Interference - Thomas Young demonstrated the concept of Interference of light in 1802 itself. Interference is based on principle of superposition of waves.

principle of superposition of waves :- When two or more waves travels simultaneously in a medium, the resultant displacement at any point is due to the algebric sum of the displacements due to individual waves.

Let us consider two waves travelling simultaneously in a medium.

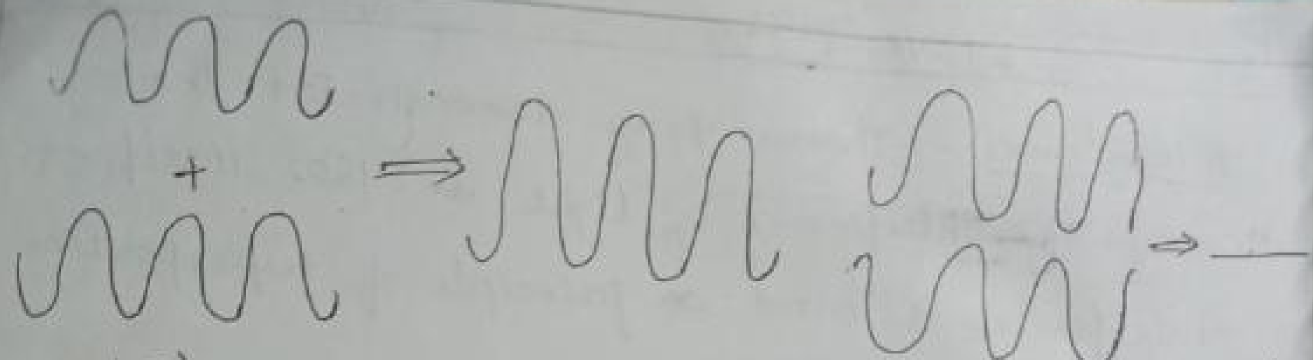
At any point, y_1 be the displacement due to one wave at any instant, in the absence of the other.

y_2 be the displacement of the other wave at the same instant in the absence of the first wave.

The resultant displacement due to presence of both waves are $y = y_1 \pm y_2$

+ve sign has to be taken when both the displacements y_1 and y_2 are in same direction.

-ve sign has to be taken, when they are in opposite direction as shown in fig



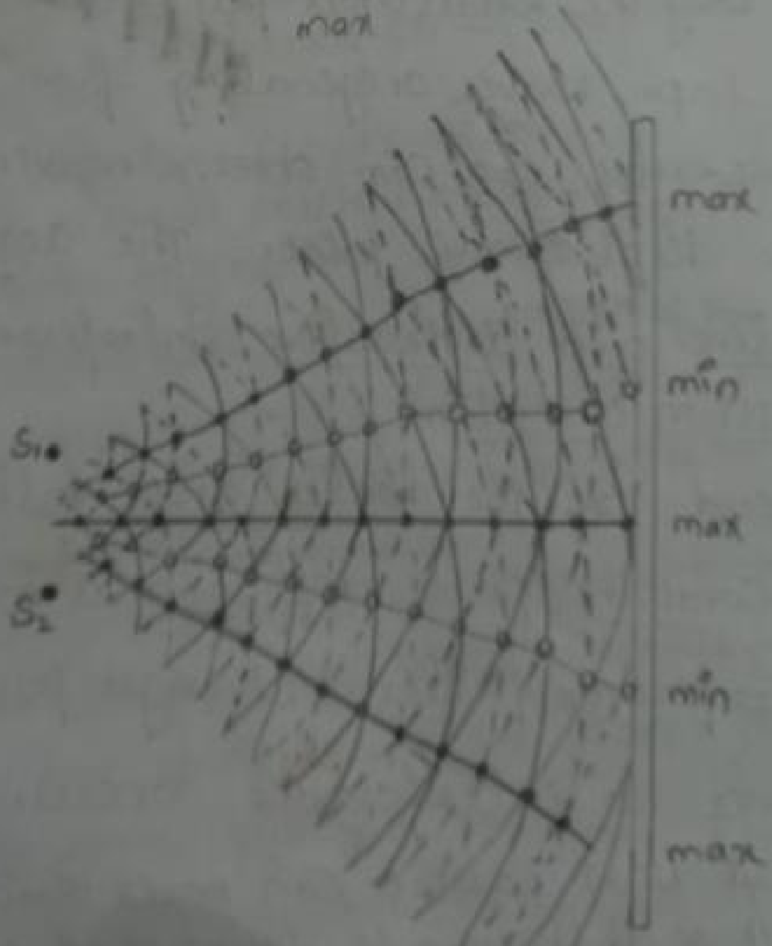
1(a) waves in phase.   1(b) waves out of phase

