According to new syllabus of all intermediate boards of Sindh.

Prof. Rawala's ……..

PHYSICS

HELPING BOOK

For
Class XI
(All science students)

UNIT -13

Physical optics.

CONTENTS

Thoroughly revised and updated 2026 – 2027

- ***Detailed notes.***
- ***Multiple Choice Questions (M.C.Q's).***
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Unit.13**.....** ✍

Physical optics

Nature of light:

Q.No.1: What is the nature of light?

Ans: Light is a form of energy, **it makes things visible**, hence when a bulb is switched off in a room there will be darkness. If the room is such that no scattered light enters into it from any side, there will be perfect darkness, nothing will be visible. We will be able to see things if the bulb is again switched on. Actually, after **irregular reflection** from objects lying in the room light enters our eye making the objects visible. We will be able to see the bulb **(source of light)** and things lying in the room. But how does light travel from the bulb to the objects and then to our eye? We don't see light itself, although it has made things visible. Hence: **"What is the nature of light?"**

"How does it travel from one place to another?"

Answer to these and many other questions were found experimentally over last several centuries. Now we have answers to these questions.

The answers are .....

Light has ***dual nature*** (in other words, light has double nature).

- In experiments such as ***interference, diffraction, polarization*** etc. light behaves as **waves, In other words** from one point to another light travels as waves. These phenomena can be explained only on the basis of ***wave theory of light***.
- In experiments such as ***photoelectric effect, Compton effect*** and ***pair production*** light behaves as **particles**. These experimental observations can only be explained if light is assumed to be traveling in the form of particles. These particles are small bundles of energy called ***photons*** (sometimes a photon is called a ***quantum*** of energy)
- Hence sometimes light beaves as ***waves*** and sometimes as ***particles***. We say light has ***dual nature***.
- There is **no single experiment** in which light behaves simultaneously both as ***waves*** as well as ***particles*** (photons).

Electromagnetic waves:

Q.No.2: How are electromagnetic waves produced?

Ans: Electromagnetic waves are produced by ***accelerated charged particles***.

When **charged particles** are made to oscillate rapidly through an antenna, varying **electric** and **magnetic** fields are produced. These electric and magnetic fields vibrate

perpendicular to each other, the frequency with which they vibrate is same as the frequency of alternating current, used to accelerate the charged particles. These vibrating fields produced are radiated, such that the radiated vibrating electric field induces further vibrating magnetic field and so on, in this manner varying electric and magnetic fields, vibrating perpendicular to each other are radiated as ***electromagnetic waves***. **Note that** once the electromagnetic waves are produced accelerating charged particles are no more needed as these waves travel away changing electric field induces further changing magnetic field, this process goes on and the electromagnetic waves are continuously produced. Electromagnetic waves travel **perpendicular** to the direction of vibrations of both the fields.

> ***Do you know that ......***
>
> Visible light ***cannot*** pass through our body that is why shadows are formed, X-rays ***can*** pass through flesh of our body but not through our bones, hence in a way shadow of our bones is formed on X-ray film. Gamma (γ) rays ***can*** pass through even our bones. Visible light, X-rays and γ-rays are All electromagnetic waves, difference between them is in their frequency. Since energy of a wave depends upon its frequency therefore, γ-rays are highly energetic because they have highest frequency and therefore, they have highest penetration power. They can penetrate even our bones !!!!

- Light waves are ***electromagnetic***, it means that light waves have electric and magnetic fields both ***vibrating perpendicular to each other*** whereas propagation of light waves takes place perpendicular to both the fields (**Example**: For a particular light wave if electric field is vibrating along x-axis, magnetic field is vibrating along y-axis then this particular light wave will travel along z-axis).
- Electromagnetic waves **can** travel through vacuum; they **do not** need any material medium for their propagation. That is why light comes from the sun (and moon and other stars in the night) to our beautiful little earth, although there is a vast free space (vacuum) between earth and the sun (and moon and other stars).
- Electromagnetic waves are ***transverse waves***. Light waves travel from its source in **all directions**.
- Speed of all electromagnetic waves including light waves is very high, speed with which light waves travel through free space is about 3×10^8 m/s or about three lac kilometer per second (300,000 km/s) (actually it is 2.98×10^8 m/s).
- Maxwell showed that speed of light in vacuum is given by:

$$c = \frac{1}{\sqrt{\varepsilon_o \mu_o}} = 3\times10^8 \text{ m/s.}$$

Where "ε_o" is ***permittivity*** and "μ_o" is ***permeability*** of free space, they are universal constants. S.I value of "ε_o" is **8.85×10^{-12} $C^2/N\text{-}m^2$**. and μ_o is **$4\pi\times10^{-7}$ web./amp.m**.

- Speed of light represented by "c" is a **universal constant**.

Electromagnetic spectrum:

Radio waves, Infrared rays, Visible light waves, Ultraviolet rays, X-rays and gamma rays are all electromagnetic waves. The difference between them is in their f**requency "*f*".** Since frequency "*f*" of a wave is **inversely proportional** to its wave length "λ", which means that **higher the frequency shorter is the wave length and vice versa**. But

energy of a wave depends upon its **frequency** (they are directly proportional to each other), higher the frequency higher is its energy. Therefore , electromagnetic waves of **high frequency** are of **high energy** but of **shorter wavelength**. In other words, **long wave length** electromagnetic waves are of **low energy**.

If we arrange all electromagnetic waves according to their frequency range (or wave length range) we will get an ***electromagnetic spectrum***.

Longest wavelength of electromagnetic waves is about 10^5 m and shortest wavelength is about 10^{-15} m, corresponding to these wavelengths smallest frequency of electromagnetic waves is about 10^3 Hz. and highest frequency is about 10^{22} Hz. (***In other words,*** wavelengths of electromagnetic waves are in the range of 10^5 m to 10^{-15} m or frequency is in the range of 10^3 Hz. to 10^{22} Hz.).

- ***Radio waves***: Frequency range: 10^3Hz.- 10^9 Hz (e.g. AM radio, FM radio, TV waves)
  Wave length range: 10^5 m - 1 m
- ***Micro-waves***: Frequency range: 10^9 Hz-10^{11}Hz (e.g. microwave oven, wi fi etc.)
  Wave length range: 1 m - 0.1 m
- ***Infra-red rays***: Frequency range: 10^{11} Hz - 10^{14}Hz
  Wave length range: 0.1 m- 10^{-6} m
- ***Visible light***: Frequency range: 10^{14}Hz - 10^{15}Hz
  Wave length range: 10^{-6} m - 10^{-7} m
- ***Ultra-violet rays***: Frequency range: 10^{15}Hz - 10^{16}Hz
  Wave length range: 10^{-7} m - 10^{-8} m
- ***X-rays***: Frequency range: 10^{16}Hz - 10^{19} Hz
  Wave length range: 10^{-8} m - 10^{-10} m
- ***γ-rays***: Frequency range: 10^{19}Hz - 10^{22}Hz
  Wave length range: 10^{-10} m - 10^{-13} m

Electromagnetic spectrum

- ***Note that*** in the entire electromagnetic spectrum, radio waves are **longest wave length** and of **smallest frequency** electromagnetic waves but gamma rays (γ-rays) are **shortest wave length** and of **highest frequency** electromagnetic waves. Since energy of waves is directly proportional to its frequency (or inversely proportional to its wavelength) therefore, gamma rays (γ-rays) are the **most energetic** electromagnetic waves (They have more energy than any other electromagnetic wave). On the other hand, radio waves are **least energy** electromagnetic waves.

Wave fronts:

- The geometrical pattern (Or locus of all points) having same state of vibration (such as a crest) is known as a ***wave front***.
- A source of light produces wave fronts in all the three directions, hence light wave fronts are three dimensional. A point source of light produces spherical wave fronts.
- According to Huygens, any point on a wave front may be considered as a source of secondary spherical wave lets. If position of a wave front at a certain instant is known then its new position at a latter instant can be located by drawing a plane tangential to secondary wave lets.
- Any small portion of a spherical wave front at a large distance from its source will be plane in shape, hence it is known as a ***plane wave front***.

If a circular pointed rod is vertically dipped into still water ***circular wave fronts*** are produced on the surface of water. If the same rod is dipped in water length-wise then ***straight wave fronts*** are produced.

Ray of light:

- Straight line which indicates the direction in which any given point on a light wave front travels is known as a ***ray of light***.

Ray of light is always ***perpendicular*** to the wave front. Hence in case of a spherical wave front rays spread out radially, but in case of a plane wave front rays are ***parallel*** to each other. Hence to get a beam of parallel rays we must take a small part of a spherical wave front at large distance from its source. In case of sun light rays are parallel.

Interference of light:

Q.No.1: What is interference of light? (***2010 Karachi Board***)

Ans: When light waves having phase coherence superpose each other (they pass through the same region of space simultaneously) then at some points they **reinforce** and at other points they **cancel** each other's effect.

As a result of interference of light ***dark and bright fringes*** are obtained. ***Bright fringes*** are obtained at those points where light waves ***reinforce (or enhance)*** each other's effect, whereas ***dark fringes*** are obtained at those points where they ***cancel*** each other's effect.

- Interference of light is in accordance with the principle of ***superposition of waves***
- Interference of light shows that light ***behaves as waves*** i.e. Interference of light proves that light has ***wave nature***.

***<u>Q.No.2</u>*: *What is phase coherence*?**

<u>Ans</u>*:** Waves are said to have phase coherence if they are **<u>exactly similar</u>** and are produced **<u>exactly at the same time</u>**. ***<u>In other words</u>, interfering waves must have **<u>same wave length</u>**, **<u>same frequency</u>** and **<u>same phase</u>**.

***<u>Q.No.3</u>*: *What is the condition for interference of waves*?**

<u>Ans</u>*:** The necessary condition for interference is that the interfering waves must have ***<u>phase coherence</u>.

***<u>Q.No.4</u>*: *What is constructive interference*?**

<u>Ans</u>*:** Waves are said to interfere constructively at those points where they ***<u>reinforce</u> each other's effect.

- In case of constructive interference of light, a ***<u>bright fringe</u>*** is produced.
- Constructive interference takes place at those points where **<u>crest of one wave overlaps crest of the other</u>** or **<u>trough of one wave overlaps trough of the other wave</u>**.
- As a result of constructive interference of waves, either a bigger crest (of larger amplitude) or a deeper trough is produced.
- Intensity of light at points of constructive interference is ***maximum***.

***<u>Q.No.5</u>*: *What is destructive interference*?**

<u>Ans</u>*:** Waves are said to interfere destructively at those points where they ***<u>cancel</u> each other's effect.

In case of destructive interference of light, a ***<u>dark fringe</u>*** is produced.

- Destructive interference takes place at those points where **<u>crest of one wave overlaps trough of the other wave</u>**.
- As a result of destructive interference of waves, **<u>neither crest nor a trough remains</u>**.
- Intensity of light at points of destructive interference is ***minimum***.

<u>Q.No.6</u>*: *What does interference of light prove?

<u>Ans</u>*:** interference of light proves that light travels in the form of ***<u>waves</u>.

***<u>Q.No.7</u>*: *What is meant by path difference*?**

***<u>Ans</u>*:** It is the <u>difference in distance covered</u> by waves measured from their sources to the given point.

