UNIT I - WAVE OPTICS

INTERFERENCE

Introduction

In the 17th century, the properties of light were explained by Sir Isaac Newton and Christian Huygens. Sir Isaac Newton was explained the properties of light by introducing Corpuscular theory in 1675. It explains reflection, refraction, and dispersion properties of light. It fails to explain interference, diffraction, polarization, photo electric effect, and double refraction.

In 1679, Christian Huygens proposed the wave theory of light. According to Huygens wave theory, each point on the wave front is to be considered as a source of secondary wavelets. It explains reflection, refraction, dispersion, double refraction, diffraction, interference, and polarization properties of light. It fails to explain, photo electric effect, black body radiation etc.

Interference of light

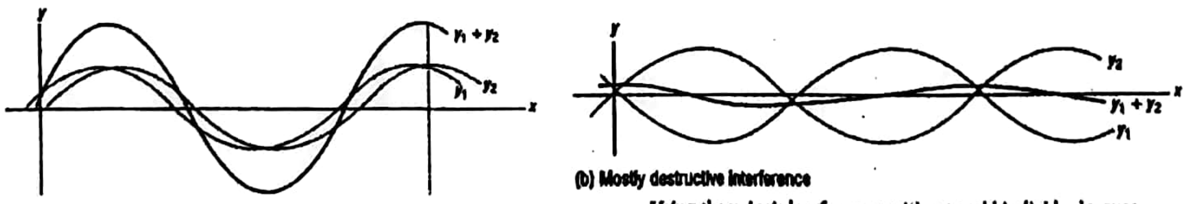
The best evidence for the wave nature of light is interference phenomenon. This was experimentally demonstrated by Thomas Young in 1801, through double slit experiment. Due to interference, we will observe many observations in our day today life, such as multiple colours on soap bubbles as well as on oil film when viewed under sun light. Interference concept is explained on the basis of superposition of wave's concept. When two light waves superimpose, then the resultant amplitude or intensity in the region of superposition is different than the amplitude of individual waves.

1. What is the principle of superposition?

Principle of Superposition of waves:

When two or more waves travel simultaneously in a medium, the resultant displacement at any point is due to the algebraic sum of the displacements due to individual waves.

Let y_1 is the displacement of the particle of first wave in a given direction and y_2 is



(a) Mostly constructive interference

(b) Mostly destructive interference

Using the principle of superposition to add individual waves

the displacement of the particle in second wave in the absence of the first wave. Therefore according to principle of superposition, the resultant displacement is

$$R = y_1 \pm y_2$$

- If the displacements are in the same direction then R = y1+y2.
- If the displacements are in opposite direction then R = y1-y2.

$$R^2 = a_1{}^2 + a_2{}^2 + 2a_1a_2\cos\delta$$

$$I = R^2 = a_1^2 + a_2^2 + 2a_1a_2\cos\delta$$

This represents the equation of resultant intensity.

Case (i): Condition for maximum intensity:

I is maximum when $\cos\delta = +1 \Rightarrow \delta = 2n\pi$, $n = 0, 1, 2, 3 \ldots$

$$2n\pi = (2\pi/\lambda) \text{ path difference}$$

path difference = $n\lambda$

$$I_{max} = a_1^2 + a_2^2 + 2a_1a_2$$

$$= (a_1 + a_2)^2$$

If $a_1 = a_2$ then $I_{max} = 4a^2$

Case (ii): Condition for minimum intensity:

I is minimum when $\cos\delta = -1 \Rightarrow \delta = (2n+1)\pi$, $n = 0, 1, 2, 3 \ldots$

$$(2n+1)\pi = (2\pi/\lambda) \text{ path difference}$$

$\Rightarrow$ Path difference = $(2n+1)\lambda/2$

$$I_{min} = a_1^2 + a_2^2 - 2a_1a_2$$

$$= (a_1 - a_2)^2$$

If $a_1 = a_2$ then $I_{min} = 0$

2. What is coherence?

Coherence: Two waves are said to be coherent if they have same phase or maintaining constant phase difference between them. Hence coherence is a measure of the correlation between the phases of the wave measured at different points.

Methods of producing coherent sources for interference:-

For the formation of interference pattern, two coherent light sources are required. To get two coherent sources form a single light source, two techniques are used. They are

i. Division of wave front

ii. Division of amplitude

i. Division of wave front

The wave front from a single light source is divided into two parts using the phenomenon of reflection, refraction, or diffraction. Young's double slit experiment is belongs to this class of interference.

ii. Division of amplitude

The amplitude of a single light beam is divided into two parts by parallel reflection or refraction. Newton's ring experiment, Michelson's interferometer belongs to this class of interference.

3. What is interference?

Interference: Modification or redistribution of light energy due to superposition of light waves from two coherent sources is known as interference. The phenomenon of interference obeys law of conservation of energy.

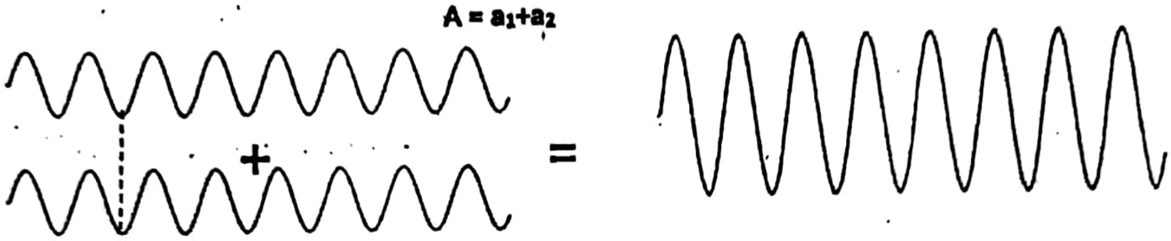
4. What are the types of interference?

Types of Interference: i. Constructive Interference ii. Destructive Interference

i) Constructive Interference: When crest of one wave falls on the crest of another wave, the resultant amplitude is the sum of the amplitudes of two waves and intensity is increased. Hence bright fringe is formed and it is known as constructive interference.

Condition: The path difference between the two waves is equal to the integral multiple of wave length (λ) the constructive interference occurs.

path diference$=n\lambda$ Where n = 0, 1, 2, 3, 4 ...



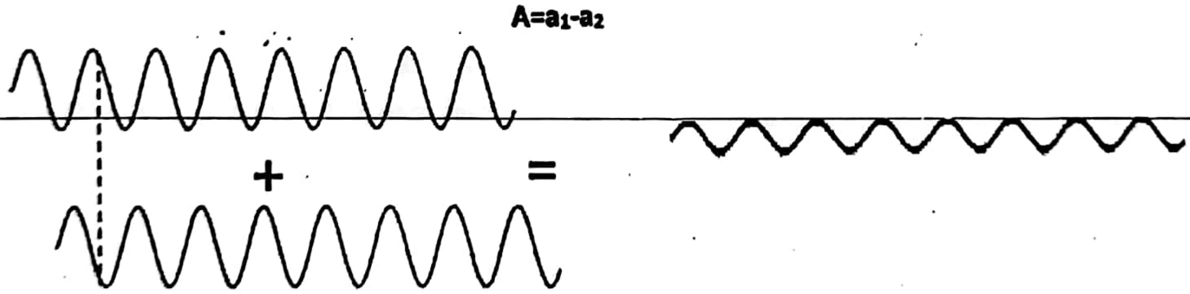
(*Waves are in phase*) Constructive interference

ii) Destructive Interference: When crest of one wave falls on the trough of another wave, the resultant amplitude is the difference of the amplitudes of two waves and intensity is decreased. Hence dark fringe is formed and it is known as destructive interference.

Condition: The path difference between the two waves is equal to the odd integral multiple of $\lambda/2$ destructive interference occurs

path diference $= (2n-1)\lambda/2$ Where n = 1,2,3,4 ... *or*

path diference $= (2n+1)\lambda/2$ Where n = 0,1,2,3,4 ...



(Close to π out of phase) *Destructive interference*

5. What are the conditions for sustained interference?

Conditions for sustained interference:

i. The two sources should be coherent.
ii. The two sources must emit continuous waves of same wavelength and frequency.
iii. The background should be dark.
iv. The two sources should be monochromatic.
v. The amplitude of interfering waves should be equal.
vi. The two sources should be narrow.
vii. The distance between the two sources should be small.
viii. The distance between sources and screen should be large.

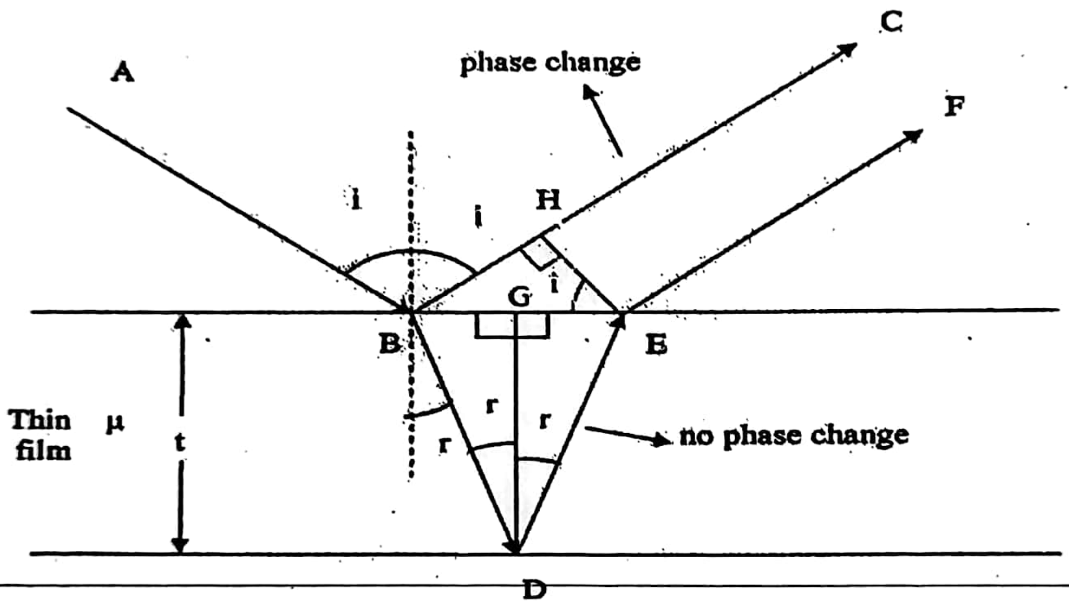
6. Explain the interference due to uniform thin films by reflected light or derive cosine law?

