = d$

So equation (1) becomes,

Path difference $= d\sin\theta$ ________ (2)

For constructive interference, we have,

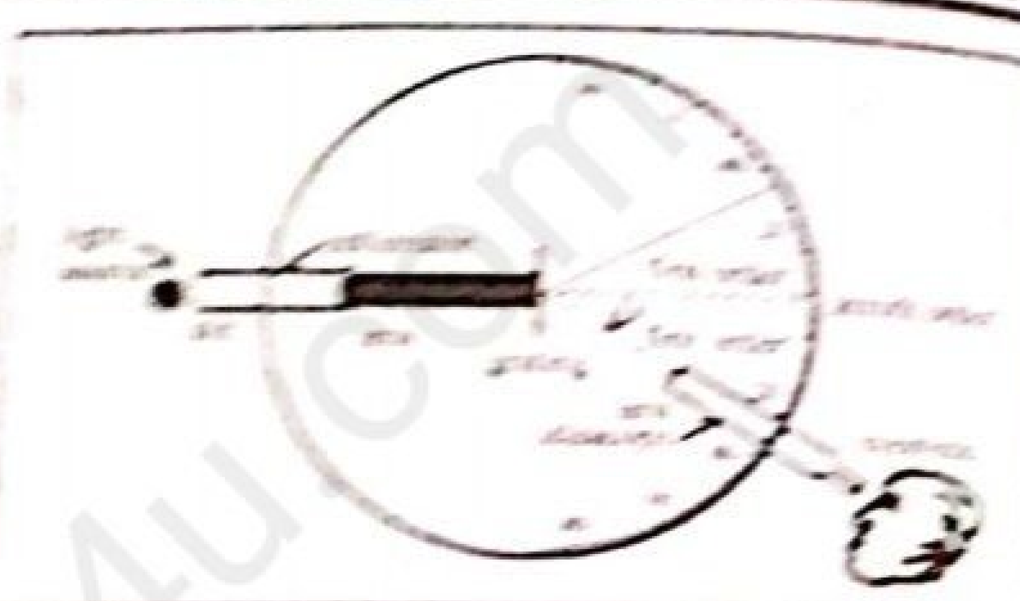
Path difference $= m\lambda$ ________ (3)

Comparing equation (2), (3), we get,

$\boxed{d\sin\theta = m\lambda}$ ________ (4)

Where $m = 0, 1, 2, 3, 4, \ldots\ldots\ldots$

Equation (4) can be used to calculate the wave-length of light. For this purpose, grating spectrometer is used as shown in the figure. Here monochromatic light falls on grating normally through the collimator. The light deviates from original path through an angle "θ" and its image can be viewed with the help of telescope. The value of "θ" can be measured with the help of telescope on both sides of central maxima for the same order "m". For one side we take "θ_1" and for other side we take "θ_2". We take their average to get "θ". Then using equation (4), wavelength "λ" of the light can be calculated.

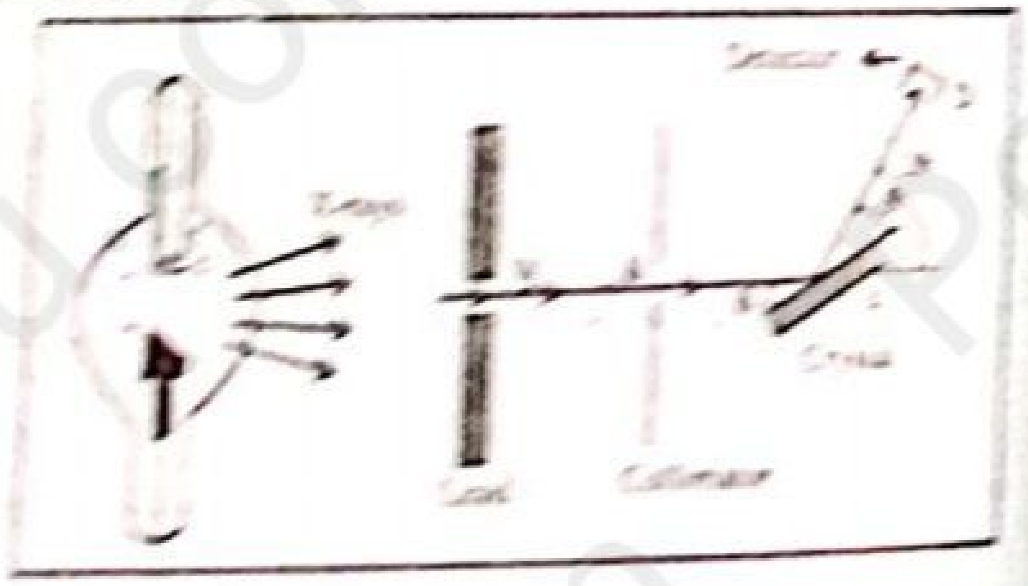


Q12: (a) Explain the diffraction of x-rays by crystal. (b) Derive an expression for Bragg's law to find the wavelength of light used.

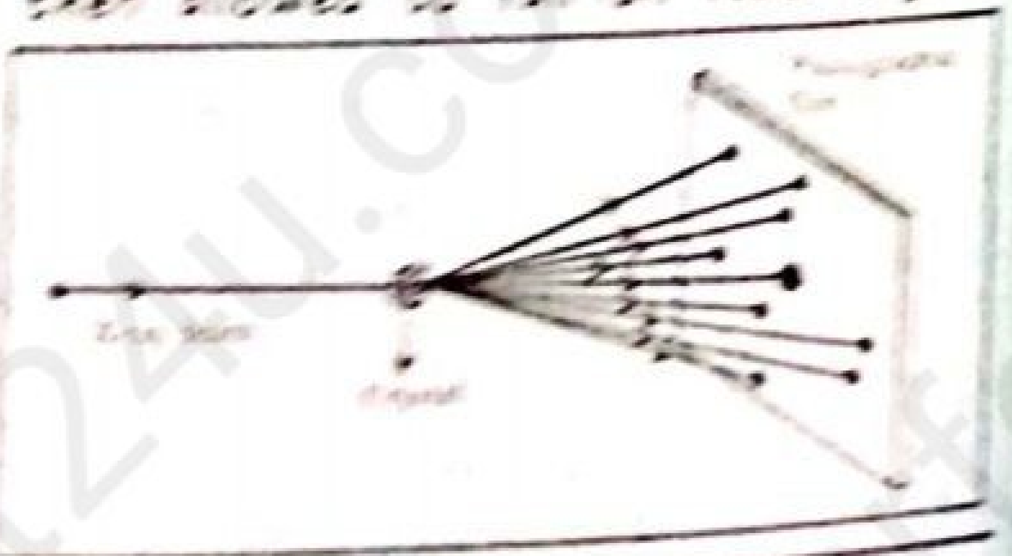
BISE Peshawar 2013

Ans: (a) **Diffraction of X-rays by Crystal:**

In case of crystals, the layers of atoms are situated very closely to each other. The separation between these layers is less than 1nm. Thus the study of crystals is possible only if we use wave of shorter wavelength like x-rays.



In the given arrangement, a beam of x-ray is obtained from x-rays source. The beam of x-rays is then allowed to fall on NaCl crystal after passing through the narrow opening of lead and then narrow slit "S" as shown in the figure. When the beam strikes the crystal, they are transmitted and enters the detector "D" as



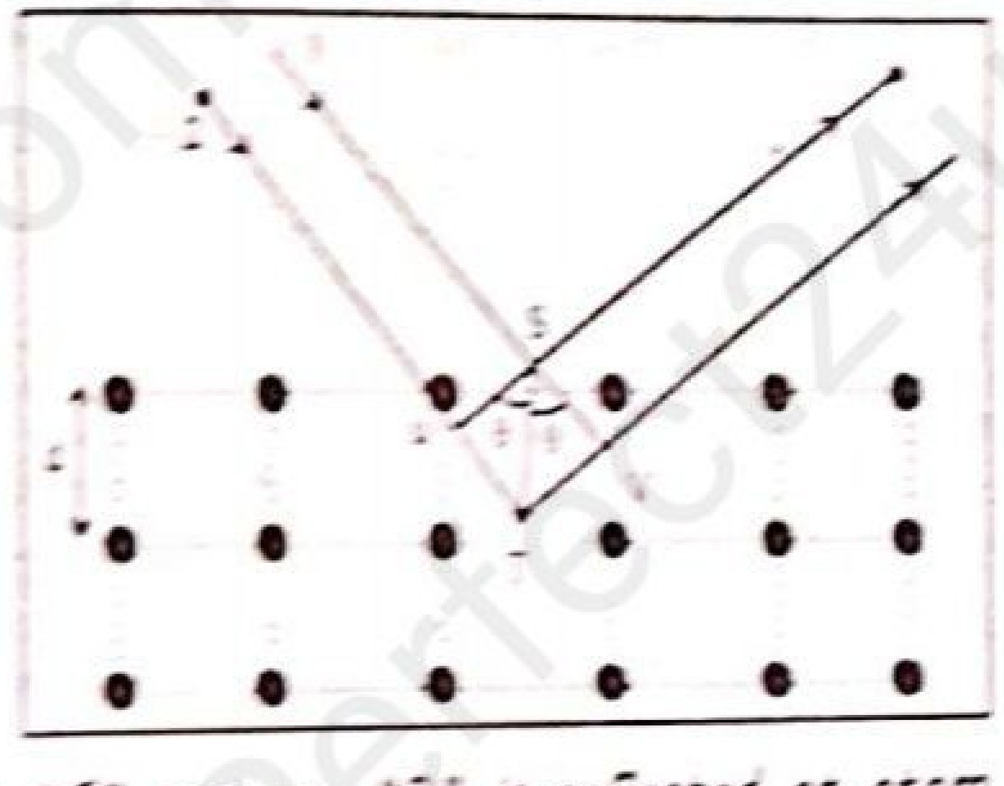
shown in the figure.

The laue photograph obtained consists of the central spot surrounded by many other spots arranged in proper manner. These spots are known as laue spots.

The arrangement of laue spots for different crystal is different depending on their structure. The above experiment shows that x-rays are electromagnetic waves and the atoms are arranged in three dimensional lattice.

(b) **Bragg's Law:**

Consider a rock salt's crystal as shown in the figure. The arrangements of atom of the crystal are shown by dots and let "d" be the distance of separation between the two atoms.



