INTERFERENCE & DIFFRACTION OF LIGHT

Principle of Superposition of - Light wave

When two waves of light travel through the medium arrived at a point of medium, the resultant displacement at any instant is the vector sum of displacement produced by them. When two waves meeting at a point are in phase resultant displacement is added and when two waves meeting at a point are out of phase resultant displcement is substracted.

Interference of Light

Variation in resultant intensity of light due to the principle of superposition os light wave is called interference of light.

Q. Explain the concept of interference of light.

1. When the two waves arriving at a point are in phase, (i.e. the crest of one wave fall on the crest of the other wave or the trough of one wave falls on the trough of the other wave) then the resultant displacement at that point is maximum. Therefore, the resultant intensity of light at that point is maximum and that point appears bright. This type of interference is called constructive interference.
2. When the two waves arriving at a point are out of phase, (i.e. the crest of one wave fall on the trough of other wave and vise versa) then the resultant displacement at that point is minimium. The resultant intensity of light at that point is minimum and point appears dark. This type of interference is called destructive interference. This variation in resultant intensity of light is called interference of light. OR the modification in intensity of light (redistribution of light energy) produced by superposition of two or more light waves is called Interference of Light.

Q. Conditions for sharp, clear and stationary interference pattern .

1. Two source of light must be coherent. Two source having same amplitude and frequency and having constant phase difference at all the time are called as coherent sources. Coherent sources are derived from single source.
2. Two sources of light must be monochromatic. Two sources of light are said to be monochromatic if they are having same wavelength.
3. Amplitude of two light wave must be equal.
4. Two sources of light must be narrow.
5. Two sources of light must be close to each other.
6. Two sources of light must emit light waves nearly in same direction.

Q.1. Explain need of coherent sources to obtain steady interference pattern :

Ans : If two sources are not coherent :

1. If we use two independent sources of light, phase difference between two waves at a point in a medium changes continuously.
2. Due to this, at any point in a medium intensity does not remains constant. Therefore, a point will appears bright for a moment, while for next moment it will appears as dark and steady interference will not obtain.

If two sources are coherent :

1. If two sourceslight are coherent then they will emit light waves of constant phase difference.

2. Hence the point of constructive interference appears as bright point and point of destructive interference appears as dark point throughout experiment Thus, the steady interference pattern which consist of alternate bright and dark band will be obtained.

Q.2. "Clear interference pattern can not be obtained unless light used is monochromatic." Explain.

Ans : The monochromatic source of light is a source which emits light waves of only one wavelength. When light sources are not monochromatic, then the sources emit light waves of more than one wavelength. There may be constructive interference at one point due to one wavelength and destructive interference at the same point due to another wavelength. This gives diffused and indistinct interference pattern.

Q.3. Explain "Two sources must be equally bright to obtain well defined interference pattern."

Ans : If two sources are equally bright means they should emit waves of equal amplitude. Intensity of light is directly proportional to square of amplitude. When amplitude is same intensity of light is same. If amplitudes are not equal, the points at which waves arrive are out of phase (i.e. creast superimposed on troughs OR troughs superimposed on creast), shall not be completely dark and interference pattern shall consist of bright points and less bright.

If amplitudes are equal, the points at which waves arrive are out of phase, shall be completely dark and resultant interference pattern shall consist of bright points and dark points. The contrast between them shall give to a clear and sharp and distinct interference pattern.

Q.4. The sources of light must be narrow :

If the sources are broad, the waves starting from different points on the sources travel different distances to reach the same point on the screen. These waves will interfere with one another and their own interference pattern will be obtained. The resultant interference pattern so obtained will not be clear and distinct. On the contrary there may be uniform illumination.

Q.5. The separation between the two light sources should be as small as possible : If the sources are sufficiently close to each other, then the interference fringes are widely spaced and can be seen clearly.

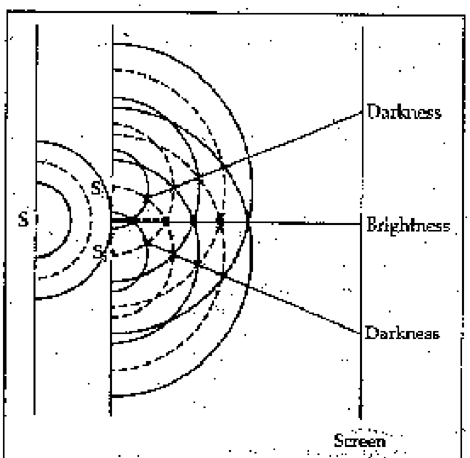
$$X = \frac{D\lambda}{d}$$

Q.6. The distance of the screen from the two sources should be large : If the screen is quite far from the sources, then the fringewidth should be appreciable and widely spaced fringes are obtained. $X = \frac{D\lambda}{d}$

Q.7. The two waves should be in the same state of polarization. This is necessary only if polarized light is used for the experiment. The explanation of this condition is beyond the scope of this book.

Young's Experiment :

S is a source illuminated with monochromatic light, S_1 and S_2 are two narrow slits, equidistant from S. Spherical waves, from S_1 and S_2 travels towards the screen and interfere with each other. At point where creast of wave from S_1 falls on the crest of the wave from S_2 or trough of the wave from S_1 falls on the trough of wave from S_2. There will be addition of amplitude of resultant wave at that point. Since intensity of light is directly proportional to square of amplitude, intensity of light at these point will be maximum. Hence this type of interference is called



Young's experiment of interference

constructive interference. At point where crest of the wave from S_1 falls on trough of the wave from S_2 or viceversa. Amplitude of resultant wave will be zero. Hence intensity of light at this point will be zero and these points will be dark. This type of interference is called as **destructive interference.** Young's first used source of light as sunlight and he got colour bands.

Importance of Young's Experiment

- First experiment for demostration of interference of light.
- From this experiment wavelength of monochromatic source can be calculated.
- It proves that light travel in the form of wave.

Conditions for Constructive and Destructive Interference

1. **Constructive Interference :** If path difference between two light wave reaching at any point (P) is intergral multiple of wavelength than that point is bright point and such a interference is called as constructive interference i.e. for constructive inteference.

   Path difference = n λ . **(n = 0,1,2,3...............)**

   Path difference = $0,\ \lambda,\ 2\lambda,\ 3\lambda,\ 4\lambda$

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

2. **Destructive Interference :** If path difference between two light waves reaching at any point (P) is odd multiple of half of the wavelength (l/2) than that point will be dark point and interference will be called destructive interference i.e. for destructive interference.