Interference in thin films by reflection: (Cosine law):

Principle:-

The formation of colours in thin films can explained using the phenomenon of interference. In this example, the formation of interference pattern is by the division of amplitude.

Consider a thin film of uniform thickness 't' and refractive index 'μ'. Let a monochromatic light ray AB is incident on the upper surface of the film at point 'A' with an angle 'i'. The incidence light ray AB is divided into two light rays ray 1 (BC) and ray 2 (EF) by the division of amplitude principle. These two light rays BC and EF are parallel and superimpose and produce interference. The intensity of interference fringe depends up on the path difference between the ray 1 and ray 2.



The path difference between the light rays (1) and (2) is

$$path\ difference = \mu(BD + DE)\ in\ film - BH\ in\ air \quad (1)$$

From ΔBDG $\cos r = \frac{DG}{BD} = \frac{t}{BD} \Rightarrow BD = \frac{t}{\cos r}$

Similarly from ΔDEG $\cos r = \frac{DG}{DE} = \frac{t}{DE} \Rightarrow DE = \frac{t}{\cos r}$

$$\therefore BD = DE = \frac{t}{\cos r} \quad (2)$$

From ΔBEH $\sin i = \frac{BH}{BE} = \frac{BH}{BG+GE}$.

$\therefore BH = (BG + GE).\sin i$

From ΔBDG and ΔDEG $BG = GE = t\tan r$

$BH = (2t\tan r).\sin i$

From Snell's law at point B

$$\sin i = \mu\sin r$$

$$\therefore BH = 2\mu t\tan r.\sin r \quad (3)$$

Substituting the equations (2) and (3) in equation (1), we get

$$Path\ difference = \frac{2\mu t}{\cos r} - 2\mu t\tan r.\sin r$$

$$= \frac{2\mu t}{\cos r} - 2\mu t.\frac{\sin^2 r}{\cos r}$$

$$= \frac{2\mu t}{\cos r}(1 - \sin^2 r)$$

$$= \frac{2\mu t}{\cos r}\cos^2 r$$

$$= 2\mu t\cos r$$

At point B the light ray (1) is reflected at the surface of thin film (denser medium). So the light ray (1) undergoes a phase change π or an additional path difference $\lambda/2$.

Total path difference $= 2\mu t\cos r - \frac{\lambda}{2}$

Constructive interference (or Bright fridge)

General condition: $path difference = n\lambda$

$$2\mu t\cos r - \frac{\lambda}{2} = n\lambda$$

$$2\mu t\cos r = n\lambda + \frac{\lambda}{2}$$

$$2\mu t\cos r = \frac{(2n+1)\lambda}{2}$$

Destructive interference (or Dark fridge)

General condition: $path difference = (2n+1)\frac{\lambda}{2}$

$$2\mu t\cos r - \frac{\lambda}{2} = \frac{(2n-1)\lambda}{2}$$

$$2\mu t\cos r = n\lambda$$

Note: In case of transmitted light, the conditions for bright and dark fringes are reversed than that of in reflected light.

- For bright fringe, **$2\mu t\cos r = n\lambda$**
- For dark fringe, **$2\mu t\cos r = (2n\pm 1)\lambda/2$**

7. Write short note on colour in thin films?

Colours of thin films:

i. When a thin film (Soap bubble) is exposed to a white light source beautiful colours are observed.
ii. The incident light will split up by reflection at the top and bottom surfaces of the film.
iii. These splitted rays interfere with each other and produces interference pattern and is responsible for colours.
iv. We have $2\mu t \cos r = (2n \pm 1)\lambda/2$ for bright fringe
v. $2\mu t \cos r = n\lambda$ for dark fringe.
vi. Hence bright and dark fringes depend on μ, t and r. Here t and r are made constant but μ changes with wavelength.
vii. At a particular point of the film and at a particular position of the eye, only certain wavelengths (colours) satisfy the condition for bright fringe. Hence only those colours appear on thin film.
viii. The colours which satisfy dark fringe condition are absent. If position of the eye changes, different set of colours are observed.
ix. We know that the conditions for bright and dark fringes in transmitted light are reversed than that in reflection. Hence colours which appear in reflected light disappears in transmitted light.

8. What are Newton's rings? Explain the formation of Newton's rings. Write the conditions for maxima and minima?

Newton's Rings: When a Plano-convex lens with its convex surface is placed on a plane glass plate, an air film of gradually increasing thickness is formed between the two. At the point of contact, the thickness of the film is zero. If monochromatic light is incident normally and the film is viewed in reflected light we observe alternate bright and dark rings around the point of contact. These rings are known as Newton's rings.

Principle:-

~~The formation of Newton's rings is due to the phenomenon of interference. In this~~ example, the formation of interference pattern is obtained by the division of amplitude.

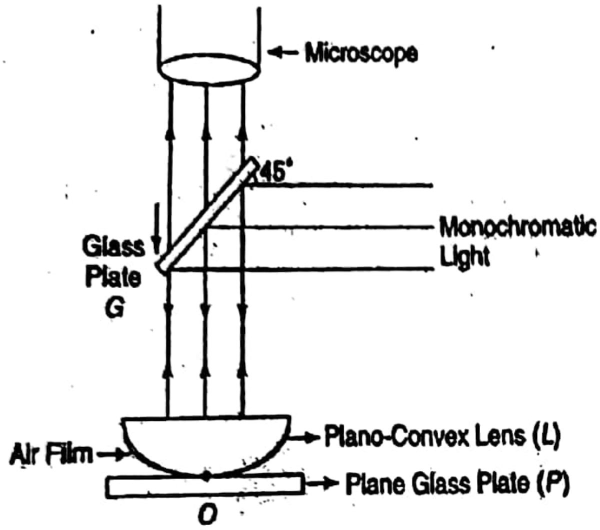
Experimental arrangement

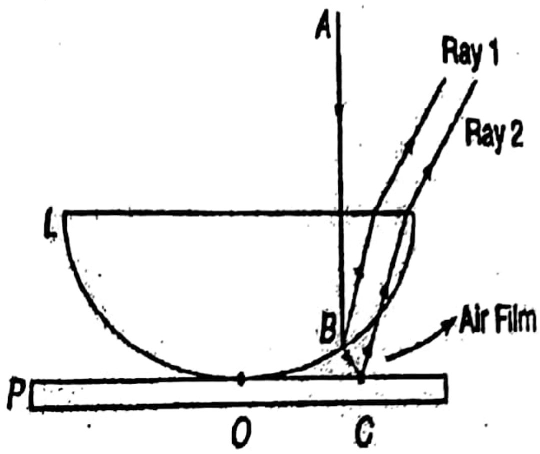
- The experimental arrangement of Newton's rings is shown in figure.
- The Plano -convex lens (L) of large radius of curvature is placed with its convex surface on the glass plate (P). The Plano convex lens touches the glass plate at O.
- A monochromatic light is allowed to fall normally on the lens with the help of glass plate M kept at 45^0 to the incident monochromatic light.
- A part of light is reflected by the curved surface of the lens 'L' and a part of light is transmitted and partly reflected back by the upper surface of the plane glass plate P. These reflected rays interfere and give rise to an interference pattern in the form of circular fringes. These rings are seen through a travelling microscope.

Explanation of Newton's rings

Newton's rings are formed due to the interference between the light rays reflected from the lower surface of the lens and the upper surface of the glass plate (or top and bottom surfaces of the air film).

Let a vertical light ray AB be partially reflected from the curved surface of plano convex lens without phase change and partially transmitted light ray BC is again reflected at C on the glass plate with additional phase change of π or path difference $\lambda/2$.





The path difference between the two rays = $2\mu t \cos r + \lambda/2$

For air film $\mu=1$ and for normal incidence $r=0$, so

The path difference $=2t+\lambda/2$

At the point of contact $t=0$, path difference is $\lambda/2$ i.e., the reflected and incidence light are out of phase and destructive interference occur. So the center fringe is always dark.

Constructive interference (or Bright fringe)

General condition: $path difference = n\lambda$

$$2t+\lambda/2=n\lambda$$

$$2t=(2n-1)\lambda/2 \text{ , Where } n=0,1,2,\ldots\ldots\ldots$$

Destructive interference (or Dark fringe)

General condition: $path difference=(2n+1)\lambda/2$

$$2t+\lambda/2=(2n+1)\lambda/2$$

$$2t=n\,\lambda \text{ , Where } n=0,1,2,\ldots\ldots\ldots$$

Theory of Newton's rings

To find the diameters of a dark and bright rings construct a circle with the radius of curvature R of a lens L. Let us choose a point P at a distance 'r' from the center of lens and t be the thickness of air film at point p.