***<u>Q.No.8</u>*: *What is the condition for constructive interference*?**

<u>Ans</u>*:** Condition for constructive interference to take place at a point is that the ***<u>path difference</u> between the interfering waves at that point must be an integral multiple of their wave length (i.e. path difference = 0, λ, 2 λ, 3 λ, ….).

$$\boxed{\text{Path difference} = m\,\lambda}$$

And ***<u>phase difference</u>*** between the waves must be an integral multiple of 2π radian (i.e. phase difference = 0, π radian, 2 π radian, 3 π radian, ….).

$$\boxed{\text{Phase difference} = 2m\pi \text{ radian}}$$

Where m is a positive integer, m = 0, 1, 2, 3……..

and λ is wave length of waves.

(When waves of same phase travel equal distance from their source, path difference = 0, either crests or troughs of the two waves simultaneously reach the given point, similarly if one wave covers more distance than the other wave such that the difference in distance covered by them, i.e. path difference is λ, again either crests or troughs from the two sources will reach simultaneously at the given point, so that in both these cases we get a bright fringe due to constructive interference).

- Constructive interference takes place at those points where crest from one source of light overlaps a crest from the other source, or a trough from one source overlaps a trough from the other source.

***Q.No.9*: What is the condition for destructive interference**?

Ans: Condition for destructive interference to take place at a point is that the ***path difference*** between the interfering waves at that point must be an odd multiple of $\lambda/2$ (i.e. path difference = $\lambda/2$, $3\lambda/2$, $5\lambda/2$, ….).

$$\boxed{\text{Path difference} = (m + \tfrac{1}{2})\,\lambda}$$

And ***phase difference*** between the waves must be an odd multiple of $\pi/2$ radian (i.e. phase difference = $\pi/2$ radian, $3\pi/2$ radian, $5\pi/2$ radian, ….).

$$\boxed{\text{Phase difference} = (m + \tfrac{1}{2})\pi \text{ radian}}$$

Where m is an integer, m = 0, 1, 2, 3, ……..
and λ is wave length of waves.

(When distance traveled by waves, from their sources, on reaching a given point is such that the path difference is $\lambda/2$, $3\lambda/2$, $5\lambda/2$ etc. or an odd multiple of $\lambda/2$, then a crest from a source will overlap a trough from the other. In such a case light from one source will cancel light from the other, no light remains. ***In other words***, a dark fringe is obtained).

- Destructive interference takes place at those points where crest from one source overlaps a trough from the other source.

Note that the phenomenon of interference is the ***basic characteristic*** of wave motion It means that ***all types of waves*** (including mechanical or electromagnetic waves) under suitable conditions show i***nterference effects***.

***Q.No.10*: What happens if two bulbs are used to observe interference?**

Ans: With two separate sources of light (e.g. light from two bulbs) no interference effect is produced, because light waves emitted by two different sources ***cannot have phase coherence***. The emission of light is a completely independent process. If one source of light produces a crest at a certain instant it is not necessary that the other source must also produce a crest at that instant.

Young's double slit experiment:

***Q.No.1*: How did Thomas Young achieve the condition of phase coherence for light in his double slit experiment?**

Ans: To produce interference effect of light, Thomas Young achieved the condition of phase coherence in his double slit experiment by using one source of monochromatic light. Light from this source was allowed to fall on a narrow slit whose width was comparable to wavelength of light. After passing through the slit light spreads out as spherical wave fronts. This single slit may be considered as a single coherent source of light. Wavefronts from this slit now pass through two more narrow slits at equal distance from the first slit. Light after passing through the two slits will have phase coherence as it was originally produced by one source. Hence light emerging from two slits can be considered to be emitted from two sources of light having **phase coherence**.

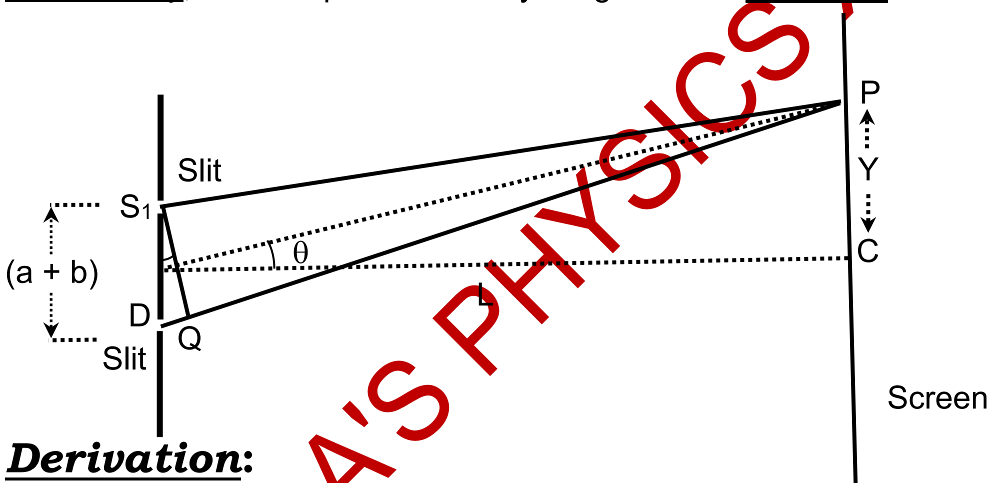
***Q.No.2*: What is monochromatic light?**

Ans*:** Light of ***one wave length is called ***monochromatic light***. Actually, monochromatic light means light of one color (mono = one, chromatic = color). Practically light of one color may have slightly different shades of slightly different wavelengths. Hence in strict sense, for scientific work, light having one wavelength is taken as monochromatic.

***Q.No.3*: Describe Young's double slit experiment.**

Ans. In Young's double slit experiment light from a monochromatic source after passing through a narrow slit, is allowed to pass through two parallel narrow slits separated by a small distance. Two beams of light emerging from the two slits ***will have phase coherence***, and will be in ***phase***, because they were originally produced by the same source. Hence the two beams of light will produce interfere effects. Due to their interference, bright and dark bands are produced on a screen placed at some distance "L" from the slits. These bands are called "***fringes***".

Bright fringes are produced at those points where light waves from the two slits interfere constructively, at these points intensity of light will be **maximum**. Whereas dark fringes are produced at those points where light waves from the two slits interfere destructively, at these points intensity of light will be **minimum**.



Derivation:

***Q.No.4*: Derive an expression for position of fringes in Young's double slit experiment.**

Ans. At any point on the screen light waves will interfere according to their path difference. Let the distance of a point "P" from the center C of the screen be "Y". To reach point "P" waves coming from slit "S_2" will cover longer distance than the waves coming from "S_1". The difference of distances covered by the two waves is called "***path difference***". We can see from the figure that the path difference between the waves coming to point "P" from S_1 and S_2 is "S_2Q". Triangles DPC and S_1S_2Q are similar, therefore:

$$\frac{PC}{S_2Q} = \frac{DP}{S_1S_2}$$

But PC = Y (Distance of point P from the center of the screen).

S_1S_2 = d (Separation of slits).

Since point "P" is practically very close to the center "C" of the screen, In other words "Y" is practically very small as compared to "L". Hence:

$DP \approx DC = L$ (D is the center of slits)

$$\therefore \quad \frac{Y}{S_2Q} = \frac{L}{d}$$

$$\therefore \quad \boxed{Y = S_2Q \times \frac{L}{d}}$$

***Position of bright fringes*:**

***Q.No.5**: Derive an expression for position of **bright fringes** in Young's double slit experiment.*

Ans. For bright fringes, where constructive interference takes place, the path difference "S_2Q" must be an integral multiple of "λ", Therefore:

$$\therefore \quad S_2Q = m\lambda$$

Where m = 0, 1, 2, 3, …….. (a positive integer)

On taking path difference $S_2Q = m\lambda$, the above equation gives us distance "Y" of various bright fringes from center C of the screen.

$$\therefore \quad \boxed{Y = m\lambda\frac{L}{d}} \qquad \text{(For bright fringes)}$$

If we take m = 0, the path difference between two beams of light coming from the two slits will be equal to zero, and light will interfere constructively forming a bright fringe. But the two beams of light will cover equal distances on reaching "C", hence the center "C" of the screen will always be ***bright***. (m = 0 corresponds to C).

Similarly, first, second, third, ……. etc. bright fringes will be formed above and below C at distances $\frac{\lambda L}{d}$, $2\frac{\lambda L}{d}$, $3\frac{\lambda L}{d}$, $4\frac{\lambda L}{d}$, ………. etc. from the center C of the screen.

***Position of dark fringes*:**

***Q.No.6**: Derive an expression for position of **dark fringes** in Young's double slit experiment.*

Ans. For dark fringes, where destructive interference takes place, the path difference "S_2Q" must be an odd integral multiple of "$\lambda/2$", Therefore:

$$\therefore \quad S_2Q = (m + \tfrac{1}{2})\lambda$$

Where m = 0, 1, 2, 3, …….. (a positive integer)

On taking path difference $S_2Q = (m + \frac{1}{2})\lambda$, the above equation gives us distance "Y" of various dark fringes from center C of the screen.

$$\therefore \quad \boxed{Y = (m + \tfrac{1}{2})\lambda\frac{L}{d}} \qquad \text{(For dark fringes)}$$

First, second, third, …….. etc. dark fringes will be formed above and below C at distances
$\frac{\lambda L}{2d}$, $\frac{3\lambda L}{2d}$, $\frac{5\lambda L}{2d}$, $\frac{7\lambda L}{2d}$, ………. etc. from the center C of the screen.

Between two bright fringes there will be a dark fringe.

Note that for each value of "m" a bright and a dark fringe, at equal distance, is obtained <u>above</u> and <u>below</u> "C" whereas C itself will always be ***<u>bright</u>*** and it will correspond to zero path difference.

<u>Fringe spacing</u>:

<u>Q.No.7</u>: What is fringe spacing? Derive an expression for fringe spacing.

<u>Ans</u>: It is the <u>***distance*** between two ***consecutive*** (side by side) ***bright*** or ***dark*** fringes</u>.

Expression for fringe spacing can be obtained by subtracting the expressions for distances of two adjacent bright or dark fringes from center of the screen. Hence:

Distance of (say) 4th and 5th bright fringes from the center of screen is given by:

$$Y_4 = \frac{4\lambda L}{d} \quad \text{and} \quad Y_5 = \frac{5\lambda L}{d}$$

$$\therefore \quad \text{Fringe spacing} = Y_5 - Y_4$$

$$= \frac{5\lambda L}{d} - \frac{4\lambda L}{d}$$

$$\boxed{\text{Fringe spacing } \Delta x = \frac{\lambda L}{d}}$$

In Young's double slit experiment, fringes are ***<u>equally spaced</u>*** (i.e. at equal distance from each other).

<u>Q.No.8</u>: How can wave length of light 'λ' be determined by Young's double slit experiment?

<u>Ans</u>: Distance between any two adjacent bright or dark fringes (called fringe spacing) in Young's slit experiment is given by:

$$\text{Fringe spacing } \Delta x = \frac{\lambda L}{d}$$

Fringe spacing 'Δx' can be measured accurately, distance between screen and the slits 'L' and the separation of slits 'd' are measurable, therefore, wave length 'λ' of light used can be calculate with high degree of accuracy. This is the reason why Young's double slit experiment is used to determine wave length of light.

<u>Q.No.9</u>: What will happen if light used in Young's double slit experiment is <u>NOT monochromatic</u>?

<u>Ans</u>: If incident light used in Young's double slit experiment is not monochromatic i.e. it is of two or more different wave lengths (colors) then for each wave length a separate bright and a dark fringe is obtained for each value of integer "m" (for given L and d).