Now consider two rays "1" and "2" which are allowed to fall on the crystal. The ray "1" is reflected at atom "S" and ray "2" is reflected at atom "T", as shown in the figure.

We see that, ray "2" covers large distance than ray "2". So there is a path difference between them. To find this path difference, we draw two perpendiculars "Su" and "SV", as shown in the figure.

Now the total path difference is given by,

Path difference = uT + TV ________ (1)

Now in "ΔSuT", we have,

$$\sin\theta = \frac{uT}{ST} \Rightarrow uT = ST\sin\theta$$

$\Rightarrow uT = d\sin\theta$ ________ (2) [ST = d]

> A polarized wave is transverse wave.
> ETEA 2013

Similarly, in "ΔSTV", we have,

$TV = d\sin\theta$ ________ (3)

Putting equations (2), (3), in equation (1), we get,

$p.d = d\sin\theta + d\sin\theta$

$\Rightarrow p.d = 2d\sin\theta$ ________ (4)

Now for constructive interference, we have,

$p \cdot d = m\lambda$ ______________ (5)

Comparing equations (4), (5), we get,

$\boxed{2d \sin\theta = m\lambda}$ ______________ (6)

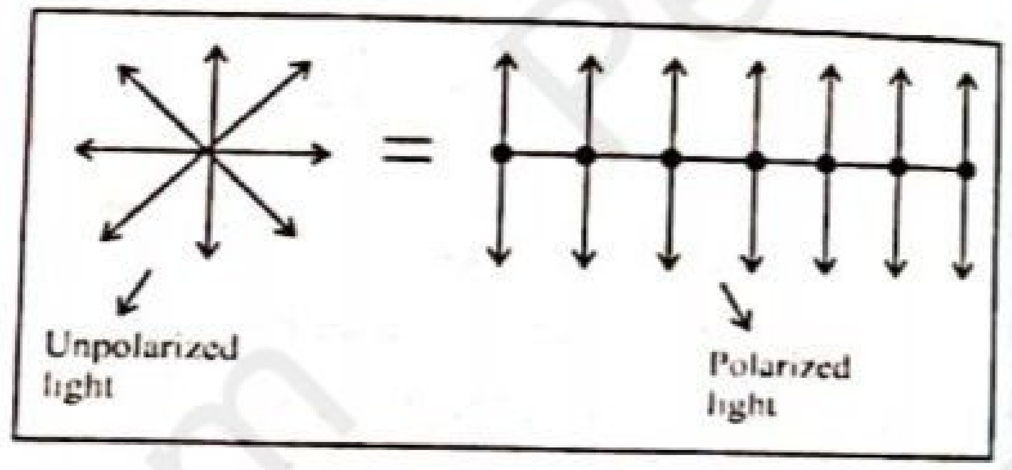
Equation (6) represents the Bragg's equation or Bragg's law. For given values of m, d, θ, we can calculate the wavelength "λ" of the given light. Similarly, for the given values of λ, θ, m we can calculate the interplanar spacing "d" between the smaller parallel planes of a crystal.

Q13: (a) What is polarization of light? (b) Define plane polarized light. (c) Explain that how this phenomenon decide that light waves are transverse in nature?

ETEA 2005, 2010, 2011, 2012, 2013

Ans. (a) <u>Polarization of Light:</u>

The process in which an ordinary light is allowed to pass through calcite crystal, then the light which is emergent out is known as polarized light and the process is called polarization of light.



(b) <u>Plane Polarized Light:</u>

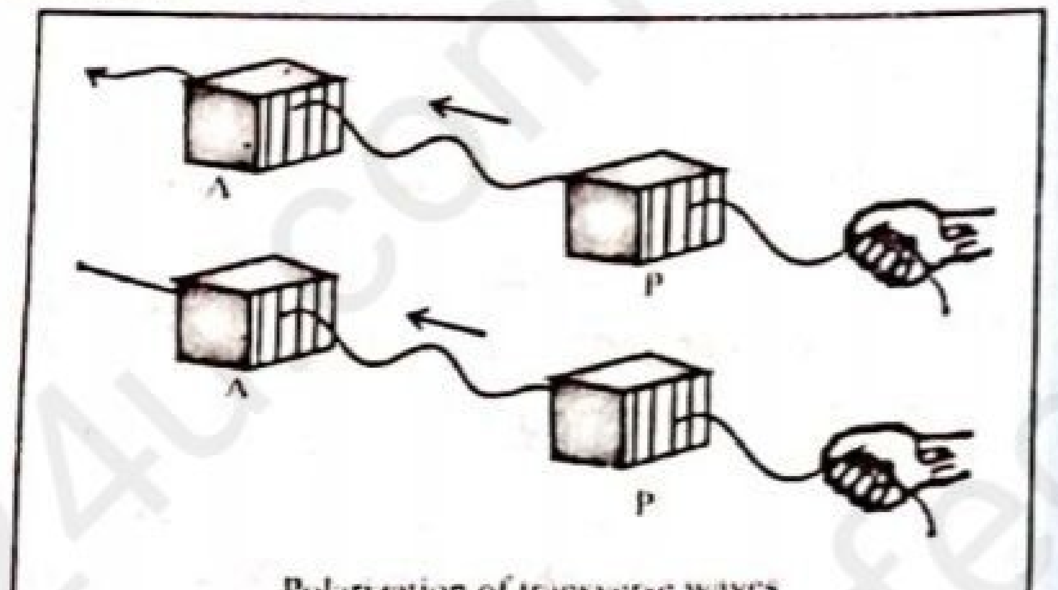
The process of forcing or confining of light waves to vibrate only in one plane is known as plane polarization and the light is called plane polarized light.

In polarization process, the electric and magnetic vibrations of light waves are restricted to a single plane of vibration.

(c) Polarization is the property exhibited by transverse waves only. It does not occur for longitudinal waves such as sound waves.

<u>Experiment with Transverse Waves:</u>

To study that only transverse wave exhibits polarization property, we consider a transverse wave on a string which passes through a slot "p" in a wooden board, as shown in the figure.



Polarization of transverse waves

When the slot is parallel to the direction of the transverse vibrations, the wave passes through the slot un-disturbed. But if we held another slot at right angle to the first one, then no wave will pass through the 2nd one.

If the string is replaced by a spring and longitudinal wave is sent into it, then the wave will pass through the slots regardless of the orientation of the slots. This shows that longitudinal waves do not show polarization property.

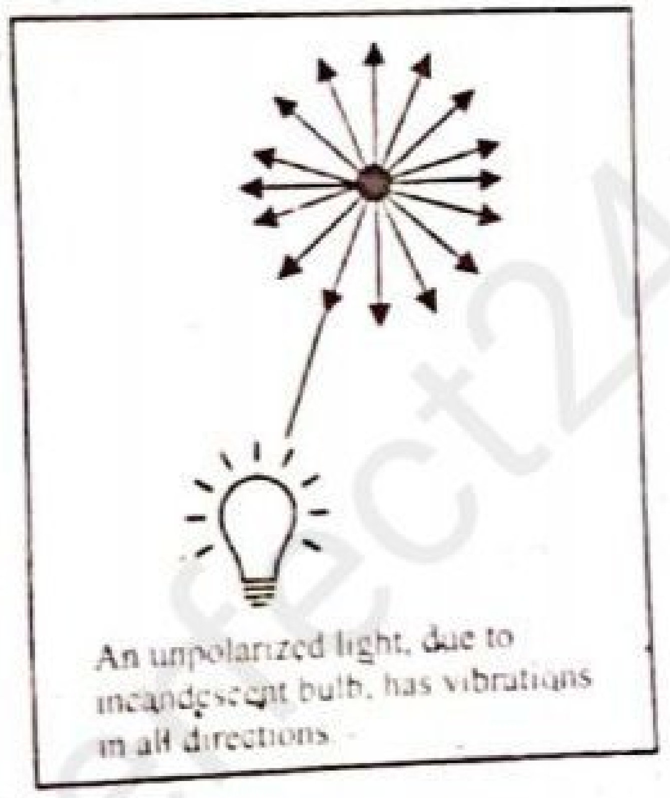
<u>Conclusion about the Nature of Light:</u>

From the above discussion, it is clear that polarization phenomenon is applicable to transverse waves only. It is not applicable to longitudinal waves. Now as we can convert ordinary light into polarized light through the process of polarization and polarization is applicable to transverse waves only, so the phenomenon of polarization clearly and successfully decides that light waves are transverse in nature.

Q14: (a) What is meant by unpolarized light and polarized light? (b) Discuss the various process through we can obtain polarized light.

Ans. (a) <u>Unpolarized Light:</u>

The light which vibrates in all directions is known as unpolarized light. The ordinary sun light, light emitted from ordinary incandescent bulb etc are the examples of unpolarized light.



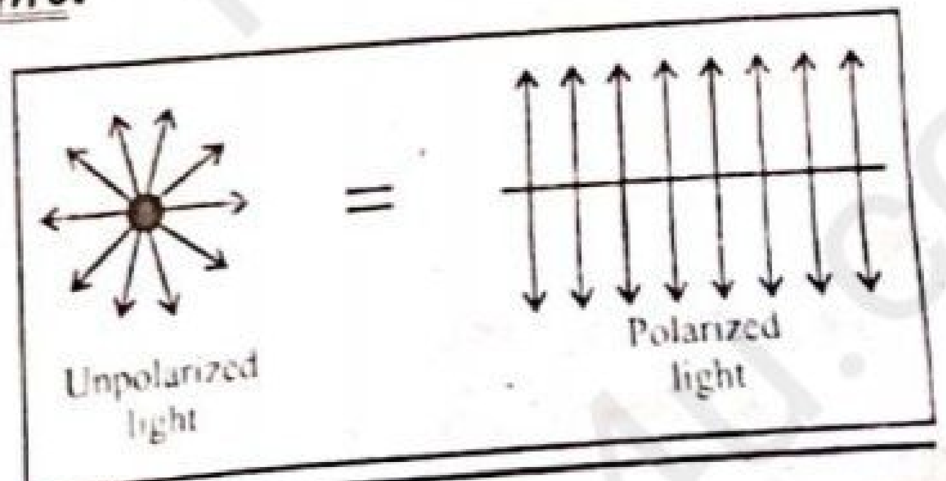
An unpolarized light, due to incandescent bulb, has vibrations in all directions

<u>Polarized Light:</u>

If the electric and magnetic vibrations of light waves are restricted to a single plane of vibrations, then such light is known as polarized light.