From the property of a circle $NP.NB = NO.ND$

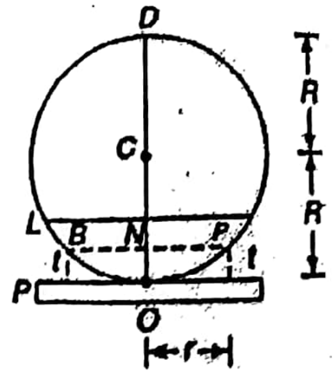
$$r.r - t.(2R - t)$$

$$r^2 = 2Rt - t^2$$

If t is small t^2 is negligible.

$$r^2 = 2Rt$$

$$t - \frac{r^2}{2R}$$



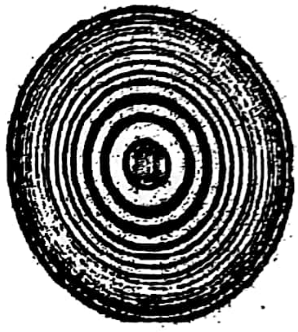
Bright rings

For bright ring, the condition is $2t = (2n-1)\frac{\lambda}{2}$

$$\frac{2r^2}{2R} = (2n-1)\frac{\lambda}{2}$$

$$r^2 = \frac{(2n-1)\lambda R}{2}$$

By replacing r by D/2, the diameter of the bright ring is



$$\frac{D^2}{4} = \frac{(2n-1)\lambda R}{2}$$

$$D^2 = 2(2n-1)\lambda R$$

$$D = \sqrt{2(2n-1)\lambda R}$$

$$D = \sqrt{(2n-1)}\sqrt{2\lambda R}$$

$$D \propto \sqrt{(2n-1)}$$

$$D \propto \sqrt{odd\ natural\ number}$$

Dark rings

For dark rings, the condition is

$$2t = n\lambda$$

$$\frac{2r^2}{2R} = n\lambda$$

$$r^2 = n\lambda R$$

By replacing r by D/2, the diameter of the dark ring is

$$\frac{D^2}{4} = n\lambda R$$

$$D = \sqrt{4n\lambda R}$$

$$D - 2\sqrt{n\lambda R}$$

$$D \propto \sqrt{n}$$

$$D \propto \sqrt{natural\ number}$$

Note: suppose a liquid is taken in between the lens and glass plate having refractive index μ, then the diameter of the dark n^{th} dark ring can be written as

$$D = \frac{\sqrt{4n\lambda R}}{\mu}$$

9. What are the applications of Newton's rings?

Applications of Newton's rings:

1. Determination of wave length of sodium light using Newton's rings:

By forming Newton's rings and measuring the radii of the rings formed, we can calculate the wavelength of the light used if the radius of curvature of the lens is known. Let R be the radius of curvature of the lens and λ is the wavelength of the light used.

So the diameter of the m[th] dark ring can be written as

$$D_m^2=4\, m\, \lambda\, R \quad \text{.........................} (1)$$

Similarly the diameter of the n[th] dark ring is

$$D_n^2=4\, n\, \lambda\, R \quad \text{.........................} (2)$$

Subtracting equation (1) from (2)

we get

$$D_n^2-D_m^2=(4\, n\lambda\, R)-(4\, m\, \lambda\, R)$$

$$D_n^2-D_m^2=4\, (n-m)\, \lambda\, R$$

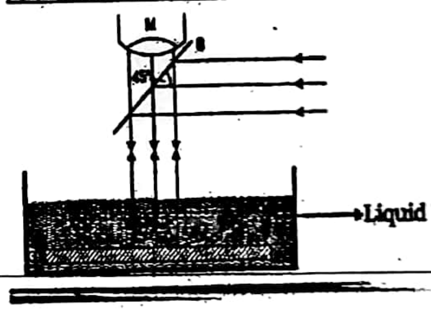
$$\lambda=\frac{D_n^2-D_m^2}{4(n-m)R}$$

Using the above relation wavelength can be calculated

2. Determination of refractive index of a liquid using Newton's rings:

Newton Rings...

Determination of refractive index of liquid:



By forming Newton's rings and measuring the diameter of the rings formed, we can calculate the refractive index of the liquid.

In air film, the diameters of the m[th] and n[th] dark rings are D_m and D_n are measured with the help of travelling microscope.

The diameter of the n[th] dark ring is

$$D_n^2=4\, n\, \lambda\, R \quad \text{.................} (1)$$

The diameter of the m[th] dark ring is

$$D_m^2=4\, m\lambda\, R \quad \text{............} (2)$$

Subtracting equation (1) from (2) we get

$$D_n^2-D_m^2=[4\, (n-m)\, \lambda\, R] \text{.........} (3)$$

The Newton's rings setup is taken in a liquid. Now the air film is replaced by liquid film. In liquid film, the diameters of the same n[th] and m[th] dark rings are D'_n and D'_m are measured with the help of travelling microscope.

$$D'^2_n=\frac{4n\lambda R}{\mu}$$

And $D'^2_m=\frac{4m\lambda R}{\mu}$

So $$D'^2_n-D'^2_m=\frac{4\,(n-m)\,\lambda R}{\mu} \qquad (4)$$

Dividing equation (3) by (4)

$$\frac{D_n^2-D_m^2}{D'^2_n-D'^2_m}=\frac{4\,(n-m)\,\lambda R}{\frac{4\,(n-m)\,\lambda R}{\mu}}$$

$$\frac{D_n^2-D_m^2}{D'^2_n-D'^2_m}=\mu$$

Using the above relation μ can be calculated.

10. What are the applications of interference?

Applications of interference: Interference phenomenon is used to

i. Determine the wavelength of light.
ii. Find the difference in wavelengths of two spectral lines having small separation.
iii. Find the thickness of transparent materials.
iv. Determine the refractive index of transparent solids, liquids and gases.
v. Find the velocity of light (Michelson interferometer experiment).
vi. Test the optical flatness of surfaces.
vii. Find the reflecting power of the lens and prism surfaces.

Assignment Questions

1. What is the principle of superposition?
2. What is interference? What are the types of interference?
3. What are coherent sources?
4. What are the conditions for sustained interference?
5. What are the applications of interference?
6. Explain the interference of light due to thin films or derive cosine law.
7. Write a short note on colors in thin films.
8. Discuss the theory of Newton's Rings with relevant diagram and discuss its applications.

Problems

1. Newton's rings are observed in the reflected light of wave length 5900 A^0. The diameter of 10^{th} dark ring is 0.5 cm. Find the radius of curvature of the lens used. (Feb 2011, Set No.4), (July 2011, Set No.3; Ans: R=1.059m)
2. A parallel beam of light (λ=5890A^0) is incident on a glass plate (μ=1.5) such that angle of refraction into plate is 60^0, calculate the smallest thickness of the plate which will make it appear dark by reflection. (Feb 2011, Set No.2, Jan 2012, Set No.2, Ans: t=3.926 x 10^{-4}mm)
3. In Newton's rings experiment, the diameters of the 4^{th} and 12^{th} dark rings are 0.40 cm and 0.70 cm respectively. Find the diameter of the 20^{th} dark ring. (Jan 2012, Set No.3, Ans: D_{20} = 0.905m)
4. In Newton's rings experiment, the diameter of the 10^{th} ring changes from1.40 cm to 1.27 cm when a liquid is introduced between the lens and the plate. Calculate the refractive index of the liquid.(Jan 2012, Set No.4, Ans: μ=1.215)
5. In Newton's rings experiment, the diameter of the 15^{th} ring was found to be 0.59 cm and that of the 5^{th} ring was 0.336 cm. If the radius of the plano convex lens is 100 cm, compute the wavelength of light used. (June 2012, set No.1, Set No.4, Ans: λ = 588 nm)
6. Calculate the thickness of a soap film (μ=1.463) that will result in constructive interference in the reflected light, if the film is illuminated normally with light whose wave length in free space is 6000 A^0.(June 2012, Set No.2, Ans: t=1.025 x 10^{-4}mm)

Objective Questions

1. The wave nature of light is evidenced by
a) Photo electric effect **b) interference**
c) Black Body Radiation d) emission

2. In interference the intensity of light gets
a) **Modified** b) Remains same
c) both (a) &(b) d) None

3. Path difference between coherence wave is
a) Constant b) Zero **c) Both (a) & (b)** d) None

4. Two light sources are said to be coherent if their waves have
a) same frequency b) constant phase difference
c) same wavelength **d) All the above**

5. In super position of waves of constant phase difference, the resultant amplitude is maximum when Ø=
a) **$2n\pi$** b) $n\pi$ c) $(2n-1)\pi$ d) none

6. In super position of waves of constant phase difference, the resultant amplitude is minimum when Ø=
a) $2n\pi$ b) $n\pi$ **c) $(2n-1)\pi$** d) none

7. The resultant intensity of the superposition of waves of constant phase difference is
a) $I = 2a^2 \cos^2\varphi/2$ **b) $I=4a^2$** c) $I= 2a^2 \sin^2 \varphi/2$ d) $I= 4a^2 \sin^2 \varphi/2$

8. The resultant amplitude of waves of equal phase and frequency is
a) **sum of the amplitudes of individual waves**
b) difference of amplitudes of individual waves
c) sum of the squares of amplitudes of individual waves
d) none

9. Two light beams interfere have their amplitudes in the ratio 2:1 then the intensity ratio of bright and dark fringes is
a)2:1 b) 1:2 c) **9:1** d) 4:1

10. In super position of waves of constant phase difference , the phase angle φ
a) **$\tan^{-1}[b \sin \varphi/ a+b \cos \varphi]$** b) $\tan^{-1} [b \cos \varphi/a+b \sin \varphi]$
c) $\tan^{-1} [b \sin \varphi/a \sin \varphi +b \cos \varphi]$ d) $\tan^{-1}[b / a+b \cos \varphi]$

11. Newton's rings and Michelson's interferometer experiments are example for
a) Division of amplitude b) Division of wave front
c) Both a & b d) none

12. In Newton's rings experiment the condition for bright fringes in the case of reflected light
a) $2t = (n+1)\lambda/2$ b) $2t = (2n-1)\lambda$ c) $2t = (n-1)\lambda$ d) $2t = n\lambda$

13. In Newton's rings experiment the condition for dark fringes in the case of reflected light

a) $2t = n\lambda$ b) $2t = (2n-1)\lambda$ c) $2t = (n-1)\lambda/2$ d) none

14. In Newton's rings experiment, wave length

a) $D^2_{n+p} - D^2_n$ /4PR b) $D^2_n - D^2_{n+p}/4PR$

c) $D^2_{n+p} + D^2_n$ /4PR d) $D^2_{n+p} - D^2_n/4\lambda R$

15. The refractive index of the liquid from Newton's rings μ=

a) $D^2_{n+p} - D^2_n / D^2_{n+p} - D^2_n$ b) $D'^2_{n+p} - D'^2_n$ / $D^2_{n+p} - D^2_n$

c) $D^2_{n+p} + D^2_n / D^2_{n+p} - D^2_n$ **d) $D^2_{n+p} - D^2_n / D'^2_{n+p} - D'^2_n$**