In other words, for each value of 'm', we will get a series of parallel lines, number of these colored lines for each 'm' depends upon the number of wavelengths present in the interfering light. It is, therefore, possible that a bright fringe of one wavelength for a given 'm' may overlap a dark fringe of another wavelength for some other value of 'm'. All these observations will take place according to the path difference for each wave length for each value of 'm'.

- Young's double slit experiment supports ***wave theory*** of light.

***Interference in thin films*:**

***Q.No.1*: What is phase reversal? When does it take place?**

Ans. When a light wave traveling in a rarer medium (medium of lower refractive index) reflects from the surface of a denser medium (medium of higher refractive index), then its crest before reflection becomes a trough after reflection and vice versa. Under this condition the wave is said to have undergone ***phase reversal***. The reflected wave is $180°$ out of phase as compared to the original wave.

No phase reversal will take place if a wave traveling in a medium of higher refractive index (a denser medium) reflects from the surface of a medium of lower refractive index (a rarer medium).

***Q.No.2*: Give examples of interference in a thin film?**

Ans. ***Example*:** When sun light falls on the surface of a very thin film made of a refracting medium, such as the surface of a ***soap solution bubble*** or ***surface of a thin layer of oil*** spread on the surface of water, colored patterns are formed. These colored patterns are ***due to the interference of light***.

In these cases, interference of light is between light waves reflected from the opposite surfaces of the soap bubble or oil film. Since sun light consists of seven colors, therefore, due to interference between waves of various wavelengths colored patterns are formed.

***Q.No.3*: Is there a phase reversal in Young's double slit experiment?**

Ans. No!

There is no phase reversal in Young's double slit experiment, because light waves travel in the same medium, there is no change of refractive index. Phase reversal takes place when light is reflected from the boundary of two media of different refractive index.

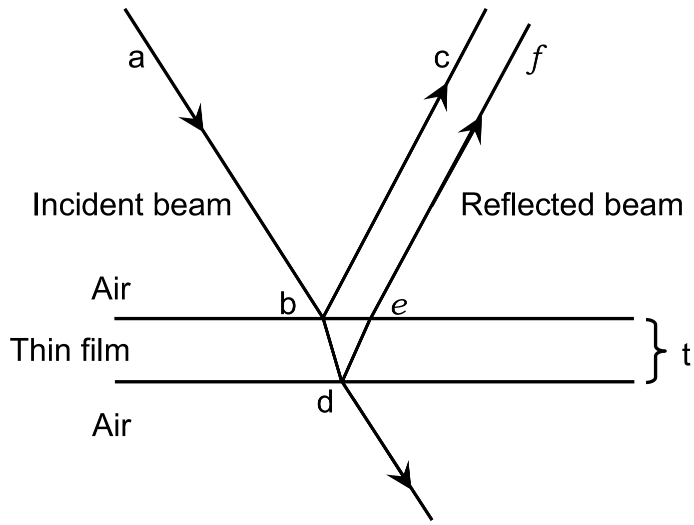
***Q.No.4*: Describe interference of light in a thin film.**

Ans. ***Explanation*:**

Consider a beam of monochromatic light traveling in air and falling on a very thin film of a refracting medium of refractive index "n". This beam of light is partially reflected from the upper surface of the film and partially refracted into it. Since the reflected part "b c" was initially travelling in air (a medium of lower refractive index) and is reflected from the surface of a denser medium, such as the surface of soap solution bubble (a medium of higher refractive index), therefore, it will undergo ***phase reversal***, it's phase will change by $180°$. It means that an ***incident crest*** after reflection from the surface of the film becomes a ***trough*** and vice versa.

The refracted part undergoes reflection from the lower surface of the film (at d) Since this part before reflection from the lower surface of the film was traveling in a denser medium e.g. soap solution (medium of higher refractive index), therefore, it does not undergo phase reversal.

The refracted part after reflection from the lower surface of the film emerges out as "$e\,f$" without phase reversal (i.e. crests as crests or troughs as troughs).



Wave length of light also <u>changes</u> in thin film interference. Hence when light of wave length "λ" travels from air (a rarer medium) to a denser medium of refractive index "n" its wave length changes (decreases) and is given by:

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

Parts "b c" and "$e\,f$" on reaching the eye will interfere according to their path difference.

<u>Q.No.5</u>*: *What is the condition for constructive interference in a thin film?

***<u>Ans</u>*:** In case of thin film interference since one of the interfering parts has undergone phase reversal, (It means that one part will have a crest and the other part will have a trough), therefore, condition for constructive interference will have to be reversed. Hence condition for constructive interference in a thin film is:

$$\boxed{\text{Path difference} = (m + \tfrac{1}{2})\,\lambda_n}$$

Where m is a positive integer, m = 0, 1, 2, 3, ……..

and λ_n is wave length of light in the refracting medium (e.g. soap solution film).

If "t" is thickness of the film, then for normal incidence (i.e. when light falls normally on the film) the path difference will be "2 t", hence condition for constructive interference will be:

$$2\,t = (m + \tfrac{1}{2})\,\lambda_n$$

OR

$$2\,t = (m + \tfrac{1}{2})\,\frac{\lambda}{n}$$

∴

$$\boxed{2\,n\,t = (m + \tfrac{1}{2})\,\lambda}$$

<u>Q.No.6</u>*:** What is the ***condition for destructive interference in a thin film?

***<u>Ans</u>*:** Condition for destructive interference in a thin film is:

$$\boxed{\text{Path difference} = m\,\lambda_n}$$

Where m is a positive integer, m = 0, 1, 2, 3, ……..

and λ_n is wave length of light in the refracting medium..

If "t" is thickness of the film, then for normal incidence the path difference will be "2 t", hence condition for destructive interference will be:

$$2\,t = m\,\lambda_n$$

OR $$2\,t = m\,\frac{\lambda}{n}$$

$\therefore$ $$\boxed{2\,n\,t = m\,\lambda}$$

Note that the conditions for constructive and destructive interference in a thin film has to be <u>reversed</u> only because of ***<u>phase reversal</u>*** in one of the interfering parts.

In Young's double slit experiment normal conditions for constructive or destructive interference apply. In that case, ***<u>no phase reversal</u>*** takes place.

***<u>Newton's rings</u>*:**

<u>Q.No.1</u>*: *What are Newton's rings? (***Karachi Board 1994***)

<u>Ans.</u> If a beam of monochromatic light is allowed to fall on a plano-convex lens placed on a plane glass plate then alternate bright and dark rings are produced, these rings are known as ***Newton's rings.***

Actually, air present between the plano-convex lens and the surface of plane glass acts as a refracting film of a variable thickness. Newton's rings are formed because of ***interference of light*** taking place between light beams reflected from the upper and lower surfaces of the air film present between lens and the plane glass.

The air film present between lens and the plane glass is circular and wedge shaped.

Centre of Newton's rings is always ***<u>dark</u>***; it corresponds to the point of contact of lens and the plane glass surface. Here path difference is ***<u>zero</u>***.

Formation of Newton's rings is due to ***<u>thin film interference</u>***.

Formation of Newton's rings also proves an important property of light …. ***Interference***, which is a basic characteristic of wave motion and shows that light travels in the form of ***<u>waves</u>***.

***<u>Derivation</u>*:**

<u>Q.No.2</u>*:Show how can Newton's rings be used to find the radius of curvature of curved surface of a convex lens?

<u>Ans.</u> For any bright Newton's ring of radius "r" let "t" is the thickness of the corresponding air film and "R" is the radius of curvature of convex lens, then from the geometry of the following figure we have:

$$AB \times BC = r \times r$$

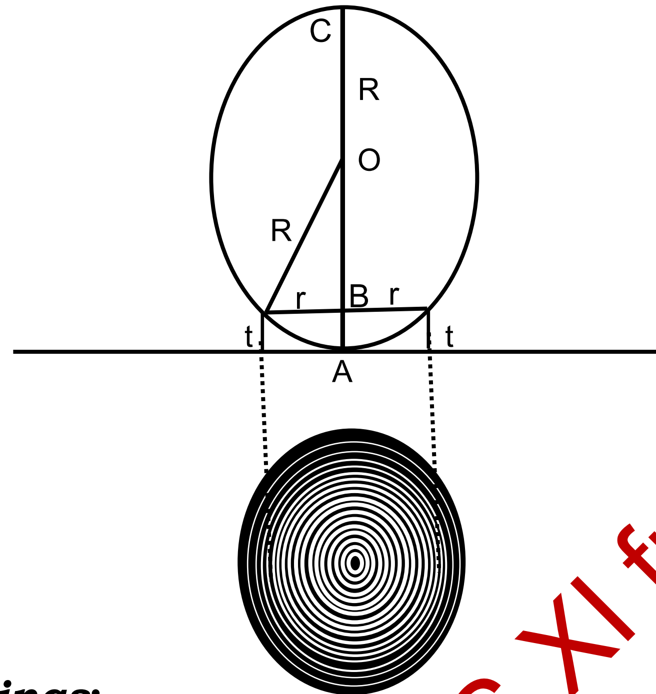
But $AB = t$ and $BC = (2\,R - t)$

$\therefore$ $$t\,(2\,R - t) = r^2$$

$$2\,R\,t - t^2 = r^2$$

Since the air film is very thin, therefore, "t" is very small, hence "t^2" is negligible. Neglecting "t^2" we get:

$$2\,R\,t = r^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (i)$$



***For bright rings*:**

The condition for constructive interference in a thin film or in other words , in this case for a bright Newton's ring is:

$$2\,n\,t = (m + \tfrac{1}{2})\,\lambda$$

In this case the thin film is made of air, whose refractive index $n = 1$,

$$\therefore \qquad 2\,t = (m + \tfrac{1}{2})\,\lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

On substituting equation (*ii*) in equation (*i*), we get:

$$r^2 = R\,(m + \tfrac{1}{2})\,\lambda$$

$$\therefore \qquad \boxed{r = \sqrt{R\,\lambda\,(m + \tfrac{1}{2})}} \ldots\ldots\ldots\ldots\ldots\ldots (iii)$$

When we put m = 0 in the above equation, we will get radius of the first bright ring, given by:

$$r_1 = = \sqrt{\frac{R\,\lambda}{2}}$$

Similarly for second, third, fourth etc. bright rings m = 1, 2, 3, ……….etc. respectively. Hence the radii of second, third, fourth etc. bright rings are given by:

$$r_2 = = \sqrt{\frac{3R\,\lambda}{2}} \qquad m = 1 \text{ (for second ring)}$$

$$r_3 = = \sqrt{\frac{5\,R\,\lambda}{2}} \qquad m = 2 \text{ (for third ring)}$$

$$r_4 = = \sqrt{\frac{7\,R\,\lambda}{2}} \qquad m = 3 \text{ (for fourth ring)}$$

$$r_5 = = \sqrt{\frac{9\,R\,\lambda}{2}} \qquad m = 4 \text{ (for fifth ring) etc.}$$

If "N" is the number of bright rings, then $N = m + 1$ OR $m = N - 1$:
On substituting the expression for "m" in equation (*iii*) we will get radius of N th bright ring.

$$r_N = \sqrt{R\,\lambda\,(N - 1 + \tfrac{1}{2})}$$

Radii of bright rings: $\boxed{r_N = \sqrt{R\,\lambda\,(N - \tfrac{1}{2})}}$

This formula gives us radius of the N th bright ring, it can also be used to find the radius of curvature "R" of the convex lens accurately.