(b) <u>Production of Polarized Light:</u>

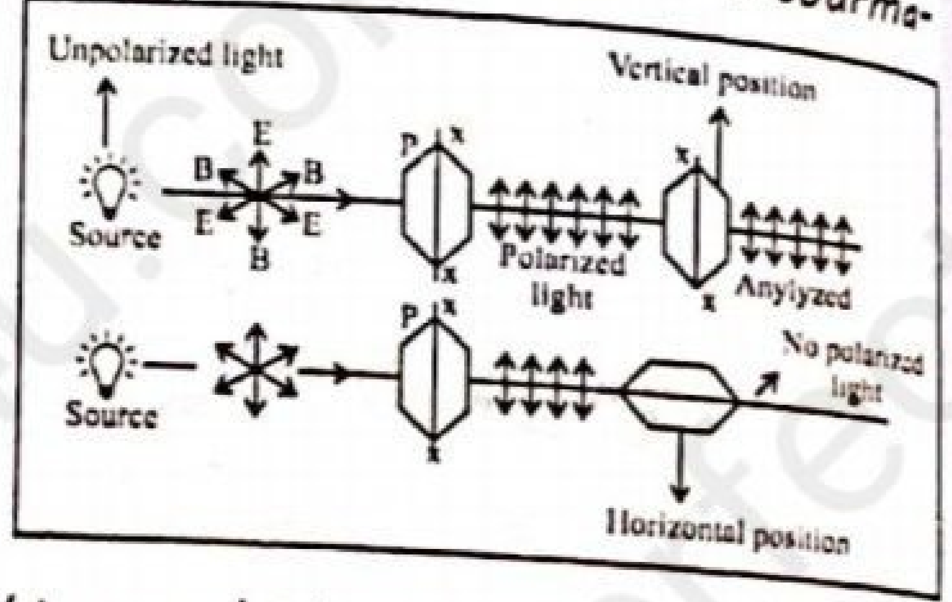
We can obtained plane polarized light from un-polarized light by removing all the waves from the beam except those having vibrations along one particular direction. This can be achieved



by various process given below:

(i) Polarization by Selective Absorption:

Consider a beam of un-polarized light is allowed to fall on a tourmaline crystal as shown in the figure.



The intermolecular structure of the crystal is such that it allows only those electric and magnetic vibrations which are parallel to its crystallographic axis and absorb all the remaining vibrations. Thus the light passed through this crystal has all the fields of vibrations in one plane and is known as the plane polarized light.

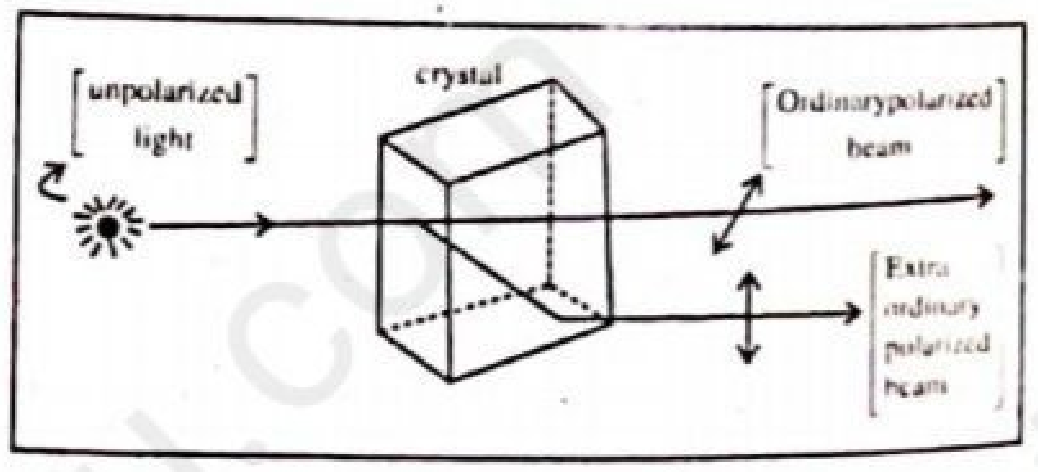
Now when another tourmaline crystal is placed in the path of this polarized light parallel to the 1st tourmaline crystal, then the polarized light will completely transmit through it.

Now if the 2nd crystal is rotated gradually, then the intensity of transmitted light decreases and when it becomes perpendicular to the 1st crystal, then no light will transmit through it, as shown in the figure.

If we rotate the 2nd crystal further, the transmitted light will be appear again. Thus the 2nd crystal is known as analyzer. In this way, we can obtain a beam of polarized light.

(ii) Polarization by Refraction:

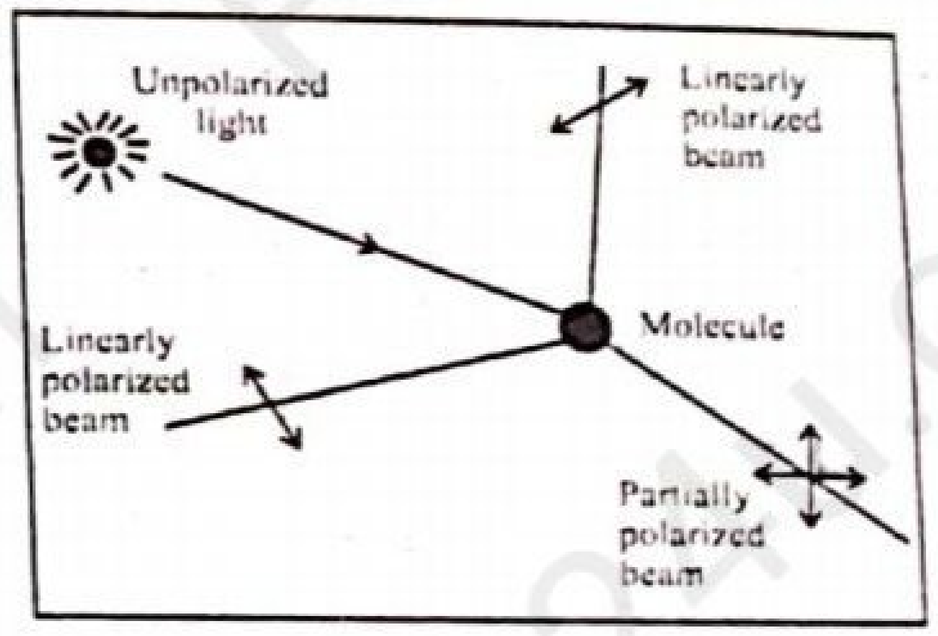
The polarization by refraction can be obtained by using calcite crystal. In the given arrangement, un-polarized beam of light is allowed to fall on calcite crystal. This beam after falling on the crystal is divided into two parts. One part is known as ordinary ray and the other part is known as extraordinary ray, as shown in the figure. When these two parts of a single beam were



observed by analyzer, they were found to be polarized beam. Such phenomenon is known as polarization by double refraction.

(iii) Polarization by Scattering:

When an un-polarized light is allowed to fall on a certain tiny particle or molecule, then this beam is absorbed by the molecule. This molecule emits the absorbed beam in the form of linearly polarized beam and partially polarized beam, as shown in the figure. Such phenomenon is known as polarization by scattering.

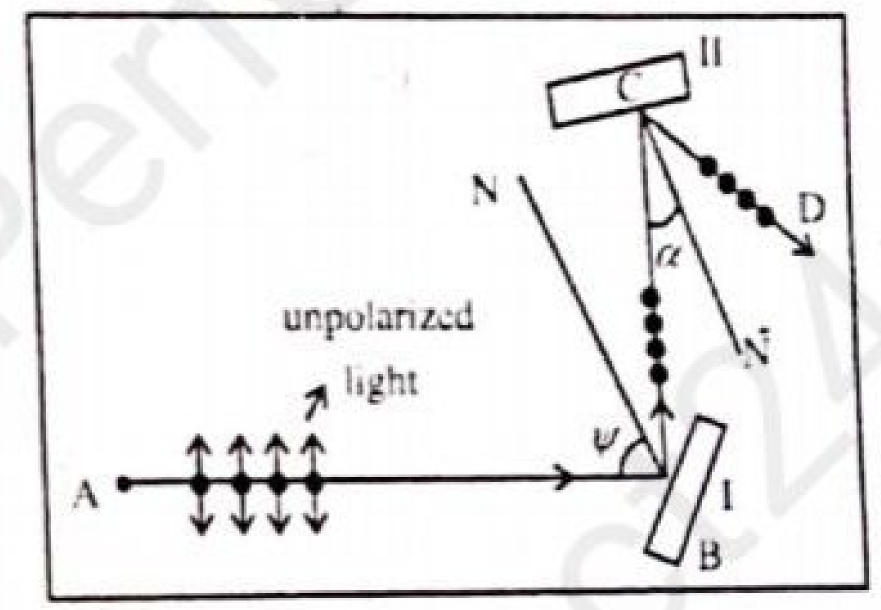


(iv) Polarization by Reflection:

Consider two glass plate "I" and "II" of the same dimension which are placed in such a way that their normals "N", "N′" are parallel to each other as shown in the figure.

Let un-polarized beam "AB" is allowed to fall on the 1st glass plate as shown in the figure.

Now the reflected beam "BC" from 1st glass plate and reflected beam "CD" from 2nd glass plate becomes polarized. Such phenomenon is known as polarization by reflection.



Q15: Describe Brewster's law of polarization.