16. In Newton's rings experiment the diameter of dark ring is proportional to

a) Odd number b) natural number

c) Even natural number **d) square root of natural number**

17. When light wave suffers reflection at interface between glass and air, the change of phase of reflected wave is equal to

a) $\pi/2$ b) π **c) zero** d) 2π

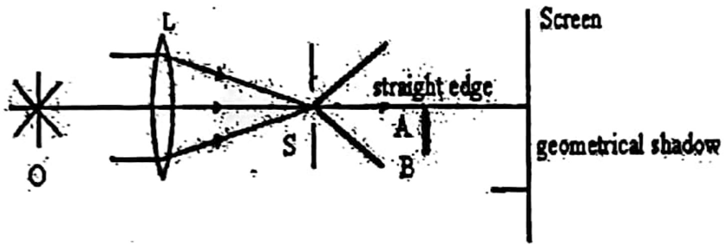
DIFFRACTION

Introduction:

The wave nature of light is first confirmed by the phenomenon of interference. Further it is confirmed by the phenomenon of diffraction. The word 'diffraction' is derived from the Latin word diffractus which means break to piece. When the light waves encounter an obstacle, they bend round the edges of the obstacle. The bending is predominant when the size of the obstacle is comparable with the wavelength of light. The bending of light waves around the edges of an obstacle is diffraction. It was first observed by Francesco Gremaldi.

1. Define diffraction. Give examples of diffraction.

Definition of Diffraction: The phenomenon of bending of light round the corners of obstacles and spreading of light waves into the geometrical shadow of an obstacle placed in the path of light is called Diffraction.



The effects of diffraction can be seen in everyday life. The most colourful examples of diffraction of light are

1. The closely spaced tracks on a CD or DVD act as diffraction grating to form a rainbow pattern when looking at a disk.
2. The hologram on a book or debit card.
3. Diffraction in the atmosphere by small particles can cause a bright ring to be visible around the sun or the moon.
4. A shadow of a solid object using light from a compact source shows small fringes near its edges.

Explanation: Consider light waves diverging from a narrow slit 'S' illuminated by a mono chromatic source 'O' and passes towards an obstacle AB. A small portion of light bends around the edge and forms a geometrical shadow on the screen which is not sharp. Outside the shadow parallel to its edge several bright and dark bands are observed. Thus when light falls on obstacles whose size is comparable with wavelength of light, the light bends round the corners of the obstacles or aperture and enter in to the geometrical shadow. It was found that diffraction produces bright and dark fringes known as diffraction bands or fringes. According to Fresnel, the diffraction phenomenon is due to mutual interference of secondary wavelets originating from various points of the same primary wave front which are not blocked off by the obstacle. Hence diffraction is also known as self interference.

2. What are the types of diffraction?

Types of diffraction: The diffraction phenomena are classified into two ways

i. Fresnel diffraction

ii. Fraunhofer diffraction.

Fresnel diffraction:-

In this diffraction the source and screen are separated at finite distance. To study this diffraction lenses are not used because the source and screen separated at finite distance. This diffraction can be studied in the direction of propagation of light. In this diffraction the incidence wave front must be spherical of cylindrical.

Fraunhofer diffraction:-

In this diffraction the source and screen are separated at infinite distance. To study this diffraction lenses are used because the source and screen separated at infinite distance. This diffraction can be studied in any direction. In this diffraction the incidence wave front must be plane.

3. Write the differences between Fresnel diffraction and Fraunhofer diffraction.

Fresnel Diffraction	Fraunhofer Diffraction
1. The source and the screen are placed at finite distances from the obstacle producing diffraction.	1. The source and the screen are placed at infinite distances from the obstacle producing diffraction.
2. No lenses are used for making the rays parallel or convergent.	2. Lenses are used for making the rays parallel or convergent.
3. The incident wave front is either spherical or cylindrical.	3. The incident wave front is plane.
4. Either a point source (or) an illuminated narrow slit is used.	4. Extended source at infinite distance is used.
5. This is also called near-field diffraction.	5. This is also called far-field diffraction.
6. It is general approach.	6. It is simplified approach.
7. Mathematical treatment is quite complicated.	7. Mathematical treatment is simple
8. Examples: Diffraction at a straight edge, thin wire, narrow slit, a small hole etc.,	8. Examples: Diffraction at a single slit, double slit and n slits (grating) etc.,

4. Write the differences between interference and diffraction.

Differences between Interference and Diffraction:

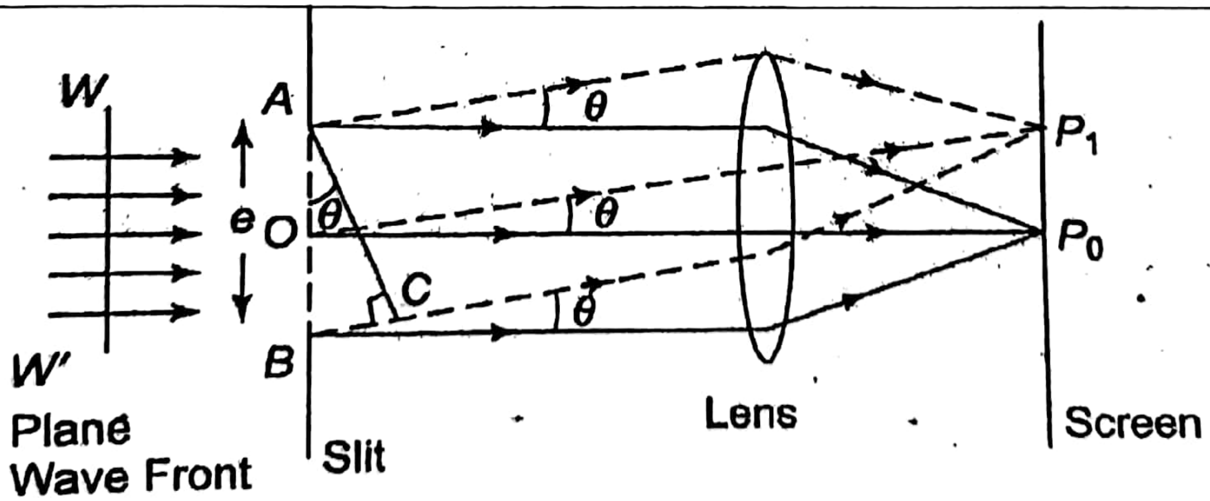
Diffraction	Interference
1. It is due to interaction of light waves coming from different parts of the same wave front. It is also called as self interference.	1. It is due to interaction of light waves coming from two different wave fronts originating from the same source (i.e. coherent sources).
2. Diffraction bands decrease in their width as the order increases.	2. Interference bands are of equal width i.e. all are equally spaced.
3. The bright fringes are of varying intensity.	3. All the bright fringes are of the same intensity.
4. Points of minimum intensity are not perfectly dark. Hence fringes will not appear with contrast.	4. Points of minimum intensity are perfectly dark. Hence fringes will appear with contrast.

5. Explain Fraunhofer diffraction due to single slit.

Fraunhofer single slit diffraction:

Let us consider a slit AB of width 'e'. Let a plane wave front *ww'* of monochromatic light of wavelength λ is incident on the slit AB.

According to Huygens principle, every point on the wave front is a source of secondary wavelets. The wavelets spread out to the right in all directions. The secondary wavelets which are travelling normal to the slit are brought to focus at point P_0 on the screen by using the lens. These secondary wavelets have no path difference. Hence at point P_0 the intensity is maxima and is known as central maximum. The secondary wavelets travelling at an angle θ with the normal are focused at point P_1.



Intensity at point P1 depends up on the path difference between the wavelets A and B reaching to point P1. To find the path difference, a perpendicular AC is drawn to B from A.

The path difference between the wavelets from A and B in the direction of θ is

$$path\ difference = BC = AB\sin\theta$$
$$= e\sin\theta$$

$$phase\ difference = \frac{2\pi}{\lambda}(path\ difference)$$
$$= \frac{2\pi(e\sin\theta)}{\lambda}$$

Let the width of the slit is divided into 'n' equal parts and the amplitude of the wave front each part is 'a'. Then the phase difference between any two successive waves from these parts would be

$$\frac{1}{n}(phase\ difference) = \frac{1}{n}\left(\frac{2\pi e\sin\theta}{\lambda}\right) = d$$

Using the vector addition method, the resultant amplitude R is

$$R = \frac{a\sin\frac{nd}{2}}{\sin\frac{d}{2}}$$

$$R = A\frac{\sin\alpha}{\alpha} \qquad \because na = A\ and\ \alpha = \frac{\pi e\sin\theta}{\lambda}$$

Therefore resultant intensity $I = R^2 = A^2\left(\frac{\sin\alpha}{\alpha}\right)^2$

Principal maximum:-

The resultant amplitude R can be written as

$$R = \frac{A}{\alpha}\left(\alpha - \frac{\alpha^3}{3!} + \frac{\alpha^5}{5!} - \frac{\alpha^7}{7!} + \cdots\right)$$
$$= \frac{A\alpha}{\alpha}\left(1 - \frac{\alpha^2}{3!} + \frac{\alpha^4}{5!} - \frac{\alpha^6}{7!} + \cdots\right)$$
$$= A\left(1 - \frac{\alpha^2}{3!} + \frac{\alpha^4}{5!} - \frac{\alpha^6}{7!} + \cdots\right)$$

In the above expression for α=0 values the resultant amplitude is maximum R=A, then I_{max}=R^2=A^2

$$\alpha = \frac{\pi e\sin\theta}{\lambda} = 0$$
$$\sin\theta = 0$$
$$\theta = 0$$

For θ=0 and α=0 value the resultant intensity is maximum at P0 and is known as principal maximum.