Note that "m" is a positive integer i.e. 0, 1, 2, 3 ………… Whereas "N" is the number of Newton's bright ring.

For dark rings:

The condition for destructive interference in a thin film, ***in other words***, in this case for a dark Newton's ring is: $2\,n\,t = m\,\lambda$ $(m = 0, 1, 2, 3, 4 \ldots)$
Since the thin film is made of air, whose refractive index $n = 1$,

$$\therefore \quad 2\,t = m\,\lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots (iv)$$

On substituting equation (*iv*) in equation (*i*), we get:

$$r^2 = m\,R\,\lambda$$

Radii of dark rings: $\boxed{r = \sqrt{m\,R\,\lambda}}$ ……………………..(*v*)

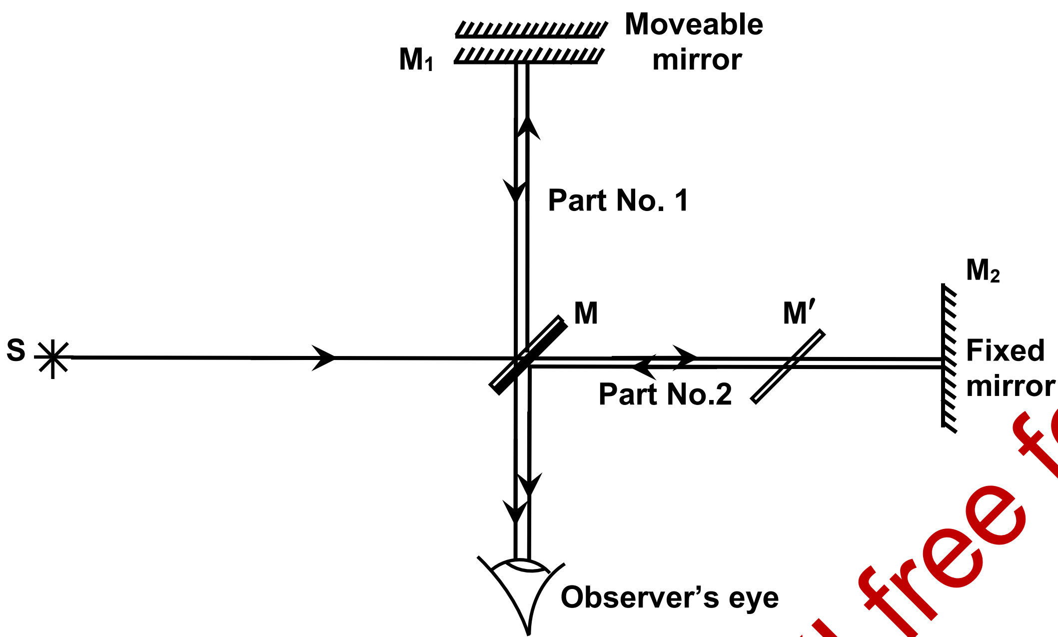
Where m = 0 for the central dark spot, which corresponds to the point of contact of lens and the plane glass plate, it is dark due to destructive interference.
Similarly, m = 1, 2, 3, …. for first, second, third ,……. dark rings.

Michelson's interferometer:

Construction and working:

In a Michelson's interferometer light from a monochromatic source "S" (Source of light may be extended, whereas in Young's double slit experiment fine beam of light is used) is allowed to fall on a semi silvered glass plate "M" (also called beam splitter) held at an angle of 45° to the beam of light. From this glass plate light is partially reflected and partially refracted through it. The reflected part No. 1 goes towards a highly polished plane mirror "M_1" which is held perpendicular to the reflected beam. After reflection from M_1 this part of light passes through the glass plate "M" and finally it enters the observer's eye.

The transmitted part No.2 after passing through another plane glass plate "M′ " which is not silvered and is of the same thickness as the semi silvered glass plate "M", falls on another highly polished plane mirror "M_2". Glass plate "M′ " is called compensating plate, it is used so that both parts of light pass through the same thickness of glass. The transmitted part after reflection from M_2 passes through M′ and is then reflected from M, also enters the eye. The two parts of light entering the observer's eye will have ***phase coherence***, because they were originally produced by the same source. Hence they will interfere, producing bright and dark fringes.



Plane mirror "M_1" is moveable and any small distance through which it is moved can be measured accurately. Mirror "M_2" is fixed.

Derivation:

Let the distances covered by part No.1 and No.2 is exactly equal when they enter the observer's eye. Hence path difference will be zero and the two parts will ***interfere constructively*** due to which a ***bright*** fringe appears at a reference point in the field of view of the observer.

Now if the moveable mirror "M_1" is moved through a distance equal to $\lambda/4$ then path difference between the two parts will be $\lambda/2$ due to which the ***bright*** fringe is replaced by a ***dark*** fringe. If the moveable mirror is further moved through a distance equal to $\lambda/4$ the path difference will become λ and now the ***dark*** fringe will be replaced by a ***bright*** one.

In this manner alternate bright and dark fringes will cross a reference point, each time "M_1" is moved through a distance $\lambda/4$.

In other words, if the moveable mirror is moved through $\lambda/2$, a bright fringe will be replaced by the next bright fringe. Hence if "m" bright fringes cross a reference point then the distance through which the moveable mirror is moved is given by:

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

If the distance "d" through which the moveable mirror is moved to observe "m" fringes crossing a reference point is known, then the wave length "λ" of the incident light can be calculated.

***Diffraction of light*:**

***Q.No.1*: What is diffraction of light?**

Ans*:** The ***bending of light across the edges of an obstacle or an opening into the geometrical shadow is called ***diffraction of light***.

- Diffraction of light takes place only when dimensions of the obstacle or the opening is ***comparable to the wave length*** of light.

After bending across the edges of an obstacle, diffracted waves interfere with each other on the screen, as a result of which alternate bright and dark fringes are obtained.

- Distance between bright fringes obtained in diffraction pattern ***increases*** as the angle of diffraction is ***increased***.
- Also, the intensity of light gradually ***decreases*** with the angle of diffraction.
- ***Note that*** diffraction of light is another phenomenon that supports ***wave theory of light*** (i.e. light travels in the form of waves). In this process light exhibits ***wave nature***.

***Difference between interference and diffraction of light*:**

- The main difference between interference and diffraction is that, the fringes in interference are ***equally spaced*** (i.e. at equal distance from each other) but in diffraction pattern they ***are not equally spaced***, their ***separation increases*** with the angle of diffraction.
- In Interference bright fringes are of ***uniform intensity*** whereas bright fringes produced in diffraction are of ***non-uniform intensity***. Intensity of light gradually ***decreases*** with the angle of diffraction.

***Diffraction grating*:**

***Q.No.2*: What is a diffraction grating?**

***Ans*:** A diffraction grating consists of a transparent glass sheet on which large number of opaque parallel lines (equally spaced) very close to each other, are ruled (Usually several hundred lines per centimeter are ruled).

The transparent portion of the glass between any two adjacent opaque lines acts as a slit. Its width is comparable to the wave length of ordinary light.

Let "a" be the width of a slit and "b" be the width of an opaque line then, (a + b) is known as the "***grating element***".

***Q.No.3*: How is grating element calculated?**

Ans*:** The grating element is calculated ***by dividing length of the diffraction gating by the number of lines ruled on it.

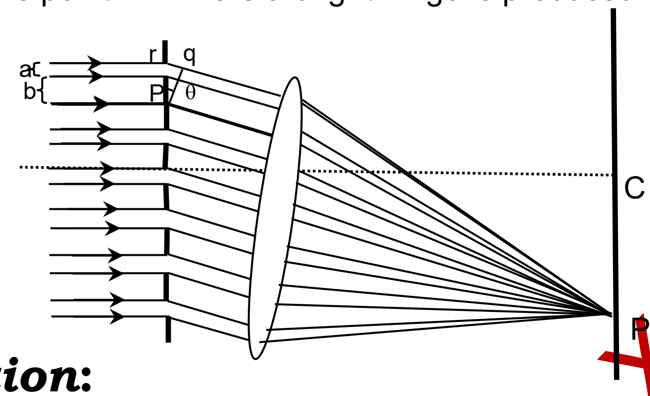
For example, let a diffraction grating has 2000 lines/cm. then grating element for this grating is given by:

$$(a + b) = \frac{1\text{ cm.}}{2000} = 5\times10^{-4}\text{ cm.} = 5\times10^{-6}\text{ m}$$

Working of diffraction grating:

Q.No.4: Show how diffraction grating can be used to find accurately the wave length of light used?

Ans: When a monochromatic beam of parallel rays falls normally on diffraction grating, they are diffracted in many directions. The parallel diffracted rays in a particular direction are allowed to pass through a convex lens of suitable focal length which focuses them on a screen at some point "P" where a bright fringe is produced.



Derivation:

For any two beams, diffracted from two adjacent slits, let the angle of diffraction be "θ". The path difference between the two diffracted beams at a point "P" is "r q", it must be an integral multiple of wave length "λ" so that a bright diffracted image is formed at "P".

In Δ p q r: $\sin\theta = \dfrac{rq}{pr}$

∴ $rq = pr \sin\theta$

But p r = (a + b) is the grating element and r q is the path difference.

∴ $rq = (a + b)\sin\theta$

For bright diffracted images the path difference "r q" must be an integral multiple of "λ".

∴ $\boxed{m\lambda = (a + b)\sin\theta}$

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

Where m = 0, 1, 2, 3, …………… (an integer)

For m = 0 we will get zero th order un-diffracted image, at the center C.

But for m = 1, 2, 3, ….. we will get 1st order, 2nd order, and 3rd order etc. images for which:

$\lambda = (a + b)\sin\theta$

$2\lambda = (a + b)\sin\theta$

$3\lambda = (a + b)\sin\theta$ …………….etc.

Selecting a suitable value of "m" (order of image), and measuring the corresponding angle of diffraction "θ", the wave length of incident light "λ" can be calculated with the help of one of the above equations.

Diffraction of X-rays through crystals:

Q.No.1: Why is a crystal needed for the diffraction of X-rays?

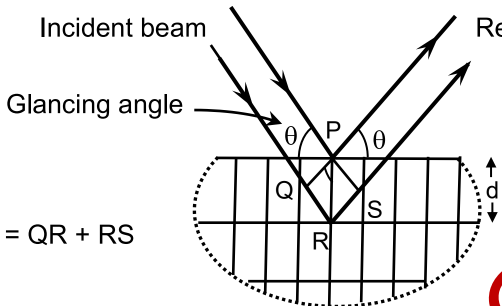
Ans: Wave length of X-rays is ***very short*** as compared to the wave length of visible light. Therefore, they ***do not*** show diffraction effects by ordinary diffracting objects (such as diffraction grating, fine slits or sharp-edged objects like shaving blade etc.). Similarly for the same reason, interference pattern of X-rays by Young's double slit or by a thin soap solution film or thin oil film ***cannot*** be produced.

In certain crystals (such as rock salt), the atoms are arranged in a regular manner such that the planes thus formed are at a distance (about 2 Å - 5 Å) comparable to the wave length of X-rays. Hence X-rays can be diffracted with the help of a suitable crystal.

***Q.No.2*: Derive Brag's law?**

***Ans*:** Consider a beam of X-rays incident upon a crystal, beams of X-rays reflected from two adjacent planes of the crystal will interfere constructively when their path difference is an integral multiple of their wave length.