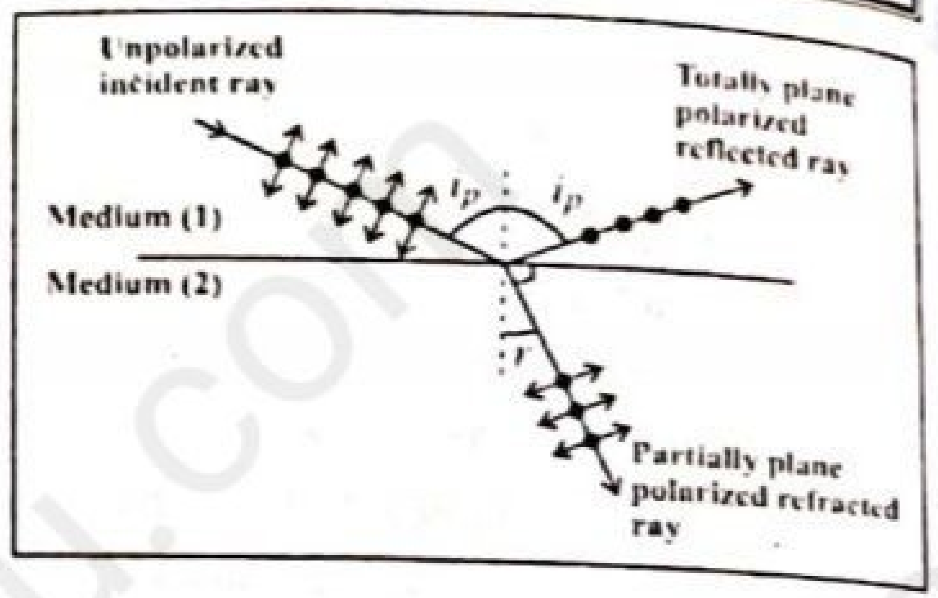
BISE Abbottabad 2019, BISE DI Khan 2019

Ans. The Brewster's law gives us the relation between refractive index of two medium and tangent of angle of incidence. i.e.

$$\boxed{\frac{n_2}{n_1} = \tan i_p}$$

Proof:

Let an un-polarized beam of light is allowed to fall on the surface of medium (1) as shown in the figure. At point of incidence, one part of incident beam is reflected 2nd is found to be polarized totally. The other part is refracted and is found to be partially polarized. Let "i_p" represent the angle of incidence or polarization angle and "r" represents the angle of refraction, then from figure, we have,



$$i_p + 90° + r = 180°$$

$$\Rightarrow r = 90° - i_p \quad \text{———— (1)}$$

Now from Snell's law, we have,

$$n_1 \sin i_p = n_2 \sin r \quad \text{———— (2)}$$

Formula:

$$[\sin(\theta_1 + \theta_2) = \sin\theta_1\cos\theta_2 + \sin\theta_2\cos\theta_1]$$

Putting equation (1) equation (2), we get,

$$n_1 \sin i_p = n_2 \sin[90° - i_p]$$

$$\Rightarrow n_1 \sin i_p = n_2[\sin 90° \cos i_p + \sin i_p \cos 90°]$$

$$\Rightarrow n_1 \sin i_p = n_2[1 \times \cos i_p + \sin i_p \times 0] = n_2[\cos i_p + 0] = n_2 \cos i_p$$

$$\Rightarrow n_1 \sin i_p = n_2 \cos i_p \Rightarrow \frac{n_2}{n_1} = \frac{\sin i_p}{\cos i_p}$$

$$\Rightarrow \frac{n_2}{n_1} = \tan i_p \Rightarrow \boxed{\frac{n_2}{n_1} = \tan i_p} \quad \text{———— (3)}$$

Equation (3) represents the Brewster's law. This equation shows that for given values of n_1, n_2, we can calculate the angle of incidence or polarization angle "i_p".

Do you know!
When light is reflecting from the glass then it is partially polarized. It is because some part of it refracts and some part reflects.

Do you know!
It is very effective to use a polarized sun glasses than using ordinary sun glasses. It is because the polarized sun glasses protect our eyes from the harmful glare of the sun light.

Q16: Discuss the application of polarized light.

Ans. Some important applications of polarized light in our daily life are given below:

1. Reducing Glare:

Glare caused by light reflected from a smooth surface such as roads and lakes can be reduced by using polarizing materials as the reflected light is partially or completely polarized.

In case of photography, the Polaroid discs are placed in front of the camera lens which enabling us to see the details which would be otherwise hidden by glare.

2. Optical Activity:

When a beam of light is made to pass through certain crystal like quartz or certain liquids like sugar solution, then the directions of vibration of the transmitted polarized light is found to be rotated. This phenomenon is known as optical activity. The angle of rotation for a solution depends upon its concentration. The concentration of the solution is measured by using a device known as polarimeter. For example, the polarimeter is used in sugar mills to measure the sugar concentration in the solution which is obtained from sugar cane.

3. Curtianless Window:

Two polarizing sheets are fixed in a window, one inside and the other outside. The outside is kept fixed and the inner one is rotated in such a way to adjust the amount of light to be admitted.

4. Control of Head Light Glare:

The head light glare in night driving can be controlled by using polarizing viewer.

5. Stress Analysis:

When a glass or plastic material is subjected to certain stress, then strain is produced. If the strain is viewed in the presence of white light, we see Polaroid's colour fringes around the strain. This effect is known as photo elasticity and is used to analyze stresses in plastic model of various structures.

6. As the polarized light is restricted to one plane only, so such light is dangerous for human eyes. To overcome this problem, we should use sunglasses which are made of polarized sheet. The light after passing through this sheet becomes partially polarized and thus our eye sight will remain unaffected.

Solution of Examples & Assignments

EXAMPLE 9·1:

Yellow light from a sodium vapour lamp of wavelength 5893×10^{-10}m is directed upon two narrow slits 0·10cm apart of the Young's experiment· Find the position of the first bright and dark fringes on a screen 100cm away?

Solution:

Given data: Wavelength of light $= \lambda = 5893\times10^{-10}\,m$

Separation of slits $= d = 0{\cdot}10cm, 0{\cdot}001m,$

Distance of slits from screen $= L = 100cm = 1m$

Order of fringe $= m = 1$

Required:

(i) Position of 1st bright fringe $= y_{Bright} = ?$

(ii) Position of 1st dark fringe $= y_{Dark} = ?$

Calculation:

(i) For bright fringe, we have,

$$y_B = \frac{L\lambda}{d} \quad \text{———} (1)$$

Putting the values in equation (1), we get,

$$y_B = \frac{1\times5893\times10^{-10}}{0{\cdot}001}$$

$$\Rightarrow y_B = 5893000\times10^{-10}\,m \Rightarrow \boxed{y_B = 5{\cdot}893\times10^{-4}\,m}$$

(ii) For dark fringe, we have,

$$y_D = \frac{L\lambda}{2d} \quad \text{———} (2)$$

Putting the values in equation (2), we get,

$$y_D = \frac{1\times5893\times10^{-10}}{(2\times0{\cdot}001)} \Rightarrow y_D = 2946500\times10^{-10}\,m$$

$$\Rightarrow y_D = 2{\cdot}9465\times10^{-4}\,m \Rightarrow \boxed{y_D = 2{\cdot}95\times10^{-4}\,m}$$

Ans· $\boxed{y_B = 5{\cdot}893\times10^{-4}\,m}$ and $\boxed{y_D = 2{\cdot}9465\times10^{-4}\,m}$

ASSIGNMENT 9·1:

The 3rd bright fringe in a double slit experiment makes a 2·4° angle with respect to the central line· The wavelength of the monochromatic light used is 480nm· Find the distance "d" between the two sources· (0·0344mm)

Solution:

Given data: For 3rd bright fringe, we put $m = 3$

Angle $= \theta = 2{\cdot}4°$

Wavelength $= \lambda = 480nm = 480\times10^{-9}\,m$ $\boxed{Nano = 10^{-9}}$

Required:

Distance between two sources $= d = ?$

Calculation: We know that for bright fringe, we have,

$$d\sin\theta = m\lambda \Rightarrow d = \frac{m\lambda}{\sin\theta} \quad \text{———} (1)$$

Putting the values in equation (1), we get,

$$d = \left(\frac{3\times480\times10^{-9}}{\sin(2{\cdot}4°)}\right)m = \left(\frac{1440\times10^{-9}}{0{\cdot}042}\right)m$$

$$\Rightarrow d = 34285{\cdot}7\times10^{-9}\,m = 0{\cdot}0342857\times10^{-3}\,m$$

$$\Rightarrow \boxed{d = 0{\cdot}0343mm}$$ $\boxed{10^{-3} = milli}$

EXAMPLE 9·2:

Light of wavelength 546nm produces Young's interference pattern· The 2nd order dark fringe is along the direction that makes an angle of 18 min, related to the direction to the central maximum· What is the distance between the slits?

Solution:

Given data: Wavelength $= \lambda = 546nm = 546\times10^{-9}\,m$

Order of dark fringe $= m = 2$

Angle $= \theta = 18min = \frac{18}{60} = 0{\cdot}30°$ $\boxed{1° = 60\,minutes}$

Required: Distance between the slits $= d = ?$

Calculation:

For mth dark fringe, we have,

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

Putting the values in equation (1), we get,

$$\Rightarrow d\times\sin(0{\cdot}30°) = \left(2+\frac{1}{2}\right)\times546\times10^{-9} = \frac{5}{2}\times546\times10^{-9}$$

$$\Rightarrow d\times5{\cdot}236\times10^{-3} = 1365\times10^{-9}$$

$$\Rightarrow d = \frac{1365\times10^{-9}}{5{\cdot}236\times10^{-3}} = 260{\cdot}7\times10^{-6}\,m$$

$$\Rightarrow \boxed{d = 260{\cdot}7\mu m}$$ $\boxed{10^{-6} = micro = \mu}$

ASSIGNMENT 9·2:

A beam of x-rays of wavelength 0·3nm is incident on a crystal, and gives a first-order maximum when the glancing angle is 9·0 degrees. Find the atomic spacing.

Solution:

Given data:

Wavelength of x-rays $= \lambda = 0{\cdot}3nm = 0{\cdot}3 \times 10^{-9} m$

Order of image $= m = 1$, Angle $= \theta = 9°$

Required:

Atomic spacing $= d = ?$

Calculation: We know that, $2d\sin\theta = m\lambda$

$\Rightarrow d = \dfrac{m\lambda}{2\sin\theta}$ ——— (1)

Putting the values in equation (1), we get,

$$d = \frac{1 \times 0{\cdot}3 \times 10^{-9}}{2 \times \sin(9°)} = \frac{0{\cdot}3 \times 10^{-9}}{2 \times 0{\cdot}16} \Rightarrow d = 0{\cdot}9375 \times 10^{-9} m \text{ OR}$$

$\boxed{d = 0{\cdot}9375\,nm}$

EXAMPLE 9·3:

A red laser light of wavelength 630nm is used in a Michelson interferometer. While keeping the mirror M_1 fixed, mirror M_2 is moved. The fringes are found to move past a fixed cross-hair in the viewer. Find the distance the mirror M_2 is moved for a single fringe to move past the reference line.