Minimum intensity positions: I Will be minimum when $\sin\alpha$=0

$$\alpha = \pm m\pi \qquad m = 1,2,3,4,5 \ldots\ldots$$

$$\alpha = \frac{\pi e \sin\theta}{\lambda} = \pm m\pi$$

$$\pi e \sin\theta = \pm m\lambda$$

So we obtain the minimum intensity positions on either side of the principal maxima for all $\alpha = \pm m\pi$ values.

Secondary maximum

In between these minima secondary maxima positions are located. This can be obtained by differentiating the expression of I w.r.t α and equation to zero

$$\frac{dI}{d\alpha} = \frac{d}{d\alpha}\left(A^2\left[\frac{\sin\alpha}{\alpha}\right]^2\right) = 0$$

$$A^2\frac{2\sin\alpha}{\alpha}\frac{d}{d\alpha}\left(\frac{\sin\alpha}{\alpha}\right) = 0$$

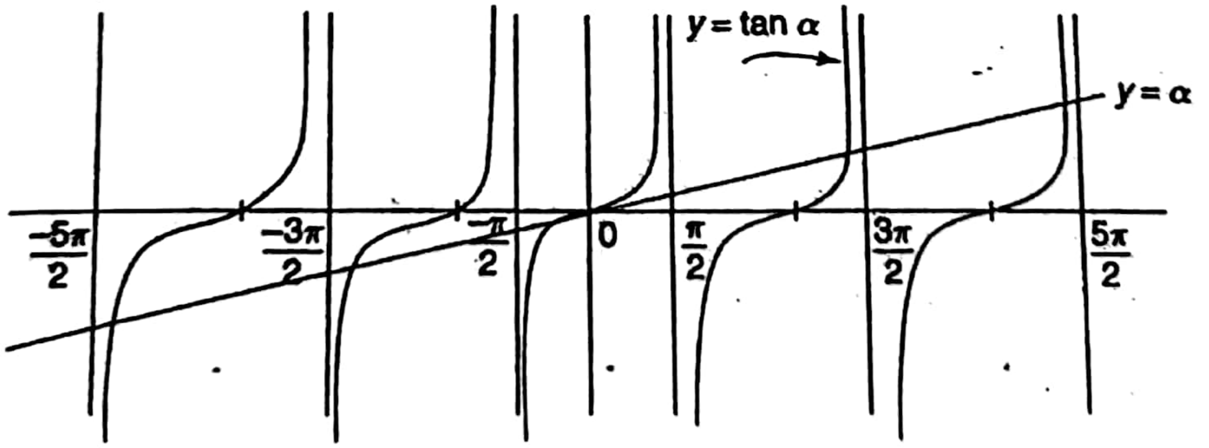
$$A^2\frac{2\sin\alpha}{\alpha}\cdot\left[\frac{\alpha\cos\alpha - \sin\alpha}{\alpha^2}\right] = 0$$

In the above expression α can never equal to zero,
so either $\sin\alpha = 0$ or $\alpha\cos\alpha - \sin\alpha = 0$
$\sin\alpha = 0$ gives the positions of minima
The condition for getting the secondary maxima is $\alpha\cos\alpha - \sin\alpha = 0$

$$\alpha\cos\alpha = \sin\alpha$$

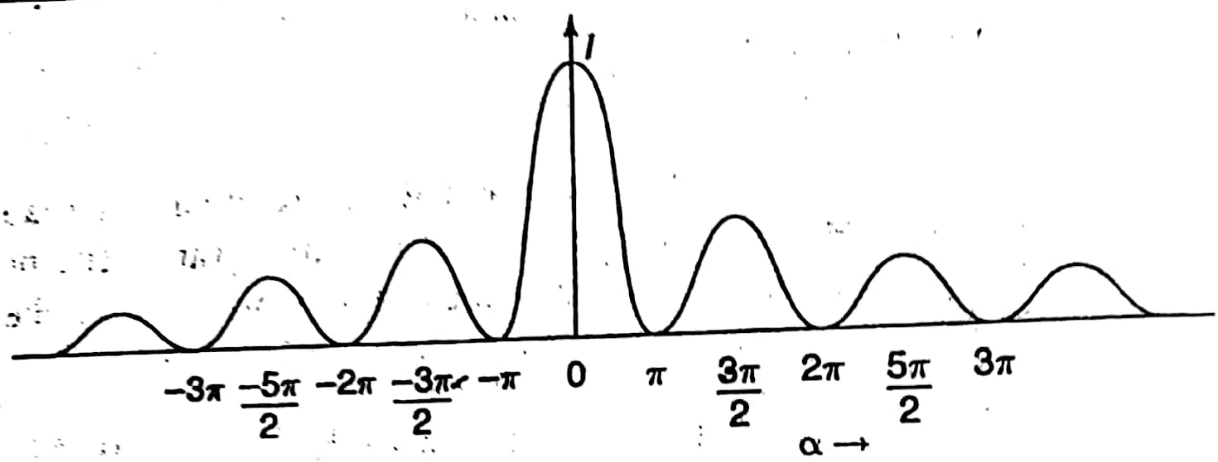
$$\alpha = \tan\alpha$$

The values of α satisfying the above equation are obtained graphically by plotting the curves $Y=\alpha$ and $Y=\tan\alpha$ on the same graph. The plots of $Y=\alpha$ and $Y=\tan\alpha$ is shown in figure.



In the graph the two curves intersecting curves gives the values of satisfying of α satisfying the above equation. From the graph intersecting points are $\alpha = 0, \pm 3\pi/2, \pm 5\pi/2, \pm 7\pi/2$...........

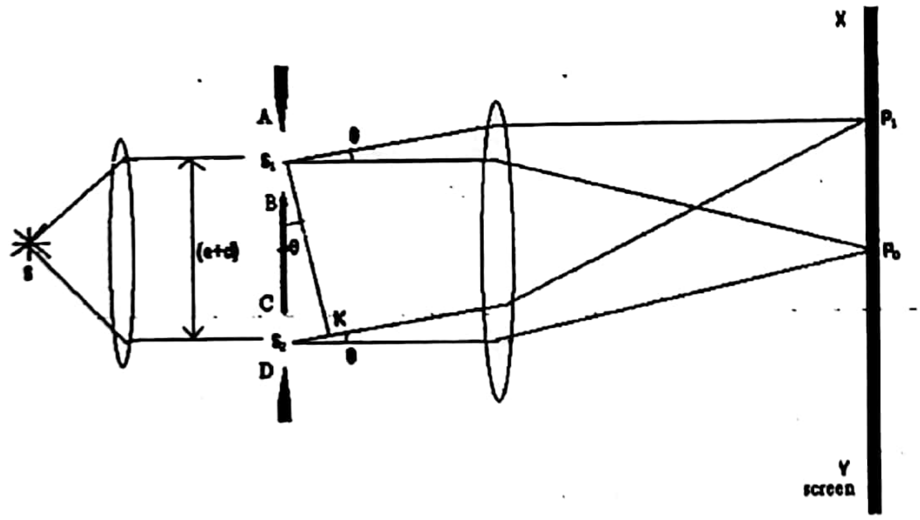
From the above concepts the intensity distribution curve verses α is shown in figure.



6. Explain Fraunhofer diffraction due to double slit and explain the intensity distribution.

Fraunhofer diffraction by a double slit:

Description: Consider two parallel slits AB and CD of equal width 'e' and separated by distance 'd'. The distance between the midpoints of the two slits is (e+d). Let a parallel beam of monochromatic light incident on the two slits normally. Then the light will be focused on the screen XY placed at the focal plane of the lens. The diffraction at two slits is the combination of diffraction as well as interference.



Explanation: When a plane wave front is incident normally on both slits, the secondary wavelets come to focus at P0 and the secondary wavelets traveling at an angle θ with normal come to a focus at P1.

Theory: For simplicity let us assume the two slits equivalent to two coherent sources S1 and S2 each sending a wavelet of amplitude **A** in a direction θ. The resultant amplitude at P1 will be the result of interference between two waves of amplitude (**A**) and having phase difference δ between them. To find δ, draw a perpendicular S_1K on S_2K.

Path difference between wavelets from S_1 and S_2 = S_2K = (e+d) sinθ

Phase difference δ = (e+d) sin θ.

Resultant amplitude $R^2 = a_1^2+a_2^2+2a_1a_2\cos\delta$

$= \{A \frac{\sin\alpha}{\alpha}\}^2 + \{A\frac{\sin\alpha}{\alpha}\}^2 + 2\{A \frac{\sin\alpha}{\alpha}\}\{A \frac{\sin\alpha}{\alpha}\}\cos\delta$

$= \{A \frac{\sin\alpha}{\alpha}\}^2 \; [1+1+2\cos\delta] = \{A \frac{\sin\alpha}{\alpha}\}^2 \; 2[1+\cos\delta]$

$= \{A \frac{\sin\alpha}{\alpha}\}^2 \; 2[2\cos^2\delta/2]$

$R^2 = 4A^2\{\frac{\sin\alpha}{\alpha}\}^2 \cos^2\delta/2$

$R^2 = 4A^2\{\frac{\sin\alpha}{\alpha}\}^2 \cos^2(\frac{\pi(e+d)\sin\theta}{\lambda})$

$R^2 = 4A^2\{\frac{\sin\alpha}{\alpha}\}^2 \cos^2\beta$ where $\beta = \frac{\pi(e+d)\sin\theta}{\lambda}$

$$I = R^2 = 4A^2 \{\frac{\sin\alpha}{\alpha}\}^2 \cos^2\beta$$

Intensity distribution: The resultant intensity depends upon two factors

1. $4A^2 \{\frac{\sin\alpha}{\alpha}\}^2$ which is same as that of single slit diffraction. This gives the intensity distribution in the diffraction pattern due to single slit.
2. $\cos^2\beta$ which gives the interference pattern due to waves starting from two parallel slits.

Therefore the resultant intensity at any point on the screen is the product of these two factors.