An X-ray beam is reflected from the upper plane and the second X-ray beam is reflected from the lower plane. These two beams will cover different distances before entering the eye (second beam will cover longer distance). Difference in distance covered, called ***path difference***, can be determined with help of the following diagram.



Path difference = QR + RS

Calculation of path difference:

In triangle PQR: $\sin\theta = \dfrac{QR}{PR}$

$\therefore$ $QR = PR \sin\theta$ But $PR = d$ (Distance between atomic planes)

$\therefore$ $QR = d \sin\theta$

Similarly: $RS = d \sin\theta$

But path difference between the two beams of X-rays = Q R + R S

$\therefore$ Path difference = $d \sin\theta + d \sin\theta$

$\therefore$ $\boxed{\text{Path difference} = 2d\sin\theta}$

Hence path difference between two X-rays beams reflected from two adjacent lattice planes of the crystal is "$2d\sin\theta$, where "d" is the distance between the two planes, and "θ" is the glancing angle. These beams of X-rays will interfere constructively if their path difference is an integral multiple of its wave length "λ". Therefore,

$$\boxed{m\lambda = 2d\sin\theta} \qquad (m = 1, 2, 3, \ldots.)$$

This relation is known as ***Brag's law***.

The separation "d" of planes of the crystal can be calculated with the help of its density and atomic weight. Since "m" and "θ" can be measured accurately by experiment, the wave length of X-rays can be calculated.

Section–A Multiple-Choice Questions MCQs:

Q.No.1: If the wavelength of an electromagnetic wave is about the diameter of a cricket ball what type of radiation is it.

(A) X-rays (B) Ultraviolet.
(C) Radio waves. (D) Visible light.

Q.No.2: Electromagnetic waves from an unknown source in space are found to be diffracted when passing through gaps of the order of 10^{-5} m. Which type of the waves are they most likely to be?

(A) Microwaves. (B) Ultraviolet.
(C) Radio waves. (D) Infra-red.

Q.No.3: Huygen's conception of secondary waves:

(A) Helps us to find the focal length of a thick lens.
(B) is a geometrical method to find a wavefront
(C) is used to determine the velocity of light.
(D) is used to explain the polarization of light.

Q.No.4: Interference fringes are produced using monochromatic light of same intensity from a double slit screen. If the intensity of light emerging from one of the slits is reduced, the effect on interference pattern will be:

(A) all the dark and bright fringes become brighter.
(B) all the dark and bright fringes become darker.
(C) Bright fringes become brighter and dark fringes become darker.
(D) Bright fringes become darker and dark fringes become brighter.

Q.No.5: In Young's double slit experiment when the distance between slits and screen is doubled, while separation of slits is halved, then fringe width will be:

(A) 4 times. (B) ¼ times
(C) doubled. (D) unchanged.

Q.No.6: A ray of light passes from air into water, striking the surface of water at an angle of incidence 45°. Which of these quantities change as the light enters water,

(i) Wavelength. (ii) frequency.
(iii) Speed of propagation.
(iv) direction of propagation.
(A) i and ii only. (B) iii and iv only.
(C) i, iii and iv only. (D) all of them.

Q.No.7: A hill separates a television (TV) transmitter from a house. The transmitter cannot be seen from the house but still the TV in the house has good reception. What wave phenomena make it possible?

(A) Coherence of waves. (B) Diffraction of waves.
(C) Interference of waves.
(D) Refraction of waves.

Q.No.8: Monochromatic light is incident on a diffraction grating and a pattern is observed. What effect is observed by replacing the grating with one that has more lines per millimeter?

(A) Number of maxima **decreases** with **decrease** in angle between first and second order maxima.
(B) Number of maxima **decreases** with **increase** in angle between first and second order maxima.
(C) Number of maxima **increases** with **decrease** in angle between first and second order maxima.
(D) Number of maxima **increases** with **increase** in angle between first and second order maxima.

Q.No.9: Optically active substances are those substances which:

(A) produce polarized light.
(B) rotate the plane of polarized light.
(C) Produce double refraction.
(D) convert a plane polarized light into a circularly polarized light.

Q.No.10: Plane polarized light is passed through a Polaroid. On viewing through the polaroid, we find that when Polaroid is given one complete rotation about the direction of light:

(A) The intensity of light gradually decreases to zero and remains at zero.
(B) The intensity of light gradually increases to maximum and remains at maximum.
(C) There is no change in intensity of light.
(D) The intensity of light varies such that it is twice maximum and twice zero.

Q.No.11: In Young's double slit experiment, the fringe spacing is:

(***2004,14 Karachi Board***)

(A) $\frac{d\lambda}{L}$ (B) $\frac{\lambda L}{d}$ (C) $\frac{d}{\lambda L}$

Q.No.12: Which of the following phenomenon cannot be explained by wave theory?

(***2005, 2004 Karachi Board***)

(A)interference (B)diffraction (c)photoelectric effect

Q.No.13: The condition for the interference in a thin film is reversed because of:

(***2016, 15, 08, 04 Karachi Board***)

(A) small thickness.
(B) phase reversal. (C) refraction.

Q.No.14: Colors in thin film of soap are due to: (***2005 Karachi Board***)

(A) Refraction of light.
(B) diffraction of light.
(C) Interference of light.
(D) Scattering of light.

Q.No.15: To replace a bright fringe by the next bright fringe in a Michelson interferometer, the moveable mirror is moved through a distance equal to: (***2005 Karachi Board***)

(A) λ (B) $\lambda/2$ (C) $\lambda/4$ (D) 2λ

Q.No.16: Which property of light is used to determine the concentration of an optically active substance such as sugar?

(***2005 Karachi Board***)

(A) Interference. (B) Dispersion.
(C) Diffraction. (D) Polarization.

Q.No.17: If 2000 lines /cm. are ruled on a grating, its grating element is:

(***2006 Karachi Board***)

(A) 5×10^{-4} m. (B) 5×10^{-3} m
(C) 5×10^{-6} m. (D) 5×10^{-7} m

Q.No.18: The transverse nature of light was confirmed by: (***2008 Karachi Board***)

(A) Interference (B) Diffraction
(C) Polarization. (D) Dispersion

Q.No.19: Yellow light from a sodium lamp is used to form Newton's rings. The central spot in Newton's rings will be:

(***2008 Karachi Board***)

(A) Yellow. (B) Bright.
(C) Dark. (D) Neither bright nor dark.

Q.No.20: In Young double slit experiment condition for constructive interference is that the path difference must be:

(A) An odd multiple of the half wavelength.
(B) An odd multiple of the whole wavelength.
(C) An integral multiple of the wavelength.
(D) An even multiple of the wavelength.

Q.No.21: According to Maxwell's theory, light travels in the form of:

(***2012 Karachi Board***)

(A) Transverse wave. (B) Longitudinal wave
(C) Mechanical wave. (D) Electromagnetic wave.

Q.No.22:***77*** Huygen's principle is used to:

(***2012 Karachi Board***)

(A) Determine the speed of light.
(B) Express polarization.
(C) Locate the wave front.
(D) Find the refractive index.

Q.No.23: Monochromatic yellow light is unable to show: (***2013 Karachi Board***)

(A) Reflection. (B) Refraction.
(C) Dispersion. (D) Interference.

Q.No.24: A wave enters from one medium to another medium, no change occurs in its:

(***2013 Karachi Board***)

(A) Frequency. (B) Wave length.
(C) Amplitude. (D) Speed.

Q.No.25: Diffraction of light is a special type of: (***2014 Karachi board***)

(A) Reflection. (B) Refraction.
(C) Interference. (D) Polarization.

Q.No.26: Newton's rings illustrate the phenomenon of: (***2015 Karachi Board***)

(A) Polarization. (B) Diffraction.
(C) Interference. (D) Dispersion.

Q.No.27: Polarization of light in tourmaline crystals takes place because of:

(***2015 Karachi Board***)

(A) Reflection. (B) Absorption.
(C) Refraction. (D) Collision.

Q.No.28: The number of lines per cm. of a diffraction grating is 4000. Its grating element is: (***2017 Karachi Board***)

(A) 2.5×10^{-4} cm. (B) 2.5×10^{-6} cm.
(C) 4×10^{2} cm. (D) 4×10^{5} cm.

Q.No.29: The experimental evidence of transverse nature of light is:

(***2018 Karachi Board***)

(A) diffraction. (B) interference.
(C) polarization. (D) dispersion.

Q.No.30: When Newton's rings are observed by reflected light, the center of rings appears dark due to: (***2018 Karachi Board***)

(A) Phase reversal only.
(B) Path difference zero only.
(C) Intensity of light being maximum
(D)Phase reversal and path difference zero

Q.No.31: The wave front of waves will be spherical when the rays of light are: (***2019 Karachi Board***)

(A) parallel. (B) perpendicular.
(C) monochromatic. (D) not parallel

Q.No.32: When a transverse wave travelling through a rare medium is reflected from a dense medium, then phase change produced in it will be equal to: (***2019 Karachi Board***)

(A) 0° (B) 90° (C) 180° (D) 360°

Q.No.33: Bragg's law is: (***2022, 16 Karachi Board***)

(A) $2\,d \sin\theta = m\,\lambda$ (B) $2\,m\,\lambda = d \sin\theta$
(C) $d \sin\theta = m\,\lambda$ (D) $d \cos\theta = m\,\lambda$

Q.No.34: The bending of light around a sharp obstacle is called: (***2022 Karachi Board***)

(A) Interference. (B) Polarization.
(C) Refraction. (D) Diffraction.

Q.No.35: Huygen's principle is used to determine: (***2022 Karachi Board***)

(A) Speed of light. (B) Position of wave front
(C) Polarization. (D) Refractive index.

Q.No.36: Wave front near the point source is (***2022 Karachi Board***)

(A) Plane (B) Spherical (C) Conical (D)cylindrical

Q.No.37: Electromagnetic waves consist of oscillating electric and magnetic fields, both are: (***2011 Karachi Board***)

(A) Parallel to each other.
(B) Perpendicular to each other.
(C) Non-parallel to each other.
(D) Neither of these.

Q.No.38: For constructive interference, path difference between two coherent waves must be: (***2025 Karachi Board***)

(A) $(m + \frac{1}{2})\,\lambda$. (B) $\frac{1}{4}\,m\,\lambda$.
(C) $m\,\lambda$. (D) $3\,\lambda/2$.

Q.No.39: This electromagnetic wave has the longest wavelength. (***2026 Karachi Board***)

(A) Radio wave. (B) Microwave.
(C) Visible light. (D) Gamma ray.

Q.No.40: The light having only single wave length 'λ' is called:(***2026 Karachi Board***)

(A) Multichromatic. (B) Dichromatic.
(C) Ordinary light. (D) Monochromatic.