Solution:

Given data: Wavelength of laser light $= \lambda = 630nm = 630 \times 10^{-9} m$

Order of fringe $= m = 1$

Required:

Distance travelled by mirror "M_2" $= p = ?$

Calculation: We know that,

$p = \dfrac{m\lambda}{2}$ ——— (1) $\boxed{10^{-9} = nano}$

Putting the values in equation (1), we get,

$$p = \left(\frac{1 \times 630 \times 10^{-9}}{2}\right) m = 315 \times 10^{-9} m \Rightarrow \boxed{p = 315nm}$$

EXAMPLE 9·4:

The deviation of the second order diffracted image formed by an optical grating having 5000 lines per centimeter is 32°. Calculate the wavelength of light used.

Solution:

Given data: Number of lines per centimeter = 5000 lines

Angle $= \theta = 32°$

Order of image $= m = 2$

Grating element $= d = \dfrac{1cm}{5000} = 0{\cdot}00020cm$

Required:

Wavelength $= \lambda = ?$

Calculation: We know that, $d\sin\theta = m\lambda$

$\Rightarrow \lambda = \dfrac{d\sin\theta}{m}$ ——— (1)

Putting the values in equation (1), we get,

$$\lambda = \frac{0{\cdot}00020 \times \sin(32°)}{2} = 5{\cdot}3 \times 10^{-5} cm$$

Ans. $\boxed{\text{Wavelength} = \lambda = 5{\cdot}3 \times 10^{-5} cm}$

EXAMPLE 9·5:

X-rays of wavelength 3nm are incident on a crystal for which the lattice spacing is 5nm. Calculate the angle at which the first Bragg diffraction is observed.

Solution:

Given data: Wavelength $= \lambda = 3\,nm = 3 \times 10^{-9} m$

Lattice spacing $= d = 5nm = 5 \times 10^{-9} m$, order of the image $= m = 1$

Required: Angle $= \theta = ?$

Calculation: As $2d\sin\theta = m\lambda$

$\Rightarrow \sin\theta = \dfrac{m\lambda}{2d}$ ——— (1)

Putting the values in equation (1), we get,

$$\sin\theta = \frac{1 \times 3 \times 10^{-9} m}{2 \times 5 \times 10^{-9} m} \Rightarrow \sin\theta = 0{\cdot}3$$

$\Rightarrow \theta = \sin^{-1}(0{\cdot}3) = 17° \Rightarrow \boxed{\theta = 17°}$

Ans. $\boxed{\theta = 17°}$

Exercise

Choose the best possible answer:

1. The principle of Young's double slits experiment is based on the division of:
   (a) Amplitude (b) Frequency
   (c) Velocity ✓(d) Wavelength
2. Which one of the following properties proves the transverse wave nature of light?
   (a) Interference (b) Refraction
   ✓(c) Polarization (d) Diffraction
3. Coloured fringes observed in soap bubbles are the examples of:
   (a) Diffraction ✓(b) Interference
   (c) Polarization (d) Reflection
4. During a sunny day we see the objects in a class room even when all the electric lights are off, due to:
   (a) Reflection of light (b) Refraction of light
   ✓(c) Diffraction of light (d) Interference of light
5. The principle of Michelson interferometer is based on the division of:
   (a) Wavefront ✓(b) Amplitude
   (c) Frequency (d) Speed of light
6. In the Young's double slit experiment the separation between the slits is halved and the distance between the slits and the screen is doubled. The fringe width is:
   (a) Halved (b) Unchanged
   (c) Doubled ✓(d) Quadrupled

Sol: We know that the fringes space is given by,

Fringe space= $\frac{L\lambda}{d}$ ______(1)

Now when slit separation is halved, then

$d' = \frac{d}{2}$ ______(2)

And when distance of slits from screen becomes double, then

$L' = 2L$ ______(3)

Now for d', L' equation (1) becomes

New fringe space= $\frac{L'\lambda}{d'}$ ______(4)

Putting equation (2), equation (3) in equation (4), we get,

New fringe space= $\frac{2L \times \lambda}{\frac{d}{2}} = \frac{4L\lambda}{d}$

$\Rightarrow$ New fringe space= $4\left(\frac{L\lambda}{d}\right)$ ______(5)

Putting equation (1) in equation (5), we get,

New fringe space= 4 (initial fringe space)

Thus the new fringe space increases quadruple i.e. four times

7. Signal from a remote control to the device operated by it travels with the speed of:
   (a) Sound ✓(b) Light
   (c) Ultrasonic (d) Supersonics
8. Light of wavelength "λ" is incident normally on a diffraction grating for which the slit spacing is equal to "3λ". What is the since of the angle between the second order maximum and the normal?
   (a) $\frac{1}{6}$ (b) $\frac{1}{3}$ ✓(c) $\frac{2}{3}$ (d) 1

Sol: For diffracting grating, we have,

$d \sin\theta = m\lambda$ ______(1)

When $d = 3\lambda$ and $m = 3$, equation (1) becomes

$3\cancel{\lambda} \sin\theta = 2\cancel{\lambda} \Rightarrow 3\sin\theta = 2$

$\Rightarrow \boxed{\sin\theta = 2/3}$ so option (c) is correct.

9. Which of the following gives three regions of the electromagnetic spectrum in order of increasing wavelength, visible radiation?
   (a) Gamma rays, microwaves, visible radiation
   (b) Radio waves, ultraviolent, x-rays
   ✓(c) Ultraviolet, infrared microwaves
   (d) Visible radiation, gamma rays, radio waves
10. Two monochromatic radiations X and Y are incident normally on a diffraction grating. The second order intensity maximum

for X coincides with the third order intensity maximum for Y. What is the ratio $\frac{\text{wavelength of } X}{\text{wavelength of } Y}$?

(a) $\frac{1}{2}$ (b) $\frac{2}{3}$ ✓(c) $\frac{3}{2}$ (d) $\frac{2}{1}$

Sol: We know that,

$d \sin\theta = m\lambda$ ____________(1)

For x-radiation, we have, $m = 2$ and $\lambda = \lambda_x$ so equation (1) becomes,

$d \sin\theta = m\lambda$ ____________(2)

For y-radiation, we have, $m = 3$ and $\lambda = \lambda_y$ so equation (1) becomes,

$d \sin\theta = 3\lambda_y$ ____________(3)

Dividing equation (2) by equation (3), we get,

$$\frac{\cancel{d \sin\theta}}{\cancel{d \sin\theta}} = \frac{2\lambda_x}{3\lambda_y} \Rightarrow \frac{2\lambda_x}{3\lambda_y} = 1 \Rightarrow \boxed{\frac{\lambda_x}{\lambda_y} = \frac{3}{2}}$$

So option (c) is correct.

11. The tip of a needle does not give a sharp image, it is due to:

(a) Polarization (b) Interference
✓(c) Diffraction (d) Refraction

Short Questions

Write short answers of the following questions:

Q1: A soap bubble looks black when it bursts, why?

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Ans. When a soap bubble bursts, it looks black due to destructive interference.

Explanation:

Here the soap bubble behaves like a thin film. Let "λ" represents the wavelength of light, "n" represents the refractive index of water, "t" represents the thickness of film and "m" represents the order of fringe, then we have,

$2nt = m\lambda$ ____________(1)

Now when bubble bursts, its thickness become so smaller such that we put $t = 0$, so equation (1) becomes,

$2n \times 0 = m\lambda \Rightarrow m\lambda = 0 \Rightarrow \boxed{m = 0}$ ____________(2)

Equation (2) shows that we get the first order dark fringe due to destructive interference. Thus when a soap bubble burst, the thickness of the film becomes zero. Under such conditions radiations of all wavelength disappears, and the soap bubble appears black when it bursts due to destructive interference.

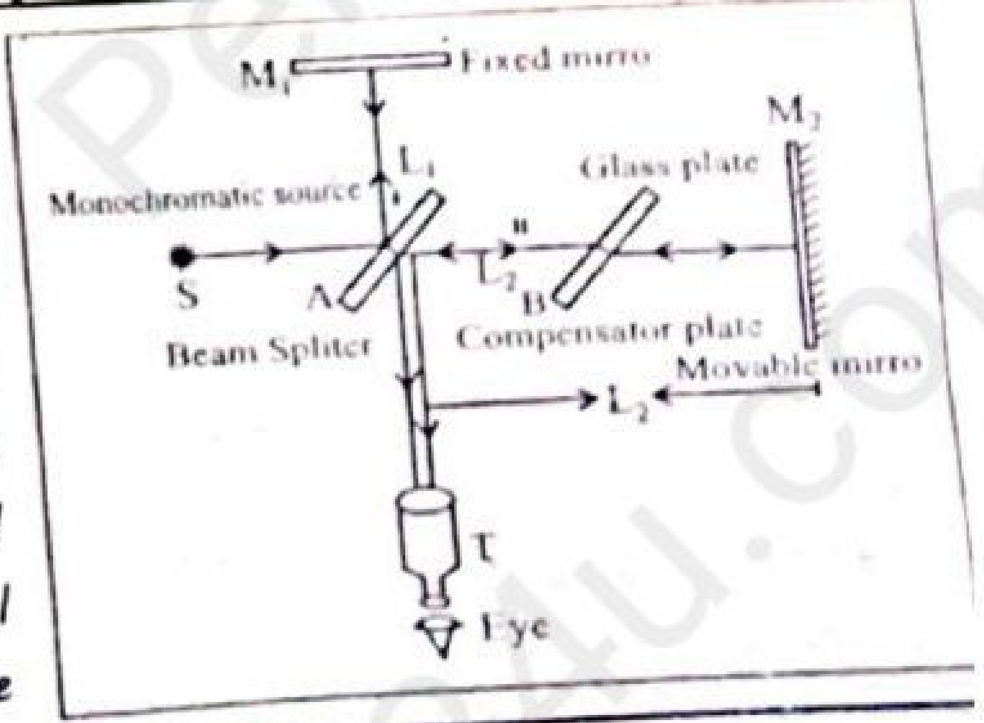
Q2: What is the difference between interference and diffraction?