In the diffraction pattern,

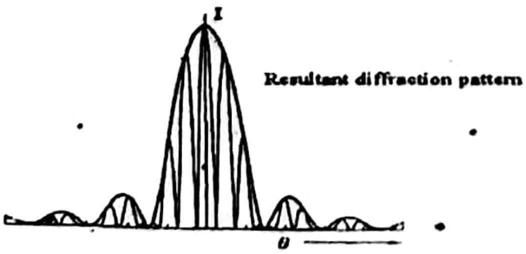
- The central maximum is obtained in the direction $\theta = 0$.
- The minima are obtained in the direction given by $e \sin\theta = \pm m\lambda$, m = 1, 2, 3, ----
- The positions of secondary maxima approaches to $\alpha = 0, \pm 3\pi/2, \pm 5\pi/2$ and so on.

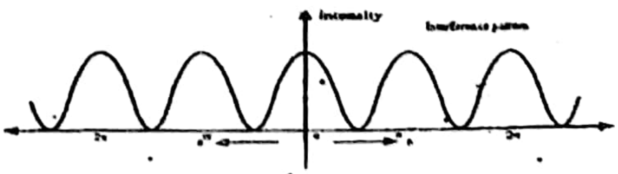
In the interference pattern,

The maxima are obtained in the direction given by $\cos^2\beta = 1 \implies \beta = \pm n\pi$

$\implies \frac{\pi(e+d)\sin\theta}{\lambda} = \pm n\pi \implies (e+d)\sin\theta = \pm n\lambda$, n=0, 1, 2...

The intensity distribution in diffraction pattern, interference pattern and the resultant pattern are as shown respectively.

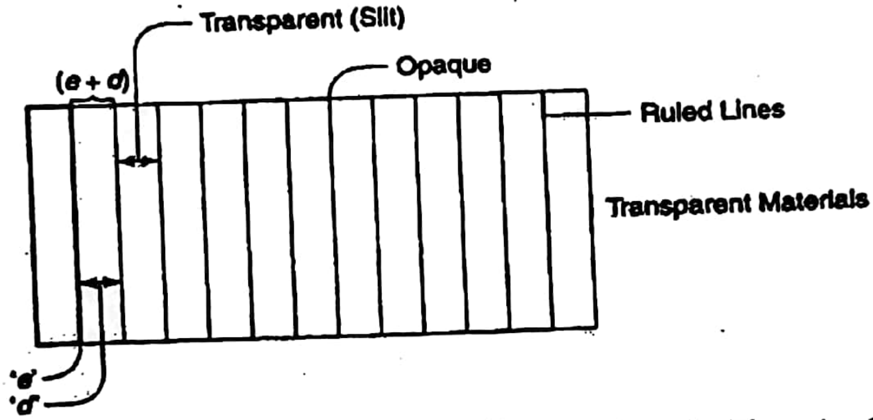




7. What is plane diffraction grating? Explain grating spectrum.

Plane diffraction grating:

Construction: An arrangement consisting of large number of parallel slits of the same width and separated by equal opaque spaces is known as diffraction grating. Fraunhofer constructed grating by placing large no. of parallel wires closely side by side at regular intervals. Now gratings are constructed by ruling equidistant parallel lines on a transparent material glass with a fine diamond point. The ruled lines are opaque to light and the space between the lines is transparent to light and acts as slit. This is known as plane transmission grating. If the lines are drawn on silvered surface then it forms plane reflection grating. Commercial gratings are produced by taking the cast of an actual grating on a transparent film like that of cellulose acetate. Solution of cellulose acetate is poured on the ruled surface and allowed to dry to form a thin film, detachable from the surface. These impressions of a grating are preserved by mounting the film between two glass sheets.



Let 'e' be the width of the line and 'd' be the width of the slit. Then (e+d) is known as grating element. If N is the number of lines per inch on the grating, then

$$N(e+d) = 1'' = 2.54 \text{ cm}$$

$$e+d = 2.54N \text{ cm}$$

There will be nearly 30,000 lines per inch of a grating. Due to the above fact, the width of the slit is very narrow and is comparable to the wavelength of light. When light falls on the grating, the light gets diffracted through each slit. As a result, both diffraction and interference of diffracted light gets enhanced and forms a diffraction pattern. This pattern is known as diffraction spectrum.

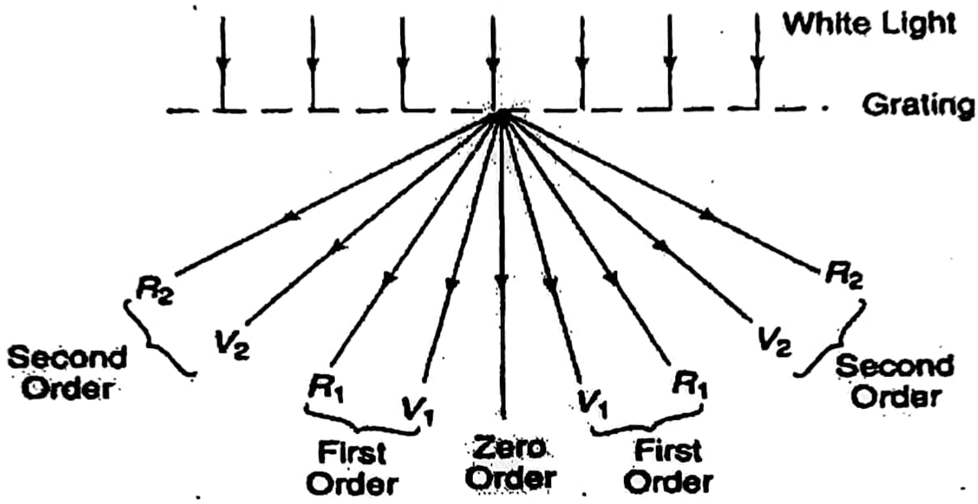
Grating Spectrum

The condition to form the principal maxima in a grating is given by $(e+d)\sin\theta = n\lambda$

Where (e+d) is the grating element and the above equation is known as grating equation. From the grating equation, the following is clear.

1. For a particular wavelength λ, the angle of diffraction θ is different for principal maxima of different orders.
2. As the number of lines in the grating is large, maxima appear as sharp, bright parallel lines and are termed as spectral lines.
3. For white light and for a particular order of n, the light of different wavelengths will be diffracted in different directions.
4. At the center, $\theta=0$ gives the maxima of all wavelengths which coincides to form the central image of the same colour as that of the light source. This forms zero order (Fig.)

5. The principal maxima of all wavelengths forms the first, second,... order spectra for n=1,2,...
6. The longer the wavelength, greater is the angle of diffraction. Thus, the spectrum consists of violet being in the innermost position and red being in the outermost positions.
7. Most of the intensity goes to zero order and the rest is distributed among other orders.
8. Spectra of different orders are situated symmetrically on both sides of zero order.
9. The maximum number of orders available with the grating is $n_{max} = (e+d)/\lambda$



8. Explain diffraction due to N-Slits?

Diffraction Grating-Normal incidence-(Diffraction at N parallel slits)

Construction

An arrangement consisting of large number of parallel slits of the same width and separated by equal opaque spaces is known as diffraction grating. Fraunhofer used the first grating consisting of a large number of parallel wires placed very closely side by side at regular intervals. The diameter of the wires was of the order of 0.05mm and their spacing varied from0.0533 mm to 0.687 mm. Now gratings are constructed by ruling equidistant parallel lines on a transparent material such as glass with a fine diamond point. The ruled lines are opaque to light while the space between any two lines is transparent to light and acts as a slit. This is known as *Plane transmission grating*. On the other hand, if the lines are drawn on a silvered surface (plane or concave) then the light is reflected from the positions of mirrors in between any two lines and it forms a *plane or concave reflection grating*. When the spacing between the lines is of the order of the wavelength of light, then an appreciable deviation of light is produced.

Theory

Fig. represents the section of a plane transmission grating placed perpendicular to the plane of the paper. Let „e" be the width of each slit and "d" be the width of each opaque part. Then (e+d) is known as grating element. XY is the screen placed perpendicular to the plane of a paper. Suppose a parallel beam of monochromatic light of wavelength λ be incident normally on the grating. By Huygen"s principle, each of the slit sends secondary wavelets in all directions. The secondary wavelets travelling in the same direction of incident light will come to a focus at a point P_0 of the screen as the screen is placed at the focal plane of the convex lens. The point P_0 will be the central maximum. Now, consider the secondary waves travelling in a direction inclined at an angle θ with the direction of the incident light. These waves reach the point P_1 on passing through the convex lens in different phases. As a result, dark and bright bands on both sides of the central maximum are obtained.

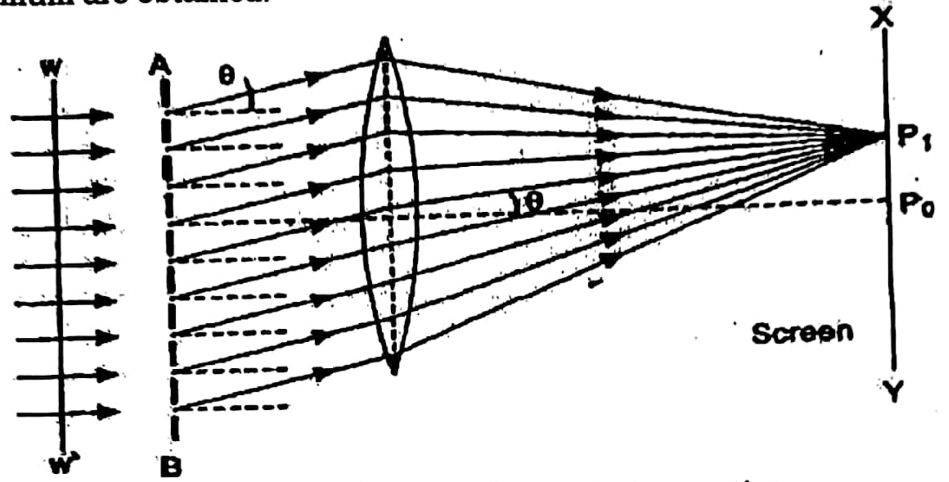


Fig. Section of a Plane transmission grating

The intensity at point P_1 may be considered by applying the theory of Fraunhofer diffraction at a single slit. The wavelets proceeding from all points in a slit along the direction Θ are equivalent to a single wave of amplitude ($A \sin\alpha/\alpha$) starting from the middle point of the slit, where

$$\alpha = (\pi e \sin\Theta/\lambda).$$

If there are N slits, then there will be N diffracted waves, one each from the middle points of the slits. The path difference between two consecutive slits is $(e+d)\sin\Theta$. Therefore, there is a corresponding phase difference of $(2\pi/\lambda)(e+d)\sin\Theta$ between the two consecutive waves. The phase difference is constant and it is 2β.