Answers:

(1) (C) Radio waves.
(2) (D) Infra-red.
(3) (B) is a geometrical method to find a wavefront.
(4) (B) all the dark and bright fringes become darker.
(5) (A) 4 times.
(6) (C) *i*, *iii* and *iv* only.
(7) (B) Diffraction of waves.
(8) (D) Number of maxima **increases** with **increase** in angle between first and second order maxima.
(9) (B) rotate the plane of polarized light.
(10) (A) The intensity of light gradually decreases to zero and remains at zero.
(11) (B) λ L / d
(12) (C) Photoelectric effect.
(13) (B) phase reversal.
(14) (C) Interference of light.
(15) (B) $\lambda/2$.
(16) (D) Polarization.
(17) (C) 5×10^{-6} m.
(18) (C) Polarization.
(19) (C) Dark.
(20) (C) An integral multiple of the wavelength.
(21) (D) Electromagnetic wave.
(22) (C) Locate the wave front.
(23) (C) Dispersion.
(24) (A) Frequency.
(25) (C) Interference.
(26) (C) Interference.
(27) (A) Reflection.
(28) (A) 2.5×10^{-4} cm.
(29) (C) polarization.
(30) (B) Path difference zero only.
(31) (D) not parallel
(32) (C) 180°.
(33) (A) $2\,d \sin\theta = m\,\lambda$
(34) (D) Diffraction.
(35) (B)Position of wave front
(36) (B) Spherical
(37) (B) Perpendicular to each other.
(38) (C) m λ.
(39) (A) Radio wave.
(40) (D) Monochromatic.

Numericals:

Q.No.1: **A monochromatic light of wavelength 6900 Å is used to illuminate two parallel slits on a screen that is 3.30 m away from the slits. Interference fringes are observed. Distance between adjacent bright fringes in the center of the pattern is 1.80 cm.**

What is the distance between slits?

Data:

Wave length of light $\lambda = 6900$ Å

($1 Å = 10^{-10}$ m) $\lambda = 6900\times10^{-10}$ m

Distance of the screen $L = 3.30$ m

Distance between adjacent bright fringes (or fringe spacing) $\Delta x = 1.80$ cm $= 0.018$ m

Distance between slits $d = ?$

Solution:

In Youngs double slit experiment fringe spacing is given by:

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

$$0.018 = \frac{6900\times10^{-10} \times 3.30}{d}$$

$$\therefore \quad d = \frac{6900\times10^{-10} \times 3.30}{0.018}$$

$$\boxed{d = 0.0001265 \text{ m} = 1.265\times10^{-4} \text{ m.}}$$

Distance between slits is ***1.265×10⁻⁴m.***

Q.No.2: **Michelson interferometer is adjusted so that a bright fringe appears on the screen. As one of the mirrors is moved 25.8 micrometer, 92 bright fringes are counted on the screen.**

What is the wavelength of light used in the interferometer?

Data:

Wavelength of light used $\lambda = ?$

Distance moved $d = 25.8$ micrometer $= 25.8\times10^{-6}$ m

Number of fringes $m = 92$

Solution:

Distance through which moveable mirror of the interferometer is moved is given by:

$$d = m\,\frac{\lambda}{2}$$

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

$$\lambda = \frac{2\times 25.8\times10^{-6}}{92}$$

$$\boxed{\begin{array}{l}\lambda = 560\times10^{-9}\text{ m}\\ \lambda = 560\text{ nm}\end{array}}$$

Wave length of light used is ***560×10⁻⁹ m.*** or ***560 nm.***

Q.No.4: **Newton's rings are formed by light of 400 nm wavelength. Determine the change in air film thickness between the third and sixth bright fringe. If the radius of curvature of the curved surface is 5.0 m**

What is the radius of third bright fringe?

Data:

Wave length of light $\lambda = 400$ nm $= 400\times10^{-9}$ m

Radius of curvature of the curved surface $R = 5.0$ m

Change in air film thickness between third and sixth bright rings $\Delta t = ?$

Radius of third bright ring $r_3 = ?$

Solution:

Condition for m^th bright Newton's ring (or for constructive interference):

$$2t = (m + \tfrac{1}{2})\lambda$$

For third ring: m= 2 for third ring

$2t_3 = (2 + \tfrac{1}{2})\,400$

$2t_3 = (5/2)\,400$ OR **$t_3 = 500$ nm.**

For sixth ring: m= 5 for third ring

$2t_6 = (5 + \tfrac{1}{2})\,400$

$2t_6 = (11/2)\,400$ OR **$t_6 = 1{,}100$ nm.**

$\therefore$ Change in air film thickness between third and sixth bright rings $\Delta t = t_6 - t_3$

$= 1100 - 500 =$ **600 nm**.

Change in air film thickness is **600 nm**. Or **600×10⁻⁹ m.**

Radius of a bright ring can be found by:

$r^2 = R\,(N - \frac{1}{2})\,\lambda$ N = 3 for 3rd ring

$\therefore$ $r_3^2 = 5(3 - \frac{1}{2})\,400\times10^{-9}$

$r_3^2 = 0.000005$ $r_3 = \sqrt{0.000005}$

$\therefore$ $\underline{r_3 = 0.002236\text{ m}}$ OR $\underline{r_3 = 2.236\text{ mm}}$

Radius of 3rd ring is **<u>0.002236 m</u>** OR **<u>2.236 mm.</u>**

***<u>Q.No.5</u>*: A soap film has an index of refraction n = 1.50. The film is viewed in reflected light.**

(a) at a spot where the film thickness is 910.0 nm. Which wavelengths are missing in the reflected light?

(b) Which wavelengths are strongest in the visible light?

***<u>Data</u>*:**

Refractive index of soap film n = 1.50
Film thickness t = 910 nm
(a) Missing wave lengths = ?
(b) Strongest wave lengths = ?

***<u>Solution</u>*:**

(a) For soap film interference (Thin film interference) for destructive interference or for dark fringes:

$2\,n\,t = m\,\lambda$

For m = 1

$2 \times 1.50 \times 910 = 1 \times \lambda$

$\therefore$ $\underline{\lambda = 2730\text{ nm}}$

For m = 2

$2 \times 1.50 \times 910 = 2 \times \lambda$

$\therefore$ $\underline{\lambda = 1365\text{ nm}}$

For m = 3

$2 \times 1.50 \times 910 = 3 \times \lambda$

$\therefore$ $\underline{\lambda = 910\text{ nm}}$

For m = 4

$2 \times 1.50 \times 910 = 4 \times \lambda$

$\therefore$ $\underline{\lambda = 682.5\text{ nm}}$

For m = 5

$2 \times 1.50 \times 910 = 5 \times \lambda$

$\therefore$ $\underline{\lambda = 546\text{ nm}}$

For m = 6

$2 \times 1.50 \times 910 = 6 \times \lambda$

$\therefore$ $\underline{\lambda = 455\text{ nm}}$

missing wavelengths are **682.5 nm, 546 nm** and **455 nm.**

(b) for constructive interference (or for strongest wavelengths)

$2\,n\,t = (m + \frac{1}{2})\,\lambda$

For m = 1

$2 \times 1.50 \times 910 = (1 + \frac{1}{2})\,\lambda$

$2730 = (3/2)\,\lambda$

$\therefore$ $\underline{\lambda = 1820\text{ nm}}$

For m = 2

$2 \times 1.50 \times 910 = (2 + \frac{1}{2})\,\lambda$

$2730 = (5/2)\,\lambda$

$\therefore$ $\underline{\lambda = 1092\text{ nm}}$

For m = 3

$2 \times 1.50 \times 910 = (3 + \frac{1}{2})\,\lambda$

$2730 = (7/2)\,\lambda$

$\therefore$ $\underline{\lambda = 780\text{ nm}}$

For m = 4

$2 \times 1.50 \times 910 = (4 + \frac{1}{2})\,\lambda$

$2730 = (9/2)\,\lambda$

$\therefore$ $\underline{\lambda = 607\text{ nm}}$

For m = 5

$2 \times 1.50 \times 910 = (5 + \frac{1}{2})\,\lambda$

$2730 = (11/2)\,\lambda$

$\therefore$ $\underline{\lambda = 496.4\text{ nm}}$

For m = 6

$2 \times 1.50 \times 910 = (6 + \frac{1}{2})\,\lambda$

$2730 = (13/2)\,\lambda$

$\therefore$ $\underline{\lambda = 420\text{ nm}}$

strongest wavelengths within the range of visible light are **780 nm, 607 nm, 496.4 nm and 420 nm.**

***<u>Q.No.6,7,8</u>*:**

See theory.

***<u>Q.No.9</u>*: The diffraction pattern from a single slit of width 0.020 mm is viewed on a screen. If the screen is 1.20 m from the slit and light of wavelength 430 nm is used. What is the width of central maximum?**

Data:

Width of slit d= 0.02mm=0.02×10^{-3} m

Distance of screen L = 1.20 m.

Wave length of light λ= 430 nm

= 430×10^{-9} m

Width of central maxima (bright fringe) =?

Solution:

Distance of 1st dark fringe on left side of central maxima (central bright fringe) $x_1 = \lambda\, L/d$

$$x_1 = \frac{430\times10^{-9}\times1.20}{0.02\times10^{-3}} = \mathbf{0.0258\ m}.$$

Since dark fringes are at equal distance on either side of central maxima, therefore,

Distance of 1st dark fringe on right side of central maxima (central bright fringe) x_2 = **0.0258 m**.

Width of central maxima (central bright fringe) will be equal to the sum of distance of these two dark fringes = 0.0258 + 0.0258

= **0.0516 m** or **5.16 cm**.

Q.No.10: **A grating has exactly 8000 lines uniformly spaced over 2.54 cm and is illuminated by light from a mercury vapor discharge lamp. What is the expected angle for the third order maximum of the light of wavelength 546 nm.**

Data:

Order of image m = 3

Angle θ = ?

Wave length of light λ= 546 nm

= 546×10^{-9} m

Number of lines = 8000

Length of grating = 2.54 cm.= 0.0254 m

Grating element (a+b)= $\frac{0.0254}{8000}$ = 3.175×10^{-6}m

Solution:

For a diffraction grating:

(a + b) Sin θ = m λ

$\therefore$ $3.175\times10^{-6}\times$ Sin θ = $3\times546\times10^{-9}$

$\therefore$ $$\text{Sin}\ \theta = \frac{3\times546\times10^{-9}}{3.175\times10^{-6}} = 0.5159$$

$\therefore$ θ = Sin $^{-1}$ 0.5159 = **31.06°**

Angle for third order maximum will be **31.06°**.

Q.No.11: **How many lines per centimeter are there in a grating which gives 1st order spectra at an angle of 30° when the wavelength of light is 6×10^{-5} cm?**

Data:

Order of image m = 1

Angle θ = 30 °

Wave length of light λ= 6×10^{-5} cm.

(No need to convert λ from cm. into m. as we are required to find No. of lines per cm.)

Number of lines/cm. = ?

Solution:

For a diffraction grating:

(a + b) Sin θ = m λ

(a + b) Sin 30° = $1\times6\times10^{-5}$

(a + b) $\times$ 0.5 = 6×10^{-5}

$$(a + b) = \frac{6\times10^{-5}}{0.5} = 12\times10^{-5}\ \text{cm.}$$

$$\text{Number of lines} = \frac{1}{12\times10^{-5}} = \mathbf{8{,}333\ line/cm.}$$

There are **8,333 lines per centimeter**.

Q.No.12: **Light of wavelength 450 nm is incident on a diffraction grating on which 5000 lines/cm have been ruled. Determine:**

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

(b) Determine the angle corresponding to each spectrum.

Data:

Wave length of light λ= 450 nm

= 450×10^{-9} m.

Number of lines = 5000 lines/cm

5000×100 lines/m.= 500000 lines/m.

Grating element (a + b) = $\frac{1}{500000}$m

= 2×10^{-6} m

(a) How many orders of spectra m =?

(b) Angle for each spectrum θ =?