   Path difference = (n - 1/2) λ , **(n = 1,2,3,4.................)**

   Path difference = $1\lambda/2,\ 3\lambda/2,\ 5\lambda/2$

   Phase difference = $\pi,\ 3\pi,\ 5\pi,\ 7\pi$

Ex . 1 A point is situated at 6.5 cm & 6.65 cm from two coherna sources. Find the nature of fillumintion at a point, if wavelength of light is $5000A^0$

Soln : Given : $\lambda = 5000A^0$ $\qquad \lambda = 5000\times10^{-10}\,m$

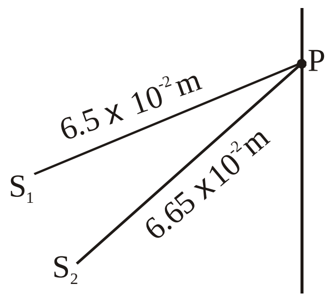
To find : Nature of illumination.

We know that

Path diff = $S_2P - S_1P$

Path diff = $6.65 \times 10^{-2} - 6.5 \times 10^{-2}$

Path diff = 0.15×10^{-2} m ...... (I)



Also Path diff = $x\lambda$ ...... (II)

$\therefore 0.15 \times 10^{-2} = x\lambda$

$\therefore x = \dfrac{0.15\times10^{-2}}{5000\times10^{-10}}$ $\qquad \therefore x = \dfrac{15\times10^{-4}}{5\times10^{-7}}$ $\qquad \therefore x = 3\times10^{3}$ $\boxed{x = 3000}$

Path diff = (3000) λ

Ex . 2 Optical path difference between two sets of similar waves from two coherent sources arving at a point on the screen is 371λ. Will the point be dark or bright ?
If optical path difference is 0.24 mm. Calculate wavelength of light used

Soln Given : Path diff. = 371λ $\qquad$ Path diff = 0.24×10^{-3} m

To find : Bright band and λ

For bright band path diff between two light waves, reaching at any point must be inegral multiple of wavelength

i.e. path diff $n\lambda$

It is given that - Path diff = 371λ

Since, path diff. is integral multiple of wavelength given point will be bright.

Now, Path diff = 371λ

Path diff = 0.24×10^{-3} m

$371\lambda = 0.24\times10^{-3}\text{m}$ $\quad\because \lambda = \dfrac{0.24\times10^{-3}}{371}$

$\because \lambda = \dfrac{0.24\times10^{-5}}{371}$ $\quad\because \lambda = 6.469\times10^{-7}$

$\because \lambda = 6469\times10^{-10}\text{m}$ $\quad\boxed{\because \lambda = 6469A^0}$

Q. Give the theory of interference and obtain an expression for band width.(4 marks)

Ans : S_1 and S_2 are two coherent sources seperated by a distance of 'd'. Screen is kept at a distance D from S_1 and S_2. OP_o is perpendicular bisector of S_1 and S_2, P is any point at a distance x from P_o, S_1M and S_2N are perpendicular from S_1 and S_2 on the screen. $(S_2P – S_1P)$ is path difference between two light waves reaching at a point P. If path difference

$(S_2P - S_1P) = n\lambda$

Where n = 0,1,2,3,..............

Then point P will be **bright point**

If path difference

$(S_2P - S_1P) = (n-1/2)\lambda$

Where n = 1,2,3 ....

then the point P will be **dark point**

Where λ ...... Wavelength of monochromatic source of light that is used.

In S_2PN

$(S_2P)^2 = (S_2N)^2 + (PN)^2$

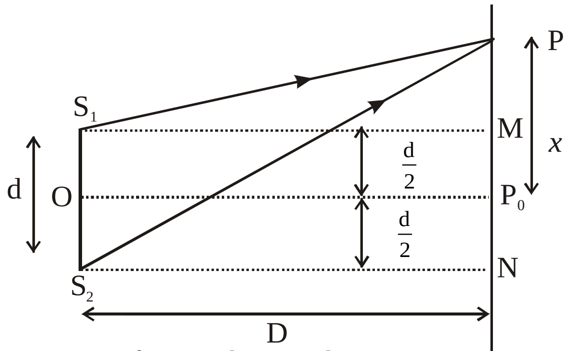
But, PN = x + d/2 and S_2N = D

$(S_2P)^2 = D^2 + (x + d/2)^2$ ....(1)

Now In S_1PM

$(S_1P)^2 = (S_1M)^2 + (PM)^2$

$(S_1P)^2 = D^2 + (x - d/2)^2$ ....(2)



Interference due to coherent sources

Now

$(S_2P)^2 - (S_1P)^2 = D^2 + (x + d/2)^2 - [D^2 + (x - d/2)^2]$

$(S_2P)^2-(S_1P)^2=D^2+x^2+xd+d^2/4-[D^2+x^2-xd + d^2 / 4]$

$$S_2P^2 - S_1P^2 = D^2 + x^2 + xd + \frac{d^2}{4} - D^2 - x^2 + xd - \frac{d^2}{4}$$

$$(S_2P)^2 - (S_1P)^2 = 2xd$$

$$(S_2P + S_1P)(S_2P - S_1P) = 2xd$$

$$\Rightarrow (S_2P - S_1P) = \frac{2xd}{(S_2P + S_1P)}$$

In actual practics point P is very closed to P_0

$$\therefore S_2P \approx S_1P = D$$

$$\Rightarrow \; S_2P - S_1P = \frac{2xd}{D+D}$$

$$\Rightarrow S_2P - S_1P = \frac{xd}{D} \ldots\ldots\ldots\ldots\ldots(3)$$

Case (I) : For Bright Band.

Path difference (S_2P - S_1P) = n λ

But From (3)

$$(S_2P - S_1P) = \frac{xd}{D}$$

$$\therefore n\lambda = \frac{xd}{D}$$

$$x = \frac{nD\lambda}{d}$$

In general, $x_n = \dfrac{nD\lambda}{d}$ ....(4)

This is a distance of n^{th} bright band from the centre of interference Pattern OR from Central bright band.

Case (II) For Dark Band

Path difference (S_2P - S_1P) = (n-1/2) λ

$$\frac{xd}{D} = (n - 1/2)\lambda$$

$$x = \frac{(n-1/2)\,\lambda\, D}{d}$$

$$\text{In General, } x_n = \frac{(n-1/2)\,\lambda\, D}{s} \ldots\ldots\ldots\ldots(5)$$

This is a distance of n^{th} dark band from the centre of interference pattern OR **from central bright band.**

Bandwidth (X)

Distance between any two successive bright band **OR** any two successive dark band is called as bandwidth.