Ans.

INTERFERENCE	DIFFRACTION
1. Interference is the superposition of two waves.	1. Diffraction is the bending of waves around an obstacle.
2. Two separate wave fronts originating from two coherent sources produce interference.	2. Secondary wavelets originating from different parts of the same wave front cause diffraction.
3. The region of minimum intensity is perfectly dark in interference.	3. In diffraction they are not perfectly dark.
4. The width of the fringes is equal in interference.	4. In diffraction the width of the fringes is never equal.
5. The intensity of all positions of maxima are of the same intensity in interference.	5. In diffraction, only zeroth order maxima has maximum intensity while all other maxima are of lower intensity than the zeroth order maxima.

Q3: In a Michelson interferometer a second glass plate is also used, why?

Ans. The principle of Michelson's interferometer is based on the division of amplitude, usually by partial reflection and transmission. Therefore, a second glass plate B, equal in thickness to plate A is placed in the path of the horizontal ray 2. So that to introduce

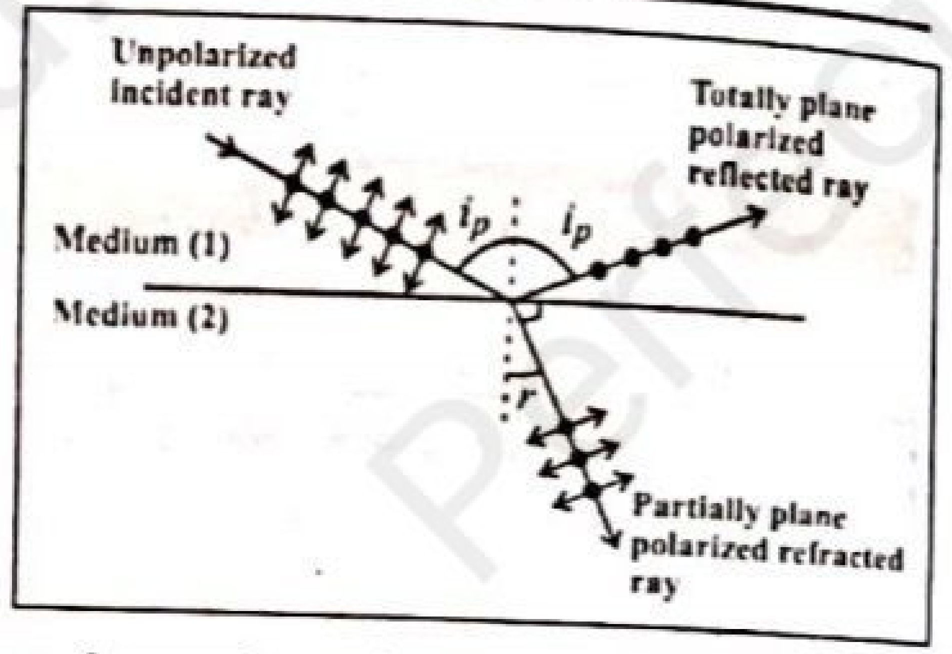


the same retardation in ray 2 as is introduced in ray 1 by its two passages through plate A. With this arrangement each ray will then pass through the same thickness of glass which equalizes the path length of the two rays. Therefore, the second glass plate is used as an equalizer of path length of the two light rays.

Q4: How you can explain Brewster's law of polarization?

The Brewster's law gives us the relation between refractive index of two medium and tangent of angle of incidence. i.e.

$$\boxed{\frac{n_2}{n_1} = \tan i_p}$$



Proof:

Let an un-polarized beam of light is allowed to fall on the surface of medium (1) as shown in the figure. At point of incidence, one part of incident beam is reflected 2nd is found to be polarized totally. The other part is refracted and is found to be partially polarized. Let "i_p" represent the angle of incidence or polarization angle and "r" represents the angle of refraction, then from figure, we have,

$i_p + 90^\circ + r = 180^\circ \Rightarrow r = 90^\circ - i_p$ ____________ (1)

Now from Snell's law, we have,

$n_1 \sin i_p = n_2 \sin r$ ____________ (2)

Putting equation (1) equation (2), we get,

> **Formula:**
> $[\sin(\theta_1 + \theta_2)$
> $= \sin\theta_1 \cos\theta_2 + \sin\theta_2 \cos\theta_1$

$$n_1 \sin i_p = n_2 \sin\left[90^\circ - i_p\right]$$

$$\Rightarrow n_1 \sin i_p = n_2 \left[\sin 90^\circ \cos i_p + \sin i_p \cos 90^\circ\right]$$

$$\Rightarrow n_1 \sin i_p = n_2\left[1 \times \cos i_p + \sin i_p \times 0\right]$$

$$\Rightarrow n_1 \sin i_p = n_2\left[\cos i_p + 0\right] = n_2 \cos i_p$$

$$\Rightarrow n_1 \sin i_p = n_2 \cos i_p \Rightarrow \frac{n_2}{n_1} = \frac{\sin i_p}{\cos i_p}$$

$$\Rightarrow n_1 \sin i_p = n_2 \cos i_p \Rightarrow \frac{n_2}{n_1} = \frac{\sin i_p}{\cos i_p}$$

$$\Rightarrow \frac{n_2}{n_1} = \tan i_p \Rightarrow \boxed{\frac{n_2}{n_1} = \tan i_p}$$ ____________ (3)

Equation (3) represents the Brewster's law. This equation shows that for given values of n_1, n_2, we can calculate the angle of incidence or polarization angle "i_p".

Q5: What is meant by the path difference with reference to the interference of two wave motion?

Ans. The difference between the lengths of the path covered by two waves having the same initial and terminal points is called as path difference.

Explanation:

When two waves pass through a medium at a point, then the resultant displacement at that point is the vector sum of the displacements due to two component waves. This modification in displacement as a result of superposition of two waves is called interference. For constructive interference, the phase difference is:

Phase difference $= \theta = 0, 2\pi, 4\pi, 6\pi, \cdots$

Which correspond respectively to the path difference of:

Path difference $= d = 0, \lambda, 2\lambda, 3\lambda, \cdots\cdots = m\lambda$

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

For destructive interference, the phase difference is:

Phase difference $= \theta = 3\pi, 5\pi, \cdots$

Which correspond respectively to the path difference of:

$$\text{Path difference} = d = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \ldots = \left(m + \frac{1}{2}\right)\lambda$$

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

Q6: Why it is not possible to see the interference where the light beams from the head lamps of a car overlap?

Ans. It is not possible to see the interference patern due to light coming from the head lamps of a car.

Explanation:

In above case, we cannot see the interference patern due to the following reasons:

1. The light beams coming from the head lamps of the car are

not phase coherent. The crest of wave of one head lamp does not match the crest of wave of the 2nd head lamp. So we cannot observe the interference.

2. We know that the fringe space is given by,

$$y = \frac{\lambda L}{d} \text{ ———— (1)}$$

Here the separation "d" between the two head lamps is very large as compare to the wavelength of light emitted. So due to larger value of "d" the fringe space becomes too smaller. Under such condition the interference maxima and minima would be too closely spaced to be observable. Thus it is not possible to see the interference due to light coming from the head lamps of a car.

Q7: A telephone pole casts a clear shadow in the light from a distant head lamp of a car, but no such effect is noticed for the sound from the car horn. Why?

Ans. A telephone pole casts a clear shadow in the light from a distance head lamp of a car but no such effect is noticed for the sound from the car horn. This is because of the diffraction of waves.

Explanation:

The diffraction of waves depends upon their wavelength. Sound and light both travel as waves. The properties of these waves differ quite considerably. Sound waves travel a million times slower than light waves and have wavelengths ranging from 1cm to 10m, and will easily diffract round corners. Light waves have much smaller wavelengths, and only diffract through very small holes. Since diffraction depends upon the wavelength of waves and the wavelength of light waves is very much shorter than those of sound waves, so light waves cannot diffract around the telephone pole, hence casts clear shadow, while sound waves diffract about the pole, therefore no such effect is observed.

Q8: Why it is not possible to obtain the diffraction of x-rays by Young's double slits experiment?

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Ans. It is not possible to attain the diffraction of x-rays by young's double slits experiment.

Reason and Explanation:

The diffraction of radiation depends upon the wavelength of radiation and the diameter of the slit. The diffraction will occur if the diameter of the slit is either equal to or less than the wavelength of light used.

We know that the wavelength of light is of the order of 10^{-6}m while the wavelength of x-rays is of the order of 10^{-10}m. But in case of Young's double slits experiment, we use slit whose diameter is of the order of 10^{-6}m. As the wavelength of light is comparable to the diameter of the slit, so light can be used to produce diffraction in Young's double slit experiment. We cannot use x-rays in Young double slit experiment, because the diameter of the slit is not comparable to wavelength of x-rays.

The diffraction of x-rays can occur in case of crystals where the space between atoms is of the order of 10^{-10}m. For example the space between atoms of NaCl crystal is about 10^{-10}m. So the x-rays can be diffracted by NaCl crystal.

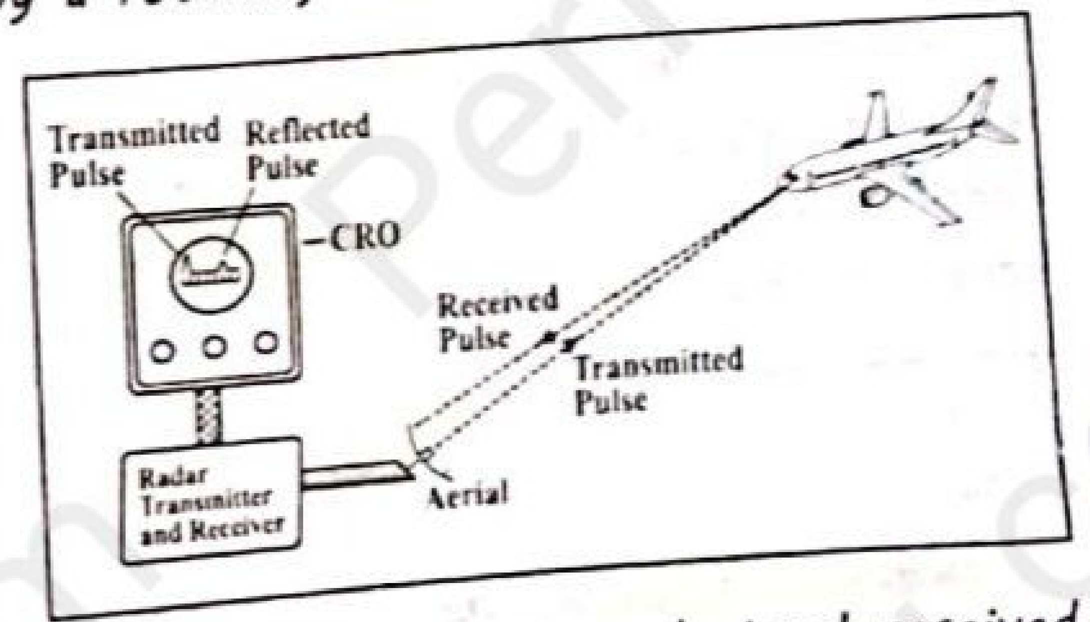
Q9: Can we apply Huygen's principle to radar waves?