Solution:

For a diffraction grating:

(a + b) Sin θ = m λ

Maximum number of orders of spectra can be found by assuming "$\theta = 90^o$".

$\therefore$ $2\times10^{-6} \times \sin 90^o = m \times 450\times10^{-9}$

(But $\sin 90^o = 1$)

$\therefore$ $m = \dfrac{2\times10^{-6}}{450\times10^{-9}} = 4$

(a) Orders of spectra that can be observed on either side of direct beam is **4**.
(**in other words** maximum four bright diffracted fringes can be observed)

(b) **Angle for m =1:**

$(a + b) \sin\theta = m\lambda$

$2\times10^{-6} \times \sin\theta = 1 \times 450\times10^{-9}$

$\sin\theta = \dfrac{1 \times 450\times10^{-9}}{2\times10^{-6}} = 0.225$

$\therefore$ $\theta = \sin^{-1} 0.225 = \underline{13^\circ}$

Angle for first order maximum will be **13°**.

Angle for m = 2:

$\therefore$ $2\times10^{-6}\times \sin\theta = 2 \times 450\times10^{-9}$

$\therefore$ $\sin\theta = \dfrac{2 \times 450\times10^{-9}}{2\times10^{-6}} = 0.45$

$\therefore$ $\theta = \sin^{-1} 0.45 = \underline{26.74^\circ}$

Angle for m = 3:

$\therefore$ $2\times10^{-6}\times \sin\theta = 3 \times 450\times10^{-9}$

$\therefore$ $\sin\theta = \dfrac{3 \times 450\times10^{-9}}{2\times10^{-6}} = 0.675$

$\therefore$ $\theta = \sin^{-1} 0.675 = \underline{42.45^\circ}$

Angle for m = 4:

$\therefore$ $2\times10^{-6}\times \sin\theta = 4 \times 450\times10^{-9}$

$\therefore$ $\sin\theta = \dfrac{4 \times 450\times10^{-9}}{2\times10^{-6}} = 0.9$

$\therefore$ $\theta = \sin^{-1} 0.9 = \underline{64.16^\circ}$.

Q.No.13: see theory.

Q.No.14: **A beam of X-rays of wavelength 0.071 nm is diffracted by a diffracting plane of rock salt with distance between the atomic planes 1.98 Å . Find the glancing angle for the second order diffraction.**

Data:

Wave length of X-rays $\lambda = 0.071$ nm $= 0.071\times10^{-9}$ m

Order of diffraction $m = 2$

Glancing angle $\theta = ?$

Separation of planes $d = 1.98$ Å $= 1.98\times10^{-10}$ m

Solution:

For X-ray diffraction from a crystal, according to Bragg's law:

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

For second order:

$2\times0.071\times10^{-9} = 2 \times 1.98\times10^{-10} \sin\theta$

$0.142\times10^{-9} = 3.96\times10^{-10} \sin\theta$

$\sin\theta = \dfrac{0.142\times10^{-9}}{3.96\times10^{-10}} = 0.3586$

$\theta = \sin^{-1} 0.3586$ $\boxed{\theta = 21.01^\circ}$

Q.No.15: **Unpolarized light passes through two polarizers in turn with polarization axes at 45° to each other. What is the fraction of the incident light intensity that is transmitted.**

Data:

Angle between polarization axes $\theta = 45^o$

Fraction of the incident light intensity transmitted $I = ?$

Solution:

While passing through first polarizer intensity of light reduces to **half**, whereas it reduces by a factor of $\cos^2\theta$ by the second polarizer.

Let "I_o" be the initial intensity of light incident upon first polarizer, then "$I_o/2$" will be the intensity of light incident upon the second polarizer.

Hence the fraction of initial intensity transmitted $= \dfrac{I_o}{2} \cos^2\theta$

$= \dfrac{I_o}{2} (\cos 45^o)^2 = \dfrac{I_o}{2} * 0.5 = 0.25\, I_o$

Net intensity of light transmitted will be **$0.25\, I_o$** which is **25%** of **initial intensity (I_o)** of unpolarized light.

Q.No.16: **If a diffraction grating produces a first order spectrum of light of wave length 6×10^{-7} m at an angle of 20° from the normal. What is its spacing.**

Data:

Order of image $m = 1$

Wave length of light $\lambda = 6\times10^{-7}$m

Angular deviation $\theta = 20°$.

Spacing of lines =?

Solution:

For diffraction grating:

$$(a + b) \sin\theta = m\lambda$$

$$(a + b) \sin 20° = 1\times 6\times10^{-7}$$

$$(a + b) = \frac{1\times 6\times10^{-7}}{\sin 20°}$$

$$(a + b) = \frac{6\times10^{-7}}{0.342} = 1.7543\times10^{-6}\text{m}$$

Therefore, spacing of slits $= \dfrac{1}{(a + b)}$

$$= \frac{1}{1.7543\times10^{-6}} = \boldsymbol{570033.57\ lines/m}$$

OR spacing of slits= ***570 lines/mm***

Q.No.17: **How far apart are the diffracting planes in a NaCl crystal for which X-rays of wavelength 1.54 Å makes a glancing angle of 15°-54′ in the first order.**

Data:

Wavelength $\lambda = 1.54$ Å $= 1.54\times10^{-10}$m

Glancing angle $\theta = 15°\text{-}54' = 15.9°$

Order of image $m = 1$.

Distance between planes $d = ?$

Solution:

According to Bragg's law:

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

$$1\times1.54\times10^{-10} = 2d\sin 15.9°$$

$$d = \frac{1.54\times10^{-10}}{2\sin 15.9°} = \frac{1.54\times10^{-10}}{2\times0.274}$$

$$\boxed{\begin{array}{c} d = 2.81\times10^{-10}\ m \\ d = 2.81\ \text{Å} \end{array}}$$

OR

Distance between diffracting planes is **2.81 Å.**

Q.No.18: **Two parallel slits are illuminated by light of two wave lengths one of which is 6.0 ×10⁻⁷ m on a screen the fourth dark line of the known wave length coincides with the fifth bright line of the unknown wave length. Calculate the unknown wave length.** (***1992 Karachi Board***)

Data:

Known wave length $\lambda_1 = 6.0\times10^{-7}$ m

Unknown wave length $\lambda_2 = ?$

Solution:

Distance of bright fringes from the center of the screen is given by:

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

Distance of fifth bright fringe of unknown wave length "λ_2" from the center of the screen will be:

$$y = \frac{5\lambda_2 L}{d}$$

Distance of fourth dark fringe of known wave length "λ_1" from the center of the screen will be:

$$y = (4 + \tfrac{1}{2})\frac{\lambda_1 L}{d} = \frac{9\lambda_1 L}{2d}$$

Since fourth dark fringe of known wave length coincides with the fifth bright fringe of unknown wave length, therefore, both must be at equal distance from center of the screen.

$$\frac{5\lambda_2 L}{d} = \frac{9\lambda_1 L}{2d}$$

$$5\lambda_2 = \frac{9\lambda_1}{2}$$

$$\lambda_2 = \frac{9\lambda_1}{10} = \frac{9\times6.0\times10^{-7}}{10}$$

$$\boxed{\begin{array}{c} \lambda_2 = 5.4\times10^{-7}\ m \\ \lambda_2 = 5400\ \text{Å} \end{array}}$$

Unknown wave length is ***5.4 ×10⁻⁷m*** or ***5400 Å***.

Q.No.19: **Interference fringes were produced by two slits on a screen 0.8 m from them when light of wave length 5.8×10⁻⁷ m was used. If the separation between the first and the fifth bright fringe is 2.5 mm. Calculate the separation of the two slits.** (***1995 Karachi Board***)

Data:

Distance between slits and screen L =0.8m.

Wave length of light $\lambda = 5.8\times10^{-7}$ m

Distance between first and fifth bright fringe =2.5 mm=2.5×10^{-3} m

Separation of slits d = ?

Solution:

Distance of the first bright fringe from center of the screen is given by: $y = \dfrac{\lambda L}{d}$

Distance of the fifth bright fringe from center of the screen is given by: $y = \dfrac{5\lambda L}{d}$

But the distance between the two fringes is 2.5 mm

Therefore $\dfrac{5\lambda L}{d} - \dfrac{\lambda L}{d} = 2.5\times10^{-3}$

$$\frac{4\lambda L}{d} = 2.5\times10^{-3}$$

$$\frac{4\times5.8\times10^{-7}\times0.8}{d} = 2.5\times10^{-3}$$

$$d = \frac{4\times5.8\times10^{-7}\times0.8}{2.5\times10^{-3}}$$

$$\boxed{\begin{array}{c} d = 7.424\times10^{-4}\ m \\ d = 0.74\ mm \end{array}}$$

Q.No.20: **Red light falls normally on a diffraction grating ruled 4000 lines/cm. and the second order image is diffracted 34° from the normal.**

Compute the wave length of light in angstroms. (***1996 Karachi Board***)

Data:

Number of lines ruled = 4000 lines /cm.

Grating element (a + b)

$= \dfrac{1}{4000}$ cm $= 2.5\times10^{-4}$cm$=2.5\times10^{-6}$ m

Angular deviation $\theta = 34°$

Order of image m = 2

Wave length λ =?

Solution:

For diffraction grating:

$$(a + b)\ \text{Sin}\ \theta = m\ \lambda$$

$$2.5\times10^{-6}\ \text{Sin}\ 34° = 2\ \lambda$$

$$2.5\times10^{-6}\times0.5992 = 2\ \lambda$$

$$\lambda = \frac{2.5\times10^{-6}\times0.5992}{2}$$

$$\boxed{\begin{array}{c} \lambda = 6.9899\times10^{-7}\ m \\ \lambda = 6989.9\ \text{Å} \end{array}}$$

Q.No.21: **How many fringes will pass a reference point if the moveable mirror of the Michelson's interferometer is moved by 0.08 mm? The wave length of light used is 5800 Å.** (***1998 Karachi Board***)

Data:

Wave length of light used λ =5800 Å

$= 5800\times10^{-10}$ m

Distance through which the moveable mirror is moved d = 0.08 mm = 0.08×10^{-3} m

Number of fringes m =?

Solution:

Distance through which moveable mirror of the interferometer is moved is given by:

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

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

$$m = \frac{2\times0.08\times10^{-3}}{5800\times10^{-10}} \qquad \boxed{m = 275}$$

275 fringes will pass the reference point.

Q.No.22: **Interference fringes were produced by light coming from two slits 0.3 mm apart. If five fringes occupied 1.75 mm on a screen at 200 mm from the slits, find the wave length of light used.**

(***2000 Karachi Board***)

Data:

Separation of slits d = 0.3 mm

$= 0.3\times10^{-3}$m

Distance in which 5 fringes were formed $5\Delta x = 1.75$ mm.

Fringe spacing $\Delta x = 1.75/5$ mm

$= 0.35$mm $= 0.35\times10^{-3}$ m

Distance of the screen L=200mm=0.2m

Wave length of light λ =?

***Solution**:*

$\Delta x = \frac{\lambda L}{d} \qquad \lambda = \frac{\Delta x\, d}{L}$

$\lambda = \frac{0.35 \times 10^{-3} \times 0.3 \times 10^{-3}}{0.2}$

$\lambda = 5.25 \times 10^{-7}$ m $\quad \boxed{\lambda = 5250\ \text{Å}}$

Q.No.23: **How much should the moveable mirror of the Michelson's interferometer be moved in order to observe 400 fringes with reference to a point? The wavelength of the light used is 5890 Å.** (***2002 Karachi Board***)

***Data**:*

Distance moved $d = ?$
Number of fringes $n = 400$
Wave length light used $\lambda = 5890$ Å

***Solution**:*

Distance, through which moveable mirror of Michelson's interferometer is moved, is given by:

$d = n \frac{\lambda}{2} = \frac{400 \times 5890 \times 10^{-10}}{2}$.