For Bright Band

We have, From (4)

$$x_n = \frac{nD\lambda}{d} \quad \text{and} \quad x_{(n+1)} = \frac{(n+1)D\lambda}{d}$$

Now band width X = $x_{(n+1)} - x_n$

$$X = \frac{(n+1)D\lambda}{d} - \frac{nD\lambda}{d}$$

$$X = \frac{D\lambda}{d}(n+1-n)$$

$$X = \frac{D\lambda}{d} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

For Dark Band

If x_n is a distance of n^{th} dark band from the centre of interference pattern and x_{n+1} is adistance of $(n+1)^{th}$ dark from the interference pattern then we have.

From (5)

$$X_n = \frac{(n-1/2)D\lambda}{d}$$

$$x_{(n+1)} = \frac{(n-1/2+1)D\lambda}{d}$$

Bandwidth (X) = $x_{(n+1)} - x_n$

$$X = \frac{(n+1-1/2)D\lambda}{d} - \frac{(n-1/2)D\lambda}{d}$$

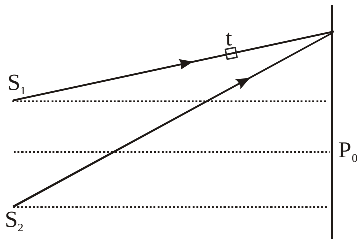
$$X = \frac{D\lambda}{d} \ldots\ldots\ldots\ldots\ldots (7)$$

Thus from (6) and (7) we can say that whatever is the distance between two bright band is same as distance between any two successive dark band. **Thus dark and bright bands are equally spaced.**

Q. Write an expression for the lateral displacement of fringes when a transparent sheet is inserted in the path of one of the interfering beams.

Ans : When a thin transparent sheet of thickness t and R.I. μ is inserted in the path of one of the interfering beams it is observed that the fringe pattern is shifted through a distance given by

$$X = \frac{D}{d}(\mu - 1)t$$



$$V = \frac{dist}{time} \qquad V_{air} = \frac{d_{air}}{t} \qquad V_{medium} = \frac{d_{medium}}{t}$$

$$\frac{V_{air}}{V_{medium}} = \frac{d_{air}}{d_{medium}} \qquad \mu = \frac{d_{air}}{d_{medium}}$$

$$\boxed{d_{air} = \mu\, d_{medium}}$$

Here extra path difference introduced or change in original path difference S_2P-S_1P is

x' =distance in air – distance in medium

=μt-t=$(\mu$-1$)$ t   Path diff.= $(\mu - 1)t$

On introduction of thin glass-slab of thickness (t) and refractive index μ, the optical path of the ray(S_1P) incrpermeases by $(\mu - 1)t$. Now the path difference between waves coming from S_1 and S_2 at any point P is given by

$$\Delta P = S_2P - (S_1P + (\mu - 1)t) \qquad \Delta P = S_2P - S_1P - (\mu - 1)t$$

$$S_2P - S_1P = \frac{xd}{D} \qquad \Delta P = \frac{xd}{D} - (\mu - 1)t$$

For central bright band path difference $\Delta P = 0$

$$0 = \frac{xd}{D} - (\mu - 1)t \qquad \frac{xd}{D} = (\mu - 1)t \qquad x = \frac{D}{d}(\mu - 1)t$$

Without glass-slab for central bright band x = 0. But $x \neq 0$ when slab is introduced it means that after introduction of glass-slab interference pattern is shifted. This shift is in the direction in which glass slab is placed.

Fringe system is shifted towards that side in which thin transparent sheet is introduced.

Note : 1) Fringe shift is independent of n i.e. order of fringe.

2) Every fringe including C.B.B. shift by Dx.

3) There is no change in fringe width due to shifting.

Example : 4

When one of the slits in Young's experiment is covered with a transperent sheet of thikness 3.6×10^{-3} cm, the central fringe shift to a position orginally occupied by the 30th bright fringe. If $\lambda = 6000 A^0$. Find the refractive index of the sheet.

Soln : Data : t = 3.6×10^{-3} cm = 3.6×10^{-5} m

30 X = x_0

$\lambda = 6000 A^0 = 6 \times 10^{-7}$ m

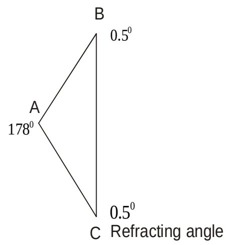
To find : μ = ?

$$30\ X = x_0 \qquad \therefore \frac{30\lambda D}{d} = \frac{D}{d}(\mu - 1)t \quad \text{OR} \quad (\mu - 1) = \frac{30\lambda}{t} \qquad \frac{30 \times 6 \times 10^{-7}}{3.6 \times 10^{-5}} \qquad \boxed{\mu = 1.5}$$

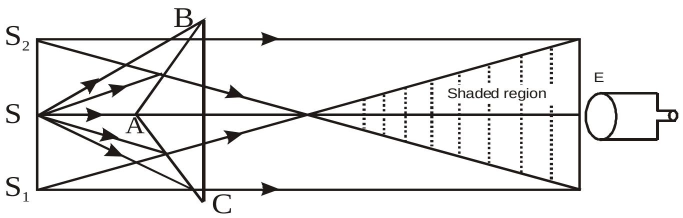
Fresnel’s Biprism

Q. Draw net ray diagram of biprism experiment showing clearly position of screen, virtual sources and region of interference. (2 marks)

Ans : Biprism consist of two right angled prism of very small refracting angle placed base to base.



Ans : Biprism consist of two right angled prism of very small refracting angle placed base to base. Refracting angle of biprism is about 178^0 to 179^0. ABC is the biprism of very small refracting angle S is a slit illuminated with monochromatic light of wavelength λ. Refracting edge of a biprism kept parallel to the slit. Light waves from S are incident on biprism. After refraction through biprism they appears to come from S_1 and S_2 Hence S_1 S_2 are virtual co-herent source. Interference fringes are produced on the screen in the region shown by shaded portion.



S: slit, B: Biprism, E: eyepiece.
Shaded region : Interference pattern

Ex. 5 State giving reasons what will happen to the bandwidth, if in the interference pattern of biprism experiment -

(a) Eye piele is moved towards the slit.

(b) Distance between virtual sources is decreased.