Ans. Yes, we can apply the Huygen's principle to radar waves.

Reason and Explanation:

Each point on the wavefront of radar wave behaves as a source for the secondary spherical wavelet. In this way the wavefront propagates from one region to another in space.

The radar waves are microwaves. Its wavelength is 3cm. These waves are emitted and picked up by a rotating aerial of radar after reflection from a aircraft.



The received signals are displayed on a CRO with a calibrated time base. On the CRO if the amplitude of the reflected signal received increases, it means that the aircraft or missile is coming. But if the amplitude of the reflected signal received on CRO decreases, it shows that the object is moving away. Thus we can apply Huygen's principle to radar waves·

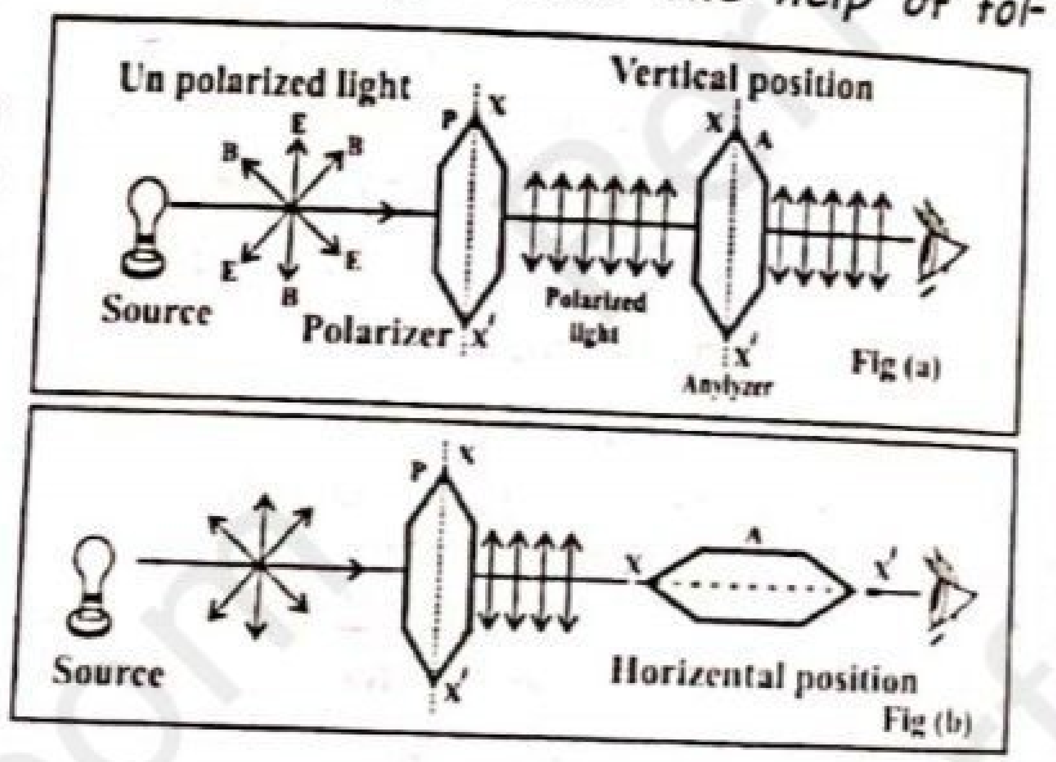
Q10: How would you justify that light waves are transverse in nature?

Ans· The transverse nature of light can be verified by the phenomenon of polarization· The theory of electricity and magnetism tells us that light is transverse in nature· The light consists of electric and magnetic field which are oscillating at right angle to the direction of propagation of light waves·

Experimental Verification:

We can justify the transverse nature of light with the help of following experiment:

In the given arrangement, a beam of un-polarized light is allowed to fall on a tourmaline crystal which acts as polarizer i·e· it converts the un-polarized light to polarized lighter· This polarized light transmitted through the 2nd tourmaline crystal which acts as analyzer i·e· it is used for the confirmation of polarized light, as shown in the figure (a)



Now of the analyzer is rotated gradually, then the amount of transmitted light decreases· When the analyzer becomes perpendicular to the 1st crystal [Polaroid], then no light will be transmit through it as shown in the figure (b)·

If we rotate the analyzer further, the transmitted light will appear again· In this way, we can obtain a beam of polarized light· As polarization occurs in case of transverse waves, so it shows that light waves are transverse in nature·

- حضرت علیؑ کا فرمان ہے: رشتے خون کے نہیں احساس کے ہوتے ہیں اگر احساس ہو تو اجنبی بھی اپنے ہو جاتے ہیں، اگر احساس نہ ہو تو اپنے بھی اجنبی ہو جاتے ہیں . . .
- حضرت علیؓ نے فرمایا: اللہ تعالیٰ کے نزدیک کسی انسان کی عزت جتنی زیادہ ہوتی جاتی ہے اس کا امتحان بھی اس قدر سخت ہوتا چلا جاتا ہے . .
- کفر کے بعد سب سے بڑا گناہ دل دکھانا ہے چاہے وہ دل مؤمن کا ہو یا کافر کا . . .

Comprehensive Questions

Q1: What is meant by the dual nature of light? Discuss the history about the nature of light in detail·

Ans· See answer of question number 1 in text·

Q2: Explain the diffraction of x-rays by crystal and derive an expression for Bragg's law to find the wavelength of light used?

Ans· See answer of question number 12 in text·

Q3: Describe the experimental arrangement for the production of interference fringes by Young's double slits method, and get an expression for the fringes space·

Ans· See answer of question number 5 in text·

Q4: State and explain Huygen's principle· What is the difference between spherical and plane wavefronts·

Ans· See answer of question number 2 in text·

Q5: Explain the interference effect produced by thin film·

Ans· See answer of question number 6 in text·

Q6: What is the principle of interference of light? Discuss the necessary condition for interference of light·

Ans· See answer of question number 4 in text·

Q7: What is diffraction grating? How can the wavelength of a beam of light be measured with it?

Ans· See answer of question number 11 in text·

Q8: Describe the construction and working of Michelson's interferometer· How one can determine the wavelength of light used by this instrument?

Ans· See answer of question number 7 in text·

Q9: What is meant by plane polarized light? How does this phenomenon decide that light waves are transverse in nature?

Ans· See answer of question number 13 in text·

Numerical Problems

Q1: In a Young double slit experiment the separation of the slits is 1mm and red light of wavelength 620nm is falling on it. Determine the distance between the central bright band and the fifth bright fringe on the screen which is 3m away from the slit. (9.3mm)

Solution:

Given data: Separation between slits

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

Wavelength $= \lambda = 620nm = 620 \times 10^{-9} m$

Distance of screen from slit = $L = 3m$

10^{-3} = milli
10^{-9} = nano

Required:

Distance between central bright band and fifth bright Fringe= $\Delta y = y_5 - y_0 = ?$

Calculation: For mth bright fringe, we have,

$$y_m = \frac{L}{d} m \lambda \quad \text{\_\_\_\_\_\_\_(1)}$$

Now for central bright fringe, we put $m = 0$ in equation (1), so we get,

$$Y_o = 0$$

For 5th bright fringe, we put $m = 5$ in equation (1), so we get,

$$y_5 = \frac{3}{10^{-3}} \times 5 \times 620 \times 10^{-9}$$

$$\Rightarrow y_5 = 9300 \times 10^{-6} m \Rightarrow y_5 = 9.3 \times 10^{-3} m$$

Now $\Delta y = (y_5 - y_0)$ _______(2)

Putting the values in equation (2), we get,

$$\Delta y = (9.3 \times 10^{-3} - 0)$$

$$\Rightarrow \Delta y = 9.3 \times 10^{-3} m$$

10^{-3} = milli

Ans. $\boxed{\Delta y = 9.3mm}$

Q2: Two parallel slits are illuminated by light of two wavelengths, one of which is $5.8 \times 10^{-7}m$. On the screen the fourth dark line of the known wavelength coincides with the fifth bright line of the light of unknown wavelength. Find the unknown wavelength. ($5.2 \times 10^{-7}m$)

Solution: Given data: Wavelength= $\lambda = 5.8 \times 10^{-7} m$

Required:

Unknown wavelength= $\lambda' = ?$

Calculation: Let "y_m" represents the position of fourth dark fringe and "y'_m" represents the position of 5th bright fringe, then according to the given conditions, we have,

$$y_m = y'_m$$

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

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

$$\Rightarrow \left(3 + \frac{1}{2}\right)\lambda = 5\lambda'$$

- For 4th dark fringe, we put $m = 3$
- For 5th bright fringe, we put $m = 5$

$$\Rightarrow \frac{7\lambda}{2} = 5\lambda' \Rightarrow \lambda' = \frac{7\lambda}{10}$$

$$\Rightarrow \lambda' = \frac{7 \times 5.8 \times 10^{-7}}{10} = 4.06 \times 10^{-7} m$$

$$\Rightarrow \boxed{\lambda' = 4.06 \times 10^{-7} m}$$

Q3: When the movable mirror of a Michelson interferometer is moved 0.1mm. How may dark fringes pass through the reference point, if light of wavelength 580nm is used?(345 fringes)

Solution:

Given data:

Total distance= $p = 0.1mm = 0.1 \times 10^{-3} m = 1 \times 10^{-4} m$

Wavelength= $\lambda = 580nm = 580 \times 10^{-9} m$

milli = 10^{-3}
nano = 10^{-9}

Required:

Number of dark fringes = m = ?