$d = 1.178 \times 10^{-4}$ m $= 0.1178$ mm

Q.No.24: **If the radius of 12 th dark Newton's ring is 1 mm when light of wave length 5890 Å is used, what is the radius of curvature of the lower surface of the lens used?**
(***2017, 03, 1990,94 Karachi Board***)

***Data**:*

Radius of the dark ring
$r_{12} = 1$ mm $= 1 \times 10^{-3}$ m
Wave length of light $\lambda = 5890$ Å
$= 5890 \times 10^{-10}$ m
Radius of curvature of lens $R = ?$
Dark ring No. $m = 12$

***Solution**:*

Radius of the m th dark ring is given by:

$r_N = \sqrt{m \lambda R}$

$m = 0,1,2,3\ldots$ (m = 0 for dark center)

Squaring both sides and putting the values we get:

$(1 \times 10^{-3})^2 = 12 \times 5890 \times 10^{-10}$ R

$1 \times 10^{-6} = 12 \times 5890 \times 10^{-10}$ R

$R = \frac{1 \times 10^{-6}}{12 \times 5890 \times 10^{-10}}$

$\boxed{R = 0.1414\ m}$

Q.No.25: **X-rays of wave length 1.54 Å are diffracted by a crystal whose planes are 2.81 Å apart. Find the glancing angle for the first order.** (***2004 Karachi Board***)

***Data**:*

Wave length of X-rays $\lambda = 1.45$ Å
Separation of planes $d = 2.81$ Å
Order $m = 1$
Glancing angle $\theta = ?$

***Solution**:*

For X-ray diffraction from a crystal, according to Bragg's law:

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

(No need to convert Å into meters, as in this case "λ"and "d" divide each other, their unit cancel out).

$1 \times 1.54 = 2 \times 2.81 \sin\theta$ (For first order)

$1.54 = 5.62 \sin\theta$

$\sin\theta = \frac{1.54}{5.62} = 0.2740$

$\theta = \sin^{-1} 0.2740 \quad \boxed{\theta = 15.90°}$

Q.No.26: **Interference fringes were produced by two slits 0.25 mm apart on a screen 150 mm from the slits. If ten fringes occupy 3.275 mm, what is the wavelength of the light producing fringes?** (***2016, 08, 02 Karachi Board***)

***Data**:*

Separation of slits $d = 0.25$mm
$= 0.25 \times 10^{-3}$m
Distance of screen $L = 150$ mm $= 0.15$m
Distance occupied by 10 fringes
$= 3.275$ mm.
Fringe spacing $\Delta x = \frac{3.275}{10}$ mm
$= 0.3275$ mm $= 0.3275 \times 10^{-3}$ m
Wave length of light used $\lambda = ?$

***Solution*:**

In Young double slit experiment fringe spacing (distance between two consecutive fringes) is given by:

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

$$0.3275\times10^{-3} = \frac{\lambda \times 0.15}{0.25\times10^{-3}}$$

$$\therefore \quad \lambda = \frac{0.3275 \times 10^{-3} \times 0.25 \times 10^{-3}}{0.15}$$

$$\boxed{\lambda = 5.458 \times 10^{-7}\ m = 5458\ Å}$$

***Q.No.27*: If radius of 14th bright Newton's ring is 1 mm and the radius of curvature of the lens is 125 mm.**

Calculate wavelength of light.

(*2010, 1997 Karachi Board*)

***Data*:**

Radius of 14th ring r_{14} =1mm= 1×10^{-3} m

Ring number N = 14

Radius of curvature of lens R = 125 mm = 125×10^{-3} m.

Wave length of light λ= ?

***Solution*:**

Radius of Nth Newton's ring is given by:

$$r_N = \sqrt{R\lambda (N - \tfrac{1}{2})}$$

$$r_{14} = \sqrt{R\lambda (14 - \tfrac{1}{2})}$$

$$1\times10^{-3} = \sqrt{125\times10^{-3}\ \lambda\ (14 - \tfrac{1}{2})}$$

$$1\times10^{-3} = \sqrt{125\times10^{-3}\ \lambda\ (27/2)}$$

Squaring both sides we get:

$$(1\times10^{-3})^2 = 125\times10^{-3}\ \lambda\ (27/2)$$

$$\lambda = \frac{(1\times10^{-3})^2}{125\times10^{-3}\ (27/2)}$$

$$\boxed{\lambda = 5.926 \times 10^{-7}\ m. \quad \lambda = 5926\ Å}$$

Q.No.28*: In a double slit experiment, eight fringes occupy 2.62 mm on screen 145 mm away from the slits. The wave length of light is 545 nm. Find the slit separation.** (2012 Karachi Board***)

***Data*:**

No. of fringes = 8

Distance occupied = 2.62 mm.

Fringe spacing $\Delta x = \frac{2.62}{8}$ mm

Δx = 0.3275 mm= 3.275×10^{-4} m

Wave length λ =545 nm= 545×10^{-9}m.

Distance of screen L =145 mm=145×10^{-3} m.

Slit separation d = ?

***Solution*:**

Fringe spacing is given by:

$$\Delta x = \frac{\lambda L}{d} \qquad d = \frac{\lambda L}{\Delta x}$$

$$d = \frac{545\times10^{-9} \times 145\times10^{-3}}{3.275\times10^{-4}}$$

$$d = \frac{7.9025\times10^{-8}}{3.275\times10^{-4}} \qquad \boxed{d = 2.413\times10^{-4}\ m \quad d = 0.2413\ mm.}$$

***Q.No.29*: Green light of wave length 5400Å. is diffracted by grating having 2000 lines/cm.**

Compute the angular deviation of the third order image.

(***2014, 05, 1999 Karachi Board***)

***Data*:**

Wave length λ=5400Å= 5400×10^{-10} m

Number of lines/cm = 2000

Grating element (a + b)

= $\frac{1}{2000}$ cm.= 5×10^{-4}cm= 5×10^{-6} m

Angular deviation θ = ?

Order of image m = 3

***Solution*:**

$$(a + b) \sin \theta = m \lambda$$

$$5\times10^{-6} \sin \theta = 3\times 5400\times10^{-10}$$

$$\sin \theta = \frac{3\times 5400\times10^{-10}}{5\times10^{-6}}$$

$$\sin \theta = \frac{16200\times10^{-10}}{5\times10^{-6}} = 0.3240$$

$$\theta = \sin^{-1} 0.3240 \qquad \boxed{\theta = 18.91^\circ}$$

***Q.No.30*: A parallel beam of X-rays is diffracted by rock salt crystals. The first order maximum being obtained when the glancing angle of incidence is 6 degree and 5 minutes, the distance between the atomic planes of crystal is 2.81×10^{-10} m.**

Calculate the wave length of radiation. (***2015, 2009 Karachi Board***)

Data:

Order $m = 1$

Glancing angle $\theta = 6^\circ$ 5 minutes $= 6.083^\circ$

Separation of planes $d = 2.81\times10^{-10}$m

Wave length of X-rays $\lambda = ?$

Solution:

According to Brag's law:

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

$\therefore\ 1\times\lambda = 2\times2.81\times10^{-10}\times\sin 6.083^\circ$

$\therefore\ \lambda = 2\times2.8\times10^{-10}\times0.106$

$\therefore\ \boxed{\lambda = 5.956\times10^{-11}\ m \quad \lambda = 0.5956\ Å}$

Wave length of X-rays is **5.956×10^{-11}m** or **0.5956 Å**.

Q.No.31: **A diffraction grating produces 3^{rd} order spectrum of light of wavelength 7000 Å at an angle of 30° from the normal. What is the grating element? Calculate the number of lines of grating per cm.**

(***2019, 17, 11, 97, 03, 01,1991 Karachi Board***)

Data:

Angular deviation $\theta = 30^\circ$

Order of image $m = 3$

Wave length of light $\lambda = 7000$ Å $= 7\times10^{-7}$ m.

Grating element $(a + b) = ?$

Number of lines per cm. $= ?$

Solution:

For diffraction grating:

$(a + b)\sin\theta = m\,\lambda$

$(a + b)\sin 30^\circ = 3\times7\times10^{-7}$

$(a + b)\times0.5 = 21\times10^{-7}$

$(a + b) = \dfrac{21\times10^{-7}}{0.5}$

$\boxed{(a + b) = 42\times10^{-7}m. = 4.2\times10^{-4}cm}$

Number of lines per cm. $= \dfrac{1}{(a + b)}$

Number of lines per cm. $= \dfrac{1}{4.2\times10^{-4}}$

Number of lines per cm. = 2380

Given grating has ***2380 lines per cm***.

Q.No.32: **271 fringes are passed through a reference point when the moveable mirror of Michelson's interferometer is moved by 0.08mm**

Find the wavelength of light used in Å.

(***2019, 2002 Karachi Board***)

Data:

Number of fringes passing reference point $n = 271$

Moveable mirror moved by $d = 0.08$ mm $= 8\times10^{-5}$ m

Wave length of light used $\lambda = ?$

Solution:

For Michelson interferometer:

$d = n\,\dfrac{\lambda}{2}$

$8\times10^{-5} = 271\,\dfrac{\lambda}{2}$

$\lambda = \dfrac{2\times8\times10^{-5}}{271}$

$\boxed{\lambda = 5.9\times10^{-7}\ m}$ OR $\boxed{\lambda = 5900\ Å}$

Q.No.33: **Find the lines per centimeter on a diffraction grating which gives a 1^{st} order spectrum at an angle of 30° when the wave length of light is 6×10^{-5} cm.**

(***2026 Karachi Board***)

Data:

Angular deviation $\theta = 30^\circ$

Order of image $m = 1$

Wave length of light $\lambda = 6\times10^{-5}$ cm.

Number of lines per cm. $= ?$

Solution:

For diffraction grating:

$(a + b)\sin\theta = m\,\lambda$

$(a + b)\sin 30^\circ = 1\times6\times10^{-5}$

$(a + b)\times0.5 = 6\times10^{-5}$

$(a + b) = \dfrac{6\times10^{-5}}{0.5}$

$\boxed{(a + b) = 12\times10^{-5}\ cm.}$

But number of lines per cm. $= \dfrac{1}{(a + b)}$

Number of lines per cm.= $\frac{1}{12 \times 10^{-5}}$

Number of lines per cm. = 0.08333×10^{5}

= **8333**

Given grating has ***8333 lines per cm***.

Do you know that **......**

Speed of light in air or vacuum is very high about 300,000,000 m/s or 300,000 km/s (three crore kilometers in one second) (actually it is about 2.98×10^8 m/s). Travelling with such a high speed you can circle about 7½ times around the earth in just one second. The distance to the sun can be covered in about slightly over 8minutes. Traveling with speed of light from earth will take about 200,000 years to cross our galaxy "Milky way", and galaxy ANDROMEDA nearest to our galaxy, can be reached in 2 million years.

Actually, all electromagnetic waves (light waves are also electromagnetic), in vacuum can travel with such a high speed.

According to Einstein's special theory of relativity, mass of material objects starts increasing as its speed approaches speed of light.