Sol^n : We know that

$$\text{band width } (x) = \frac{D\lambda}{d} \qquad \text{..........} (I)$$

a) If eyepiece is moved towards the slit, distance between slit & the section (D) decreases, there by (I) band width decreases,

b) If distance bet'n virtual sources (d) decreases, then from (I), band width increases.

Ex. 6 In biprism experiment distance between slit and the screen is 1m, distance between images of the slit is 0.274 mm. If the fringe width is 0.2 cm. What is the wavelength of light used ?

Sol^n: Given : D - 1m, $d = 0.274 \text{ mm} = 274\times10^{-3}\text{m}$ $\quad d = 274\times10^{-6}\text{ m}$

$X = 0.2 \text{ cm} = 0.2\times10^{-3}\text{ m}$

To find : λ

$$\text{We know that Wavelength } (\lambda) = \frac{Xd}{D}$$

$$\therefore\ \lambda = \frac{2\times10^{-3}\times274\times10^{-6}}{1} \qquad \lambda = \frac{548\times10^{-9} = 5480\times10^{-10}\text{m}}{1} \qquad \therefore\ \boxed{\lambda = 5480A^0}$$

Ex. 8 In biprism experiment, distance between slit and the eyepiece is 80 cm. The seperation between two virtual image of the slit is 0.25 mm. If the slit is illuminated by a light of wavelength 6000 A^0, find the distance of second bright band from the central bright band.

Sol^n Given $D = 80\text{cm} = 80\times10^{-2}\text{m}$ $\qquad d = 0.25\text{mm} = 0.25\times10^{-3}$

$\lambda = 6000A^0\times10^{-10}\text{m}$ $\qquad n = 2$

To find : $(X_2)_B$

We know that, the distance of nth bright band from the central bright band is given by

$$(X_n)_B = \frac{nD\lambda}{d} \qquad \text{For } n = 2 \qquad X_2 = \frac{2\times80\times10^{-2}\times6000\times10^{-10}}{0.25\times10^{-3}}$$

$$X_2 = 32\times1200\times10^8 \qquad X_2 = 3.84\times10^{-3} \qquad \therefore\ \boxed{X_2 = 3.84\text{mm}}$$

Methods for Obrtaining Coherent Sources :

In Young's double slit experiment, we obtained two coherent sources by making the light from a single source pass through two narow slits. There are other ways to get two coherent sourcs.

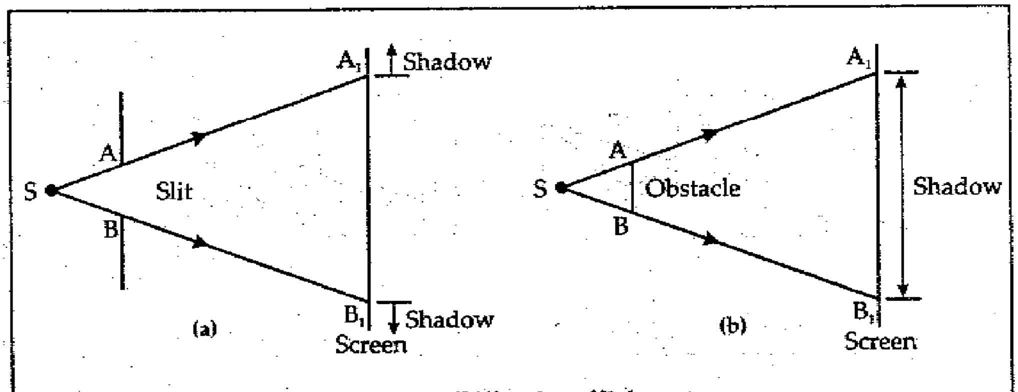
Q. What are coherent sources ? How they are obtained.

Ans : Coherent Source : Two sources having constant phase difference OR inphase at all the time are called as coherent sources.

Coherent sources are derived from single sources.

1. In Young's experiment coherent sources are obtained by two slit in the form of sources.In Young's experiment coherent sources are real.
2. In biprism experiment virtual images of the slit from the coherent sources. In this case coherent sources are virtual coherent sources.
3. **Lloyd's mirror :** This is an extensively used device. The light from a sources is made to fall at a grazing angle on a plane mirror as shown . Some of the light falls directly on the screen as shown by the blue lines in the figure and some light falls after rerlection, as shown by red lines. The reflected light appears to come from a virtual source and so we get two sources. They are derived from a single source and hence are coherent. They interfere and an interference patern is obrtained as shown in the figure. Note that even through we have shown the direct and reflected rays by blue and red lines, the light is monochromatic having a single wavelength.

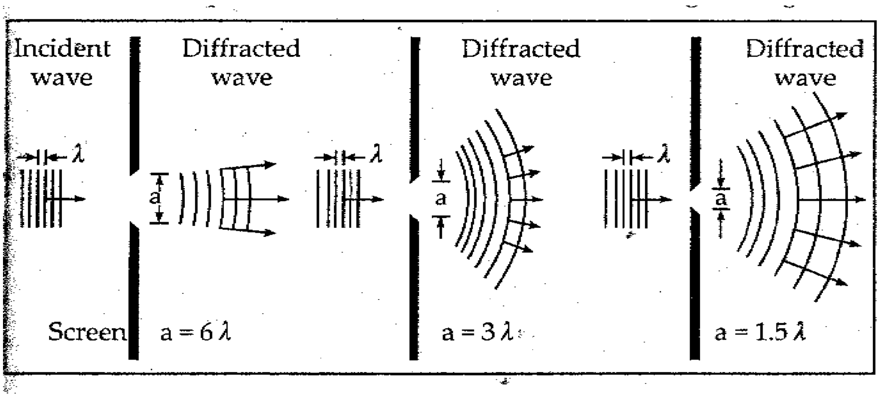
DIFFRACTION



Diffraction of light

Light propagate in the form of waves and they travels in a straight line. If slit AB is placed in the path of light then it produces illumination on screen in region A_1B_1. On either side of A_1B_1 there is geometrical shadow as shown in figure. **The light does not enters in shadow region.**

If an obstacle is placed in the path of light then it produces geometrical shadow in the region A_1B_1 as shown in figure. **The light does not enters in shadow region.** The phenomenon of light which is explained above is possible only when the size of slit or obstacle is large.



If the size of slit or obstacle is **very small and it is comparable to the wavelength of light then light enters in shadow region**. It bend round the corners of slit or obstacle. This phenomenon of light is called as **diffraction of light.**

The phenomenon of light bending around a sharp corners of small object and spread into shadow region is called as diffraction of light.