Calculation: In case of Michelson interferometer, we have,

$$\lambda = \frac{2p}{m} \Rightarrow m = \frac{2p}{\lambda} = \frac{1 \times 10^{-4}}{580 \times 10^{-9}} \Rightarrow m = 0.003448 \times 10^{5}$$

$$\Rightarrow m = 0.00345 \times 10^{5} = 345 \text{ fringes}$$

Q4: A soap film has a refractive index of 1.40. How thick must the film be, if it appears black, when mercury light of wavelength 546.1nm falls on it normally? ($1.95 \times 10^{-7}m$)

Solution:

Given data: Refractive index = $n = 1.40$
Wavelength of light = $\lambda = 546.1nm$
$\Rightarrow \lambda = 546.1 \times 10^{-9}m, \ m = 1$

Required:
Thickness of film = t = ?

Calculation: We know that,

$$2nt = m\lambda \Rightarrow t = \frac{m\lambda}{2n} \Rightarrow t = \frac{1 \times 546.1 \times 10^{-9}}{2 \times 1.40}$$

$\Rightarrow t = 1.95 \times 10^{-7} m$

Ans. $\boxed{t = 1.95 \times 10^{-7} m}$

Q5: A diffraction grating has 5000 lines per centimeter. At what angle does the second order spectrum of the sodium yellow light of wavelength 589nm occur?

Solution:

Given data: $N = 5000$ lines/cm = 500000 lines/m
$\Rightarrow N = 5 \times 10^5$ lines/m

$$\Rightarrow d = \frac{1}{N} = \frac{1}{5 \times 10^5} = 0.2 \times 10^{-5} m$$

For 2^{nd} order, we put $m = 2$
Wavelength = 589nm = $589 \times 10^{-9} m$

Required: Angle = θ = ?

Calculation: We know that, $d \sin\theta = m\lambda$

$$\Rightarrow \sin\theta = \frac{m\lambda}{d} = \left(\frac{2 \times 589 \times 10^{-9}}{0.2 \times 10^{-5}}\right)$$

$$\Rightarrow \sin\theta = \frac{2 \times 589 \times 10^{-9+5}}{0.2} \Rightarrow \sin\theta = 5890 \times 10^{-4} = 0.5890$$

$\Rightarrow \theta = \sin^{-1}(0.5890) \Rightarrow \boxed{\theta = 36^\circ}$

Ans. $\boxed{\theta = 36^\circ}$

Q6: Light is incident normally on a grating which has 250 lines /mm. Find the wavelength of spectral line for which the deviation in second order is 12°. ($\lambda = 4158 \times 10^{-10} m$)

Solution:

Given data: $N = 250$ lines/mm = 250000 lines/m
$\Rightarrow N = 2.5 \times 10$ lines/m

For 2^{nd} order, $m = 2, \ \theta = 12^\circ$

Required: Wavelength = λ = ?

Calculation: We know that, $d \sin\theta = m\lambda$ $\quad \left[d = \frac{1}{N}\right.$

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

$$\Rightarrow \sin\theta = 2.5 \times 10^5 \times 2 \times \lambda$$

$$\Rightarrow \sin 12^\circ = 5 \times 10^5 \lambda \Rightarrow 0.20791169 = 5 \times 10^5 \lambda$$

$$\Rightarrow \lambda = \frac{0.20791169}{5 \times 10^5} = 0.041580 \times 10^{-5} m$$

Ans. $\boxed{\lambda = 4158.0 \times 10^{-10} m}$

Q7: In a certain x-rays diffraction experiment the first order image is observed at an angle of 5° for a crystal plane spacing of 2.8×10^{-10}m. What is the wavelength of x-rays used? ($\lambda = 0.49 \times 10^{-10} m$)

Solution:

Given data: $m = 1$ [First order], $\theta = 5^\circ$, $d = 2.8 \times 10^{-10} m$

Required: Wavelength = λ = ?

Calculation: According to Bragg's law, we have,

$$2d\sin\theta = m\lambda \Rightarrow \lambda = \frac{2d\sin\theta}{m} = \frac{2 \times 2.8 \times 10^{-10} \times \sin 5^\circ}{1}$$

$\Rightarrow \lambda = 0.4880 \times 10^{-10} m \Rightarrow \boxed{\lambda = 0.49 \times 10^{-10} m}$

Q8: An x-ray beam of wavelength 0.48×10^{-10}m is used to get Bragg reflection from a crystal at an angle of 20° for the first order maximum. What are the possible layer plane spacing which give rise to this maximum? (0.70×10^{-10}m)

Solution:

Given data: Wavelength = $\lambda = 0.48 \times 10^{-10} m$
$\theta = 20^\circ$, $m = 1$ [First order]

Required: Layer plane spacing = d = ?

Calculation: According to Bragg's law, we have,

$$2d\sin\theta = m\lambda \Rightarrow d = \frac{m\lambda}{2\sin\theta} = \frac{1 \times 0.48 \times 10^{-10}}{2 \times \sin 20^\circ}$$

$$\Rightarrow d = \frac{0.48 \times 10^{-10}}{2 \times 0.342020143}$$

$\Rightarrow d = \dfrac{0{\cdot}45\times10^{-10}}{0{\cdot}66\times0{\cdot}0286} = 0{\cdot}70\times10^{-10}\,m$

Ans: $\boxed{d = 0{\cdot}70\times10^{-10}\,m}$

Q9: The spacing of one set of crystal planes in NaCl (table salt) is d = 0·282nm. A monochromatic beam of x-rays produces a Bragg maximum when its glancing angle with these planes is θ = 7°. Assume that this is a first order maximum (n = 1), find the wavelength of the x-rays. (0·069nm)

Solution:

Given data:

Plane spacing = d = 0·282nm = $0{\cdot}282\times10^{-9}$ m. $\boxed{10^{-9} = \text{nano}}$

Angle = θ = 7°, order = m = 1

Required:

Wavelength = λ = ?

Calculation: According to Bragg's law, we have,

$$2d\sin\theta = m\lambda \Rightarrow \lambda = \frac{2d\sin\theta}{m} \quad \text{———} (1).$$

Putting the values in equation (1), we get,

$$\lambda = \frac{2\times0{\cdot}282\times10^{-9}\times\sin(7^\circ)}{1} = 2\times0{\cdot}282\times10^{-9}\times0{\cdot}122\,m$$

$$\Rightarrow \lambda = 0{\cdot}069\times10^{-9}\,m$$

Ans: $\boxed{\lambda = 0{\cdot}069\,nm}$

+++

۞ حضرت علیؓ کا قول ہے "دنیا اور آخرت کی مثال دو بیویوں کی طرح ہے، جب ایک کو راضی کرو تو دوسری ناخوش ہو جاتی ہے۔"

۞ اپنے حصے کا کام کیے بغیر دعا پر بھروسہ کرنا حماقت ہے اور اپنی محنت پر بھروسہ کر کے دعا سے گریز کرنا تکبر ہے۔۔۔

۞ ایمان والی عورت کا اصلی زیور سونا چاندی نہیں بلکہ حیا اور پردہ ہے۔۔۔

۞ مایوس وہ ہوتا ہے جو اللہ تعالیٰ پر یقین نہیں رکھتا اور محروم وہ ہوتا ہے جو اللہ تعالیٰ کی نعمتوں کا شکر ادا نہیں کرتا۔۔۔

۞ نیکی اس کے نصیب میں آئی جس نے اپنی خواہشات کو چھوڑا اور محروم ہی ہے جس نے دنیا کے مقابلے میں آخرت سے منہ موڑا۔ (ابن الجوزی)

۞ مصیبت میں آرام کی تلاش مصیبت کو ترقی دیتی ہے۔ (امام جعفر صادقؓ)

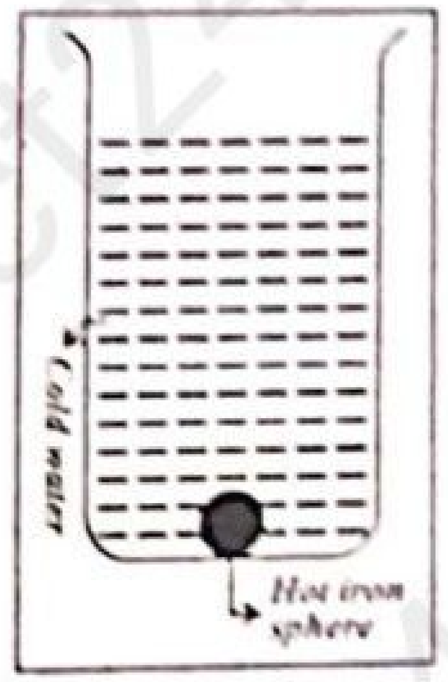
CHAPTER 10 THERMODYNAMICS

Q1: Define and explain thermal equilibrium.

Ans: **Thermal Equilibrium:**

Bodies are said to be in thermal equilibrium if they are at the same temperature and there is no net exchange of heat between them.

Explanation:



Consider a solid hot sphere is placed in cold water as shown in the figure. In the beginning, there is a temperature difference between water and solid sphere. i.e. the solid sphere is at high temperature and cold water is at low temperature.

Due to the temperature difference, the hot sphere losses heat and the cold water gain the heat. As a result, the temperature of sphere decreases and that of the water increases gradually with the passage of time. This process goes on till the water and sphere attain the same temperature. At this stage, the net flow of heat stops and they are said to be in thermal equilibrium.

> **Point to Ponder:**
> Two bodies, one hot and the other cold, are kept in vacuum. What will happen to the temperature of the hot body after some time?
> Ans: Hot bodies emit thermal radiations which are electromagnetic in nature. Electromagnetic waves don't require material medium to pass through. Heat energy is transmitted even through vacuum. We get heat energy from sun in this way. Hence the temperature of hot body will fall until it comes in thermal equilibrium with the cold body.

Q2: Define and explain the following terms used in thermodynamics: (a) Work (b) Heat (c) Internal energy

Ans: (a) **Work:**

The energy which is added to the system in such a way, that a dif-