To Under stand the phenomenon of interference, Let us consider the waves produced on the surface of water. Let us consider a wide water tank with two water taps A and B above it. Let us adjust the water taps so as to make the water drops to fall from both the taps simultaneously. The points S_1 and S_2 on the water surface where the drops fall act as two sources of waves. If the water drops are of same mass and fall from same height waves of Equal Amplitude spreading out as Expanding circular wave-fronts from S_1 and S_2. In the too regions where both the waves superpose, we have to apply the principle of superposition to find the resultant displacement as shown in the fig.

The waves are shown by continuous curves as well as dotted curves to represent crests and troughs respectively.

The points shown by dots in the figure have the resultant displacement maximum. Since either crests or troughs superpose. If we assume 'a' as the amplitude of each wave then the resultant displacement is given by

$$y = a + a = 2a$$



As the Intensity is directly proportional to the square of the amplitude ($I \propto A^2$), the intensity at these points is four times the intensity due to one wave (i.e, $4a^2$). This means that at those points waves reinforce with each other and produce constructive Interference. At the points shown by circles in figure; the crests superpose with troughs resulting in resultant displacement zero.

$$i.e., \; y = a - a = 0.$$

The points of destructive Interference, the intensity is zero.

** ⟹ So long the water drops fall simultaneously from both the taps, waves originating from S_1 and S_2 simultaneously, one can observe maximum and minimum displacement points. The regions of constructive and destructive Interference do not change with position and time.

⟹ Instead if the water drops fall randomly i.e., the constant phase difference is not maintained, the Interference pattern changes position and time and hence no interference occurs. Since two independent light sources can never emit waves with constant phase difference so Young used a single lamp to derive two sources of light waves to Explain Interference