The phenomenon of diffraction occurs in all types of waves.

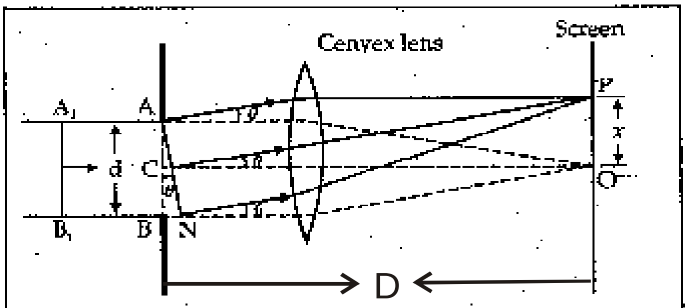
Diffractionof light is classified into two groups such as.

1. Fresnel diffraction

2. Fraunhofer diffraction

In Fresnel diffraction, the source of light is close to he narrow slit. It means that a spherical wave front or cylindrical wave front is used to obtain diffraction pattern. In Fraunhofer diffraction, the source of light is at infinite distance from narrow slit. It means that a plane wave front is used to obtain the diffraction pattern. The diffraction pattern is obtain by using convex lens.

Fraunhofer diffraction due to single slit :



Diffraction due to single slit

Suppose a parallel beam of monochromatic light of wavelength λ is incident normally upon a narrow slit AB of width d which is kept perpendicular to the plane of paper. Suppose the diffracted light is focused by a convex lens L on the screen which is kept in the focal plane of the lens.

According to Huygens's principle each and every point on the AB is a source of secondary disturbance. Let C be the centre of the slit. The secondary waves travelling in the direction parallel to CO come to focus at O and bright central image is observed. The secondary waves from points quidistant from C and situated in the upper and lower halves CA and CB of the slit travel the same distance in reaching O and hence the path difference is zero because all secondary waves meet at O are in same phase. The secondary waves reinforce one another and O will be a point of maximum intensity. It is called **central maximum** and it is the brightest band in diffraction pattern.

Draw perpendicular AN as shown in figure.

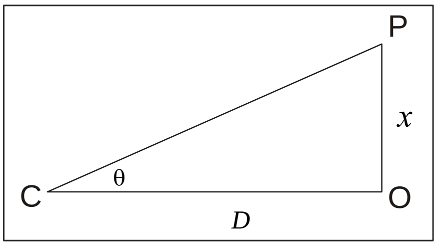
The path difference between secondary waves from A and B to reach point P is BN.

$\therefore$ In Δ ABN.

Sin $\theta = \dfrac{BN}{AB}$

$\therefore$ BN = AB sin θ

path difference = d sin θ .... (I)



From figure

Sin $\theta = \dfrac{x}{D}$

As θ is small $\therefore$ sin $\theta \approx \theta$

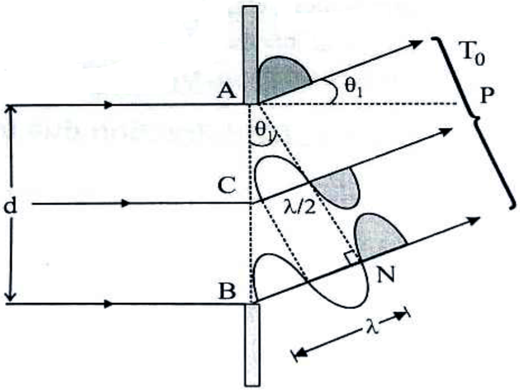
$\therefore \theta = \dfrac{x}{D}$ $\quad \dfrac{x}{D} = \dfrac{\lambda}{d}$ ......(2)

putting this value in equation (1) we get

$\therefore$ path diff. = $\dfrac{x\,d}{D}$ .... (3)

Note : Focal length (f) of the lens is approximately equal to the distance (D) of the slit from the screen.

Hence path diff. = $\dfrac{xd}{f}$



Secondary minima :

The point P in diffraction pattern will be dark or minima if the path difference between secondary waves to reach point P is λ.

i.e. d sin $\theta = \lambda$ or in general dsin θ_n = nλ

$\therefore \dfrac{x\,d}{D} = \lambda$

Hence $\dfrac{x}{D} = \dfrac{\lambda}{d}$ | From 2 | $\theta = \dfrac{\lambda}{d}$ angular separation of first secondary minima

To explain this, assume that the wave front is divided into two equal parts AC and CB. As the path difference between secondary waves from A and B to reach point P is λ , therefore path difference between secondary waves from A and C to reach point P is λ/2 and from C and B is also λ/2. Thus each pair of waves from AC and CB reaches out of phase at point P. Hence point P is dark i.e. **first secondary minima.**

Similarly for **second secondary minima**

i.e. d sin $\theta = 2\lambda$

$\therefore \dfrac{x\,d}{D} = 2\lambda$

In this way for n[th] secondary minima

path diff. = nλ

d sin θ_n = nλ $\quad \theta_n$ - direction of nth order minima n = 1,2,3.....

$\frac{xd}{D} = n\lambda$ 1st Secondary minima n = 1 ......(4)

where n = 1,2,3, ... $\frac{xd}{D} = \lambda$ | $x = \frac{D\lambda}{d}$ | $x_n = \frac{n D \lambda}{d}$

Position of Secondary maxima :

If path difference = d sin θ is an odd multiple of λ /2 then constructive interference (bright point) takes place at point p. Hence point p is the position of secondary maxima.

Similarly for nth secondary maxima

Path diff. = (n+1/2) λ

$$d \sin \theta_n = (2n+1)\frac{\lambda}{2}$$

n = 1,2,3....

$$\text{Path diff.} = (2n+1)\frac{\lambda}{2}$$

where n = 1,2,3....

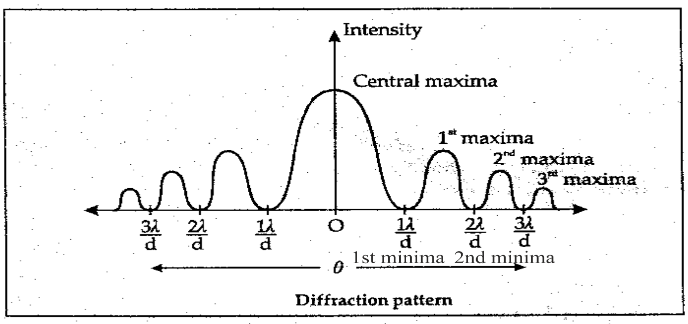
1st Secondary maxima

n = 1 | $\frac{xd}{D} = (2+1)\frac{\lambda}{2}$

$\frac{xd}{D} = \frac{3}{2}\lambda$ $\therefore x = \frac{3}{2}\frac{D\lambda}{d}$

The diffraction pattern due to a single slit consists of a central bright maximum at O followed by alternate secondary minima and maxima on both sides of O.