Hence, the problem of determining the intensity in the direction Θ reduces to finding the resultant amplitude of N vibrations each of amplitude ($A \sin\alpha/\alpha$) and having a common phase difference

$$(2\pi/\lambda)(e+d)\sin\Theta = 2\beta \rightarrow (1)$$

Now, by the method of vector addition of amplitudes, the direction of Θ will be

$$R^* = (A\sin\alpha/\alpha)(\sin N\beta/\sin\beta)$$

And $I = R^2 = (A\sin\alpha/\alpha)^2 (\sin N\beta/\sin\beta)^2 = I_o (\sin\alpha/\alpha)^2 (\sin^2 N\beta/\sin^2\beta) \rightarrow (2)$

The factor $(A\sin\alpha/\alpha)^2$ gives the distribution of intensity due to single slit while the factor $(\sin^2 N\beta/\sin^2\beta)$ gives the distribution of intensity as a combined effect of all the slits.

Intensity distribution in N-Slits

Principle maxima

The intensity would be maximum when $\sin\beta = 0$. or $\beta = \pm n\pi$ where, n=0, 1, 2, 3,...
but at the same time $\sin N\beta = 0$, so that the factor $(\sin N\beta/\sin\beta)$ becomes indeterminate.
By applying the Hospital's rule
The resultant intensity is $I = R^2 = (A \sin\alpha/\alpha)^2 . N^2$
The maxima are most intense and are called as principal maxima.

The maxima are obtained for

$$\beta = \pm n\pi$$

$$[\pi\,(e+d)\sin\theta]/\lambda = \pm n\pi$$

$$\text{or } e+d \sin\theta = \pm n\lambda \quad \text{Where, } n = 0, 1, 2, 3....$$

n=0 corresponds to zero order maximum. For n=1, 2, 3...etc., the first, second, third, etc., principal maxima are obtained respectively. The ± sign shows that there are two principal maxima of the same order lying on the either side of zero order maximum.

Minima

A series of minima occur, when Sin Nβ = 0 but sinβ≠0

For minima, Sin Nβ = 0

$$N\beta = \pm m\pi$$

$$[N\pi\,(e+d)\sin\theta]/\lambda = \pm m\pi$$

$$N\,(e+d)\sin\theta = \pm m\lambda$$

Where m has all integral values except 0, N, 2N ...nN, because for these values sinβ becomes zero and the principal maxima is obtained. Thus, m = 1, 2, 3... (N-1). Hence, they are adjacent principal maxima.

Secondary maxima

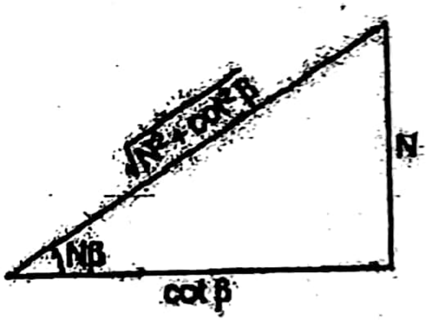
To find out the position of these secondary maxima, equation (2) must be differentiated with respect to β and then equate it to zero. Thus, $dI/d\beta = 0$ and on solving

$$N\tan\beta = \tan N\beta$$

The roots of this equation other than those for which β = ±nπ give the positions of secondary maxima. To find out the value of (sin² Nβ/sin²β) from equation N tanβ = tan Nβ; a triangle shown below, in the figure is used.

$$\sin N\beta = \frac{N}{\sqrt{(N^2+\cot^2\beta)}}$$

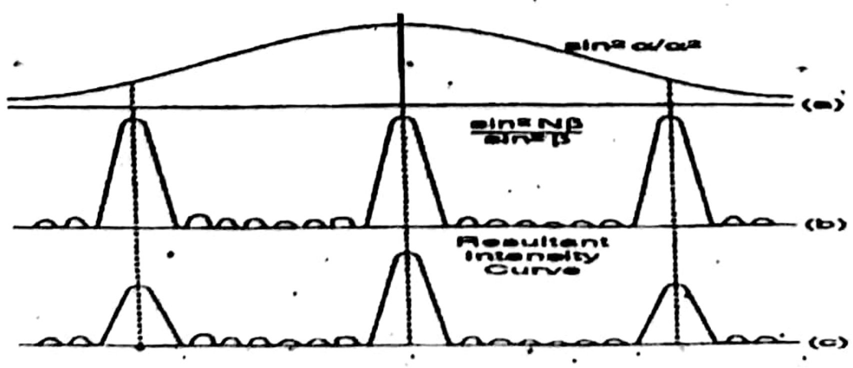
$$\frac{\sin^2 N\beta}{\sin^2\beta} = \frac{N^2}{(N^2+\cot^2\beta)\times\sin^2\beta} = \frac{N^2}{N^2\sin^2\beta+\cos^2\beta} = \frac{N^2}{1+(N^2-1)\sin^2\beta}$$



Therefore, $$\frac{\text{Intensity of secondary maxima}}{\text{Intensity of principal maxima}} = \frac{1}{1+(N^2-1)\sin^2\beta}$$

As N increases, the intensity of secondary maxima relative to principal maxima decreases and becomes negligible when N becomes large.

Figures (a) and (b) show the graphs of variation of intensity due to the factors $\sin^2\alpha/\alpha^2$ and $\sin^2 N\beta/\sin^2\beta$ respectively. The resultant is shown in figure (c).



9. What are the characteristics of grating spectra?

Characterization of grating spectra:

i. Spectra of different orders are situated symmetrically on the both sides of zero order image.

ii. Spectral lines are almost straight and quite sharp.

iii. Spectral lines are in the order from violet to red.

iv. The spectral lines are more and more dispersed as we go to higher orders.

v. Most of the incident intensity goes to zero order and rest is distributed among the other orders.

10. Explain the condition for maximum number of orders available with grating?

Maximum no. of orders available with a grating:

For principal maxima, $(e+d)\sin\theta = n\lambda$

$$\Longrightarrow n = \frac{(e+d)\sin\theta}{\lambda}$$

The maximum angle of deflection is $\theta = 90^0$ $\quad \therefore (n)_{max} \leq \frac{(e+d)}{\lambda} \leq \frac{1}{N\lambda}$

Where $N=\frac{1}{e+d}$ = Number of lines per unit distance of grating.

$$(n)_{max} \leq \frac{(e+d)}{\lambda} \leq \frac{1}{N\lambda}$$

This condition gives the maximum number of orders possible with a grating.

Ex: If N=5000 lines/cm and λ = 420 nm then $(n)_{max} \leq 4.76$

Here n has to be an integer, so maximum number of orders possible is only 4.

11. Explain dispersive power of a grating.

Dispersive power of grating:

Dispersive power of grating is defined as the ratio of variation of angle of diffraction with wavelength.

If $\theta 1$ & $\theta 2$ are the angles of diffraction in a particular order for wavelengths $\lambda 1$ & $\lambda 2$ Respectively, then $\frac{\theta 1 - \theta 2}{\lambda 1 - \lambda 2}$ is called dispersive power. If $\lambda 1 - \lambda 2$ is very small then it was represented by $\frac{d\theta}{d\lambda}$

We have $(e+d)\sin\theta = n\lambda$ differentiating w.r.t λ we have $(e+d)\cos\theta\, d\theta = n\, d\lambda$ ==>

$$\frac{d\theta}{d\lambda} = \frac{n}{(e+d)\cos\theta}$$

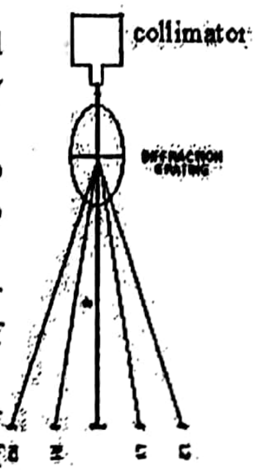
Therefore $\frac{d\theta}{d\lambda} = \frac{n}{(e+d)\cos\theta}$

Therefore $\quad \frac{d\theta}{d\lambda} \,\alpha\, n; \quad \frac{d\theta}{d\lambda} \,\alpha\, \frac{1}{(e+d)}; \quad \frac{d\theta}{d\lambda} \,\alpha\, \frac{1}{\cos\theta}$

12. Explain the determination of wavelength of light by a diffraction grating.

Determination of wavelength:

To determine the wavelength of mono chromatic light using diffraction grating and spectrometer, the procedure is as follows.



1. The collimator C of the spectrometer is adjusted to produce parallel rays and the telescope T is adjusted to receive the parallel rays by focusing the distant object.
2. The grating G is placed on the grating table such that it is normal to the axis of collimator. It is illuminated by source whose wavelength is to be determined.
3. The telescope is slowly turned to one side and coincide the first order diffracted image with vertical cross wire of eyepiece. The reading of telescope is noted.
4. Now the telescope is turned to another side and coincide the first order diffracted image with the vertical cross wire of eyepiece. The reading of telescope is noted. The difference of these two readings gives 2θ.

By substituting the value of θ in the given equation λ can be determined.

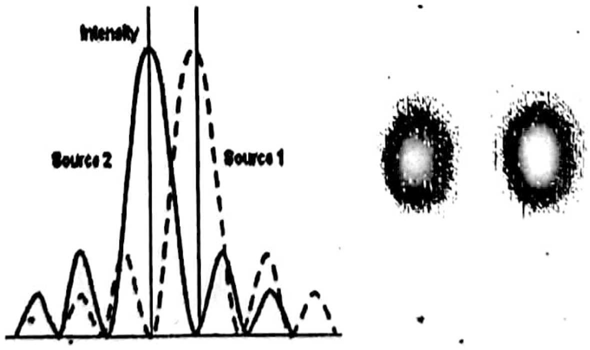
$$\lambda = \frac{\sin\theta}{nN}$$

Where n is order of the spectrum and N is no. of lines per unit width of the grating.