Width of central maxima :



The width of central maxima is the distance between first secondary minima on either side of point O. For first minima at onc side of point O

$$x_1 = \frac{\lambda D}{d}$$

$\therefore$ (Width of central maxima) $= x_1 + x_1$

$$\beta_0 = 2x_1$$

$$\boxed{\beta_0 = 2\frac{\lambda D}{d}} = \frac{2\lambda f}{d} \qquad \beta_0 = 2\beta$$

Thus the width of central maxima is twice the width of secondary maxima or minima.

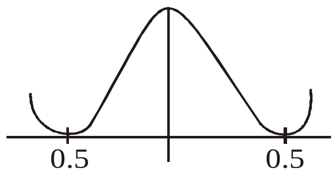
Example No. : 8

In Fraunhofer difraction due to a narrow slit, a screen is placed 2 m away from the lens to obtain the pattern. If The slit width is 0.2 mm and the first minimum is 5 mm on either side of the central maximum. Find the wavelength of light.

Soln : Given = D = 2m d = 0.2 mm = 2×10^{-3}m $x = 5\text{mm} = 5\times10^{-3}$m

To find : wavelength (λ)

Width of central maxima = $\frac{2D\lambda}{d} = \frac{2\times2\times\lambda}{0.2\times10^{-3}}$



$\lambda = 5000A^0$

Limit of Resolution & Resolving power

The ability of an optical insrument to produce separate images of two objects which are very close to each other is called as resolving power of that instrument.

Each optical instrument has certain limit to form the separate images of two objects placed very close to each other. That certain limit is called as limit of resolution.

The minimum distance between two objects so that they can be seen separately through an optical instrument is called as limit of resolution of that instrument.

If limit of resolution is small then the resolving power of that instrument is large.

The resolving power of an optical instrument is the reciprocal of limit of resolution

$\therefore$ Resolving power = $\frac{1}{\text{Limit of resolution}}$

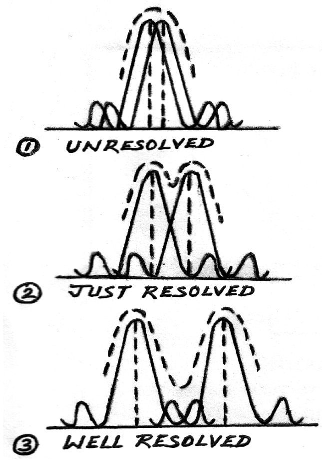
Rayleigh's Criterion :

If two point objects are very close to each other then their diffraction patterns are close to each other and they overlap on each other. If the overlapping is small then both objects are seen separately from an optical instrument. If the overlapping is large then two objects can not be seen as separate objects through an optical instrument.

Loard Rayleigh's has given the criterion about resolving power of an optical instrument.

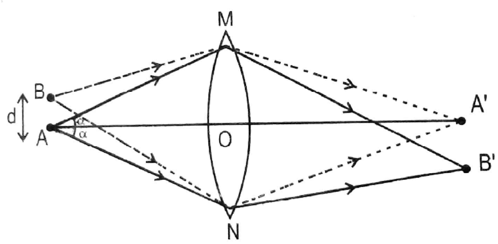
The resolving power of optical instruments like microscope, telescope, prism etc. is based on Rayleigh's criterion. The resolution of images of two close objects depends on the separation between their central maxima of diffraction pattern.

According to Raylegih's criterion, the resolution of two objects can be explained as follows :



1. If the distance between central maxima of two objects is **less than** the distance between central maxima and first minima of diffraction pattern then two objects are not resolved i.e. they are unresolved, as shown in figure (1)
2. If the distance between central maxima of two objects is **nearly equal** to the distance between central maxima and first minima of diffraction pattern then two objects are said to be **just resolved** as shown in figure.(2)
3. If the distance between central maxima of two objects is **greater than** the distance between central maxima and first minima of diffraction pattern then two objects are said to be **completely resolved** or well resolved as shown in figure. (3)

I) Resolving power of microscope :



The reciprocal of the limit of resolution of microscope is called as resolving power of microscope. In case of microscope the object is very close to the objective. Object makes large angle with objective therefore limit of resolution of microscope is determined by minimum linear distance between two objects so that their images appears just resolved.

Consider two point objects A and B which are separated by small distance d. The light from two objects will be scattered and enters in objective (Lens) of microscope. It produces two images A'B'. The limit of resolution of microscope can be given as

$$\boxed{d = \frac{1.22\,\lambda}{2\sin\alpha}} \qquad \text{(I)}$$

Equation I is based on the assumption that the objects A and B are self luminous. But generally, these objects are illuminated with light. It is found that the resolving power depends upon the mode of illumination. According to Abbe, the least distance between two objects so that they are just resolved is given by

$$\boxed{d = \frac{\lambda}{2\sin\alpha}}$$ Objects are illuminated with light.

If μ is the refractive index of medium between object and objective lens of microscope ie. oil immersion objective (lens) is used ie. space between objective and objects is filled with an oil so that resolving power of microscope is increase then $\boxed{d = \lambda / 2\mu\sin\alpha}$

Where λ is the wavelength of light in air or vacuum α be the angle subtended by an object at eye. The resolving power of microscope can be given as

resolving power = $\frac{1}{d}$ R.P. = $\frac{2\mu\sin\alpha}{\lambda}$

In above equation the factor μ sin α is called as **numerical aperture (NA)**

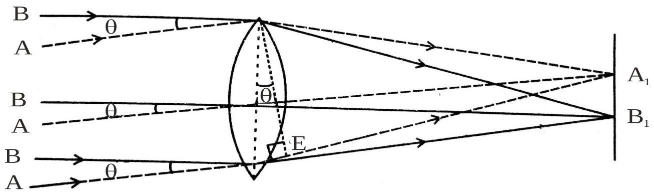
Thus to increase the resolving power of microscope

1. Wavelength of light should be decreased by using medium between object and objective or by using ultraviolet light to illuminate the object.
2. Refractive index (μ) should be increased
3. The angle α should be increased by increasing aperature of lens.

II. Resolving power of telescope :

Telescope is used to see the distant object. In case of telescope the object distance is very large. Therefore the resolving power of telescope can be defined in terms of angular separation instead of linear separation.

Consider two distant objects A and B are observed through telescope. Objective lens of telescope produces two diffracted images A_1 and B_1 at the focal plane which is shown in fig.



The resolving power of telescope is defined as, the reciprocal of minimum angular separation between two distant objects so that their images can be seen separately. OR
The reciprocal of the angular limit of resolution of two distant objects through telescope is called as resolving power.

$$\therefore \text{ Resolving power} = \frac{1}{\text{angular Limit of resolution}} = S = \frac{1}{\theta}$$

In case of telescope the angular limit of resolution can be given as $d\theta = \frac{1.22\,\lambda}{D}$

where λ is the wavelength of light in air and D is the diameter of objective lens of telescope. Now the resolving power of telescope can be given as

resolving power = $\frac{1}{d\theta}$ R.P. = $\frac{D}{1.22\,\lambda}$

From above equation it is clear that the resolving power of telescope can be increased by

i) increasing the diameter of objective lens

ii) by decreasing the wavelength.

Difference between Interference and Diffraction.

	INTERFERENCE		DIFFRACTION
1.	It is produced by light waves from two different wave fronts from two sources.	1.	It is produced by light waves from two different parts of same wave front.
2.	All the fringes in interferences are of same width.	2.	The width of central bright fringe is twice that of secondary fringes.
3.	The intensity of all bright fringes is same	3.	The intensity of bright fringes decreases as the order of fringes increases.
4.	The minima in interference is perfectly dark.	4.	The minima in diffration are not perfectly dark.
5.	In Interference the bright and dark bands are distinct from each other.	5.	In diffraction the bright and dark bands are not well distinct from each other.
6.	Resolving power of optical instruments are not related to interference.	6.	Resolving power of optical instruments are related to diffraction.

Question Bank

1. State the conditions to get constructive and destructive interference of light.
2. State the conditions for obtaining a steady interference pattern.
3. What are coherent sources ? How are they produced ?
4. Explain 'two sources must be equally bright to obtain well defined interference pattern'.
5. What are the monochromatic sources of light ? How are they produced ?
6. Explain need of coherent sources to obtain steady interference of light.
7. Why the two sources of light must be monochromatic sources to obtain steady interference of light ?
8. Explain why the two sources must be narrow and very close to each other to get steady interference of light ?
9. Describe how coherent sources were obtained by Young and Fresnel in their respective experiments.
10. Write the differences between interference of light and diffraction of light.
11. Define diffraction of light. Explain types of diffraction of light.
12. Using analytical method, obtain an expression for path difference between two light waves.

13 Explain the concept of interference of light and state the conditions for constructive and destructive interference of light.

14. Explain in brief Rayleigh's criterion at limiting resolution.
15. Explain in brief resolving power of microscope.
16. Explain in brief resolving power of telescope.

17 Describe young's experiment to observe an interference of light.

18 Give the theory of interference bands and hence obtain an expression for fringewidth.

OR

Give the theory of interference bands and hence show that dark and bright bands are equally spaced.

OR

Give the theory of interference bands and hence show that distance between any two successive bright bands is equal to distance between any two successive dark bands.

OR

Derive an expression for optical path difference between two light waves and hence obtain an expression for fringe width.

Assignment

1. Consider interference between waves from two sources of intensities I and 4I. Find the intensity at a point where phase difference is i) $\frac{\pi}{2}$ ii) π (Ans : 5I - 4I = I)
2. Two slits in Young's experiment have widths in the ratio 81:1. What is the ratio of the amplitudes of light waves coming from them? (Ans : 9:1)
3. Two coherent sources, whose intensity ratio is 81:1 produce interference fringes. Calculate the ratio of intensity of maxima and minima in the fring system. (Ans : 25:16)
4. In Biprism experiment, slit is illuminated by red light of wavelength 6400 Au and cross wire in eyepiece is adjusted to be at centre of 3rd bright band by using blue light, 4th bright band is at centre of cross wire. Find wavelength of blue light. (Ans : $\lambda_B = 4800 Au$)

5. In biprism experiment a slit is illuminated by a light of wavelength 4800 Au. The distance between slit and biprism is 20 cm and the distance between biprism and eyepiece is 80 cm. If the distance between virtual sources is 0.30 cm determine the distance between 5th bright band on one side and 5th dark band on the other side of central band.

(Ans : $(X_5)_B + (X_5)_D = 1.52\ mm$)

6. State the factors on which resolving power of microscope depends how can it be increased? **(Feb 2020)**

7. In a biprism experiment. light of wavelength 5200Å is used to obtain an interference pattern on the screen. The frigewidth changes. by 1.3 mm when the screen is moved towards the biprism by 50 cm. Calculate the distance between the two virtual images of the slit. **(Feb 2020)**

8. In Young's experiment interference bands were produced on a screen placed at 150 cm from two slits, 0.15 mm apart and illuminated by the light of wavelength 6500 A^0. Calculate the fringe width. **(Feb 2019)**

9. Monochromatic light of wavelength 4300 A^0 falls on a slit of width 'a'. For what value of 'a' the first maximum falls at 30^0? **(Feb 2019)**

10. Two coherent sources of light having intensity ratio 81 : 1 produce interference fringes. Calculate the ratio of intensities at the maxima and minima in the interference pattern. **(Feb 2019)**

11. In a biprism experiment light of wavelength 5200Å is used to get an interference pattern on the screen. The fringe width changes by 1.3 mm when the screen is moved towards biprism by 50 cm. Find the distance between is moved towards biprism by 50 cm. Find the distance between two virtual images of the slit. (Ans : $2\times10^{-4} M$) **(Feb 2018)**

12. In biprism experiment, 10th dark band is observed at 2.09 mm from the central bright opint on the screen with red light of wavelength 6400 $\overset{0}{A}$. By how much will fringe width change if blue light of wavelength 4800 $\overset{0}{A}$ is used with the same setting ? (Ans : 0.055 mm) **(March 2016)**

13. In a biprism experiment, when a convex lens was placed between the biprism and eyepiece at a distance of 30cm from the slit, the virtual images of the slits are found to be separated by 7 mm. If the distance between the slit and biprism is 10 cm and between the biprism and eyepiece is 80 cm, find the linear magnificatin of the image. (Ans = 2) (**October - 2015)**