13. What is resolving power? Derive the expression for resolving power of grating.

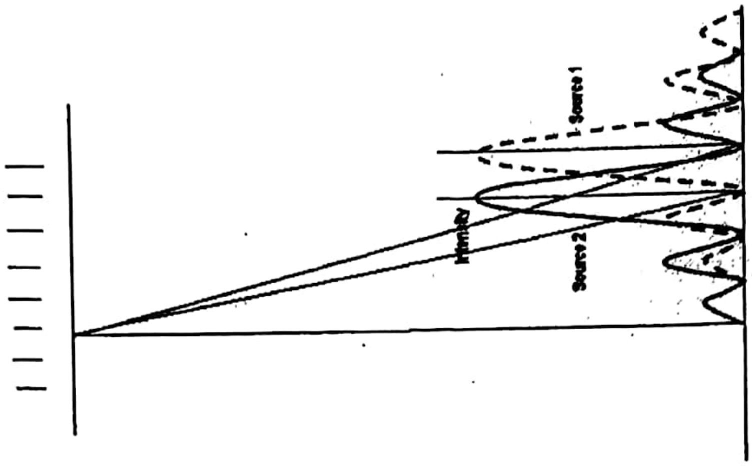
Resolving power: When the two objects are very near to each other or at very large distance from our eye it cannot able to see them separately. To see them separately, optical instruments like telescope, microscope, prism and grating etc. are employed. Thus an optical instrument is said to be able to resolve two point objects if the corresponding diffraction patterns are distinguishable from each other.

Definition of resolving power: The ability of the instrument to produce two separate images of very close objects is known as resolving power.



Resolving power of a grating: The resolving power of a diffraction grating is its ability to separate spectral lines which have nearly the same wavelength. This is measured by (λ/dλ) where dλ is the smallest difference in two wavelengths which are just resolvable by grating. λ is the wavelength of either (or) mean wavelength.

Expression for resolving power of grating:



Let AB be the plane transmission grating having grating element (e+d), N be the total no. of slits. Let a beam of light having two wavelengths λ and $\lambda+d\lambda$ incident normally on the grating. P1 is n^{th} primary maximum of spectral line of λ at an angle of diffraction θ_n and P2 is the n^{th} primary maximum of $\lambda+d\lambda$ at an angle of diffraction $(\theta_n+d\theta_n)$. According to Rayleigh criterion, the two wavelengths will be resolved if the position P2 corresponds to first minimum of P1 and vice versa. Consider the first minimum of P1 in the direction of $(\theta_n+d\theta_n)$.

The principal maximum of λ in the direction θ_n is given by

$(e+d)\sin\theta_n = n\lambda$ -----------(1)

Similarly the principal maximum of $\lambda+d\lambda$ in the direction $(\theta_n+d\theta_n)$ is given by

$(e+d)\sin(\theta+d\theta_n) = n(\lambda+d\lambda)$ ----------------------(2)

The path difference between the rays corresponding to the angle of diffraction θ_n and $(\theta_n+d\theta_n)$ is (λ/N), where N is the total number of lines on the grating surface.

$$n(\lambda+d\lambda) - n\lambda = \lambda/N$$

$$n.d\lambda = \lambda/N$$

$$\Rightarrow \frac{\lambda}{d\lambda} = nN \qquad \Rightarrow \frac{\lambda}{d\lambda}\ \alpha\ n, \quad \frac{\lambda}{d\lambda}\ \alpha N$$

This is the required equation.

15. What are the applications of diffraction?

Applications of diffraction:

1. The wavelength of spectral lines can be measured by using diffraction grating.
2. The wavelength of x-rays can be determined by x-ray diffraction.
3. The structures of the crystal can be determined by the x-ray diffraction.
4. The velocity of sound in liquids can be determined by using ultrasonic diffraction.
5. The size and shape of tumors, ulcers etc., inside the human body can be assessed by ultrasound scanning.

Assignment Questions

1. What are the differences between interference and diffraction?
2. What are the types of diffraction and give differences between them.
3. What is meant by diffraction of light and explain Fraunhofer diffraction due to single slit.
4. Give the theory of Fraunhofer diffraction due to double slit. Using this obtain intensity distribution curve.
5. Explain with the necessary theory of Fraunhofer diffraction due to n slits.
6. What is resolving power? Derive the expression for resolving power of grating.
7. Explain the determination of wavelength of light by a diffraction grating.
8. What are the applications of diffraction?
9. Explain dispersive power of a grating

Problems

1. How many orders will be visible, if the wave length of light is 5000 A^0. Given that the number of lines per centimeter on the grating is 6655 (Ans: 3)
2. Show that the grating with 500 lines / cm cannot give a spectrum in the 4^{th} order for the light of wavelength 5890A^0.
3. A plane transmission grating having 4250 lines per cm is illuminated with sodium light normally. In second order spectrum the spectral lines are divided by 30^0 are observed. Find the wavelength of the spectral line. (Ans: λ = 5882 A^0)
4. A diffraction grating having 4000 lines / cm is illuminated normally by light of wavelength 5000A^0. Calculate its resolving power in the third order spectrum. (Ans: 1mm, 2mm)
5. A grating has 6000 lines/cm. Find the angular separation b/w two wave lengths 500 mm and 510 mm in the 3^{rd} order. (Ans: $d\theta$ = 2.48^0)
6. Find the highest order that can be seen with a grating having 15000 lines / inches. The wave length of the light used is 600 mm. (Ans: 2)
7. A plane transmission grating having 6000 lines / cm is used to obtain a spectrum of light from a sodium lamp in the second order. Calculate the angular separation between two sodium lines D1 and D2 of wave length 5890A^0 and 5896 A^0. ($d\theta$ = 0.06^0)

Objective Questions

1. When white light is incident on a diffraction grating, the light that will be deviated more from central image will be

a. Yellow b. Violet c. Indigo **d. Red**

2. The diffraction phenomenon is

a. Bending of light around an obstacle b. rectilinear propagation of light
c. Oscillation of light wave in one direction d. None of them

3. To find prominent diffraction, the size of the diffracting objects should be

a. Greater than the wavelength of light used **b. Of the order of wavelength of light**
c. Less than the wavelength of light d. None of them

4. In Fresnel diffraction
   a. Source of light is kept at infinite distance from the aperture
   b. Source of light is kept at finite distance from the aperture
   c. Convex lens is used
   d. Aperture width is selected so that, it can act as a point source.

5. In Fraunhofer diffraction, the incident wave front should be
   a. Elliptical **b. Plane** c. Spherical d. Cylindrical

6. Significant diffraction of X-rays can be obtained
   a. By a single slit b. By a double slit
   c. By a diffraction **d. By an atomic crystal**

7. Rising and setting sun appears to be reddish because
   a. Diffraction sends red rays to the earth at these times
   b. Scattering due to dust particles and air molecules is responsible for this effect
   c. Refraction is responsible for this effect
   d. Polarization is responsible for this effect

8. The penetration of waves into the regions of the geometrical shadow is
   a. Interference **b. Diffraction** c. Polarization d. Dispersion

9. In a single slit experiment if the slit width is reduced
   a. The fringes become brighter b. The fringes becomes narrower
   c. The fringes become wider d. The colour of the fringes changes

10. In diffraction due to double slit we observe
   a. Wider interference fringes and narrower diffraction bands
   b. Interference and diffraction fringes of equal width
   c. Wider diffraction bands and within that narrower interference fringes
   d. Diffraction pattern due to both the slits independently

11. In double slit diffraction if the width of the slit is equal to the spacing between the slits then
   a. Even order interference maxima will be missing
   b. All interference maxima will be present
   c. All interference maxima will be missing
   d. Diffraction fringes & interference fringes exactly coincide and hence totally disappear.

12. A parallel beam of mono chromatic light falls normally on a plane diffraction grating having 5000 lines/cm. A second order spectral line is diffracted through an angle of 30^0. The wavelength of light is
   a. $5x10^{-7}$cm b. $5x10^{-6}$cm c. $5x10^{-5}$cm d. $5x10^{-4}$cm

$$HINT: \lambda = \frac{(e+d)\sin\theta}{n}, (e+d) = \frac{1}{5000cm}, \theta = 30^0, n = 2)$$

λ

13. Maximum number of orders possible with a grating is
   a. Independent of grating element **b. directly proportional to grating element**
   c. Inversely proportional to grating element d. directly proportional to wave length

14. If 1000 is the resolving power of a grating in it first order, its resolving power in 2^{nd} order is

a. 500 b. 1000 **c. 2000** d. None

15. The class of diffraction in which lenses required is
 a. Fresnel **b. Fraunhofer** c. Both a & b d. None

16. A diffraction grating is
 a. Large number of equidistant slits b. Large number of random distant slits
 c. More than two slits d. None

17. In diffraction grating, the conditions for principal maxima
a. $(e+d)\sin\theta = n\lambda$ b. $d\sin\theta = n\lambda$ c. $\sin\theta = n\lambda$ d. $e\sin\theta = n\lambda$

18. Resolving power of a grating is
 a. Directly proportional to N b. Inversely proportional to N
 c. Independent of N d. Directly proportional to N^2

19. The expression for number of orders possible in diffraction grating is
 a. $n_{max}=1/N\lambda$ b. $n_{max}=(e+d)/\lambda$ **c. Both a & b** d. None

20. The intensity of various fringes in the diffraction pattern is
 a. Constant **b. Varies** c. Zero d. None

21. When the number of lines on the grating surface is large, the grating spectrum becomes
 a. Bands b. Continuous colors **c. Line** d. None

22. The expression of resolving power of grating is R=
 a. $\lambda/d\lambda$ b. n N **c. Both a & b** d. None