14. In a single slit diffraction pattern, the distance between first minima on the right side and first minima on the left of central maximum is 4 mm. The screen on which pattern is displaced, is 2 m from the slit and wavelength of light used is 6000Å Calculate width of the slit and width of central maximum. (Ans : 4×10^{-3}m) (**October - 2015)**

15. In a biprism experiment, a slit is illuminated by a light of wavelength 4800 Å. The distance between the slit and biprism is 15 cm and the distance between the biprism and eyepiece is 85 cm. If the distance between virtual sources is 3 mm, determine the distance between 4 th bright band on one side and 4th dark band on the other side of the central bright band
(Ans : $12\times10^{-4} m$) **(Oct. 2014)**

16. A red light of wavelength 6400Å in air has wavelength 4000Å in glass. If the wavelength of violet light in air is 4400Å. find its wavelength in glass (SAssume that $\mu_r \approx \mu_v$)
(Ans : $\lambda_{g(\upsilon)}$ = 2750 Å) **(Oct. 2014)**

Multiple Choise Questions

1. In a biprism experiment with yellow light $(\lambda = 590\,\text{nm})$ 55 fringes are obtained in the given region. The number of fringes obtained in same region with green light $(\lambda = 550\,\text{nm})$

   a) 55 b) 50 c) 60 d) 59

2. When interference fringes are obtained, the distance between 10th bright band on one side and 6th bright band on other side of bright band is

   a) 4 times band width b) 8 times band width
   c) 16 times band width d) 32 times band width

3. In biprism experiment, the slit is illuminated by light of wavelength $5000\,\text{Å}$. The number of fringes passing on the screen if path differnce is changed by 0.005 cm will be

   a) 60 fringes b) 80 fringes c) 100 fringes d) 120 fringes

4. In the interference pattern, energy is :

   a) Destroyed at the positions of minima b) Created at the position of maxima
   c) Conserved but redistributed d) Not conserved

5. In Young's experiment 4th bright band with wavelength λ_1 coincides with 5th dark band with wavelength λ_2, the ratio λ_1/λ_2 is equal to :

   a) 8/9 b) 5/4 c) 4/5 d) 9/8

6. The relation between phase differnce $(\delta\phi)$ and path difference (δx) is :

   a) $\delta\phi = \frac{2\pi}{\lambda}\delta x$ b) $\delta\phi = \frac{2\pi\lambda}{\delta x}$ c) $\delta\phi = 2\pi\lambda\delta_x$ d) $\delta\phi = \frac{\pi\delta_x}{\lambda}$

7. In Young experiment, the wavelength of light used is 632 nm, the first interference minima will occur at a path difference of :

   a) 1264 nm b) 632 nm c) 316 nm d) 158 nm

8. In Young Experiment keeping the distance of the slit from screen constant and if slit width is reduced to half :

   a)The fringe width will be doubled b)The fringe width will be reduced to half
   c) The fringe width will be not change d) The fringe width will be becomes four times

9. Fringe width in Young experiment is X. If the frequency of light used is halved then the fringe width will become.

   a) x b) x/2 c) 2x d) x/4

10. In a Biprism experiment the bandwidth is found to be increased by 25% of initial when the distance between slit and focal plane of eyepiece is increased by 20cm. The original distance between slit and eyepiece will be :

    a) 60 cm b) 80 cm c) 100 cm d) 120 cm

11. Interference of light is a proof of

a) wave nature of light b) particle nature of light

c) transverse nature of light d) longitudinal nature of light

12. If the distance between source and screen is halved then band width will

a) 2 x b) 3 x c) 4 x d) 0.5 x

13. The firnge separation is 3.2 mm for red light of wavelength 6400 $\mathring{A}$ The fringe separation for blue light of 4000 A.U. will be

a) 0.2 mm b) 2.5 mm c) 2 mm d) 3 mm

14. Band width in interference pattern is 1.2 mm. The distance of 4th bright band from centre of interference is

a) 2.4 mm b) 0.6 mm c) 4.8 mm d) 3.6 mm

15. In interference, n^{th} bright band of wavelength 6500 A.U. coincides with $(n+1)^{th}$ bright band of wavelength 5200 A.U. The number of that band is ....

a) 2 b) 3 c) 4 d) 5

16. Optical path difference between two identical waves meeting at a point is 5.7×10^{-6} m. Which of the following wavelength will give dark point ?

a) 3000 A.U. b) 5700 A.U. c) 6000 A.U. d) 600 A.U.

17. To obtain sharp and clear interference pattern the ratio of intensities of two sources must be

a) 1 : 1 b) 1 : 4 c) 16 : 1 d) 25 : 4

18. Path difference between two interfering light waves meeting at a point on screen is $\frac{175}{2}\lambda$. The band obtained at the point is

a) 88^{th} bright band b) 175^{th} dark band c) 88^{th} dark band d) 175^{th} bright band

19. The distance of 10^{th} dark band from central bright band is 9.5 mm. The fringe separation will be

a) 1 mm b) 1.2 mm c) 1.4 mm d) 1.8 mm

20. The first diffraction minima due to single slit diffraction is at $\theta = 30^0$ for a light of wavelength 5×10^{-7} m. The width of slit is

a) 10^{-2} cm b) 10^{-4} cm c) 10^{-6} cm d) 10^{-1} cm

21. In the diffraction pattern, intensity of secondary maxima is

a) more than central maxima b) less than central maxima

c) equal to central maxima d) zero

22. About central maxima in diffraction pattern, correct statements are

a) width of central maxima is proportional to wavelength

b) width of central maxima decreases

c) both a and b are correct

d) neither or nor b are correct

23. A diffraction pattern is obtained using red light. Which of the following happens if the red light is replaced by blue light ?
a) There is no change
b) Diffraction bands become narrow and crowded
c) Diffraction bands become broader and farther
d) Bands disappear

24. The width of diffraction fringes varies :
a) Directly as the distance between slit and the screen
b) Inversely as the wavelength
c) Direct;y as the width of the slit
d) Independent of distance between slit and the screen

25. When light of wavelengths λ_1 and λ_2 $(\lambda_1 > \lambda_2)$ are used one by one in telescope, resolving power is
a) higher for light of wavelength λ_1
b) higher for light of wavelength λ_2
c) equal for both wavelengths λ_1 and λ_2
d) either 'a' or 'c'

26. The numberical aperature of microscope with transparent liquid between object and objective is 1.0. If light of wavelengths 6000A^0 is used the limit of resolution is
a) 3×10^{-5} m
b) 3×10^{-9} m
c) 3×10^{-7} m
d) 3×10^{9} m