②

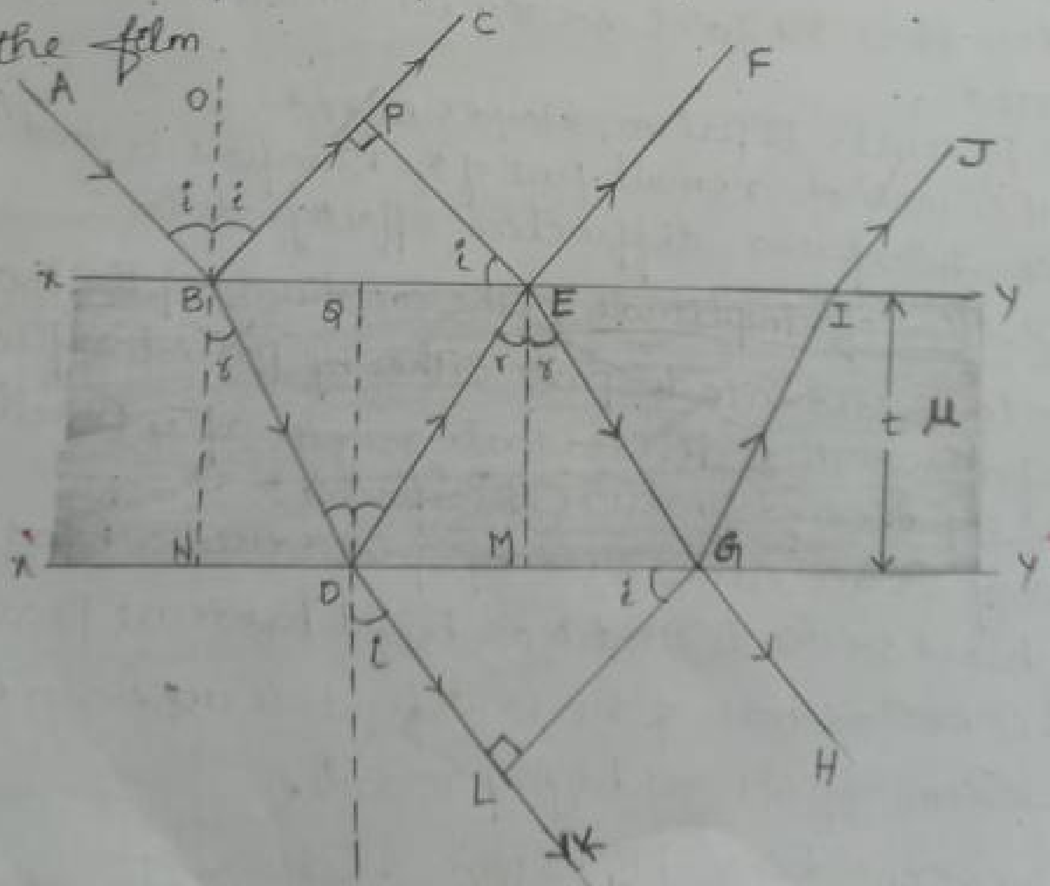
Condition for Sustained Interference:-

(i) Coherent sources:- The two Interfering sources must Emit waves having a Constant phase difference b/w them. If the phase difference b/w two sources does not remain constant then the places of maximum and minimum intensities shift continuously and sustained Interference is not possible.

2) Same frequency (or) wavelength and Equality of amplitudes:- The two Interfering sources should emit light of same frequency (or) wave length. If it is not so, the resultant Intensity at any point will be maximum and minimum like beats in sound.
The amplitudes of the two Interfering waves should be equal (or) approximately equal then $I_{max} = (a_1+a_2)^2$, $I_{min} = (a_1-a_2)^2$. If the (a_1-a_2) is more than I is less.

⇒ Interference in thin films (Reflected light):-

In thin films Interference is due to superposition of light reflected from the top and bottom surfaces of the film



Reflected and Refracted rays in thin films.

Let us consider a thin film of thickness 't' bound by two plane surfaces XY and X'Y' and let 'μ' be the refractive index of the material of the film. A ray of light AB incident on the surface XY at an angle 'i' is partly reflected along BC and partly refracted along BD. Let the angle of refraction be r. On the surface X'Y', the refracted ray is partly reflected along DE and partly refracted (transmitted) along DK. Similarly the reflection and refraction occur at E & G as shown in fig.

The rays BC and EF constitute reflected system. To find the path difference b/w these reflected rays EP is drawn $\perp^r$ to BC.

$$\text{path difference} = (BD + DE)\mu - BP.$$

In $\triangle BDQ$, $\cos r = \frac{DQ}{BD} = t/BD$

$$\text{or } BD = \frac{t}{\cos r} = DE$$

$$\text{Hence path difference} = \frac{2\mu t}{\cos r} - BP$$

In $\triangle$le BPE, $\sin i = \frac{BP}{BE}$

(or) $BP = BE \sin i = (BQ + QE)\sin i$

In $\triangle BDQ$, $\tan r = \frac{BQ}{QD}$

$$\text{or } BQ = t\tan r = QE.$$

or $BP = 2t \tan r \sin i$

$$= 2t \frac{\sin r}{\cos r} \mu \sin r \quad \left(\because \mu = \frac{\sin i}{\sin r} \right)$$

Substituting in path difference

$$\text{path difference} = \frac{2\mu t}{\cos r} - 2\mu t \frac{\sin^2 r}{\cos r}$$

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

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

Since the ray BC is reflected at the air medium (rarer - denser) interface, it undergoes a phase change of π (or) path difference of $\lambda/2$. Hence the path difference b/w the ray BC and EP is

$$= 2\mu t \cos r - \lambda/2$$

(i) <u>Condition for bright band</u> :-

The film will appear bright if the path difference

$$2\mu t \cos r - \lambda/2 = n\lambda.$$

$$\text{(or) } 2\mu t \cos r = (2n+1)\lambda/2.$$

where $n = 0, 1, 2, 3 \dots$ etc.

(ii) <u>Condition for dark Band</u> :-

The film will appear dark if the path difference

$$2\mu t \cos r - \lambda/2 = (2n+1)\lambda/2.$$

$$2\mu t \cos r = (n+1)\lambda.$$

where $n = 0, 1, 2, 3 \ldots$ etc.

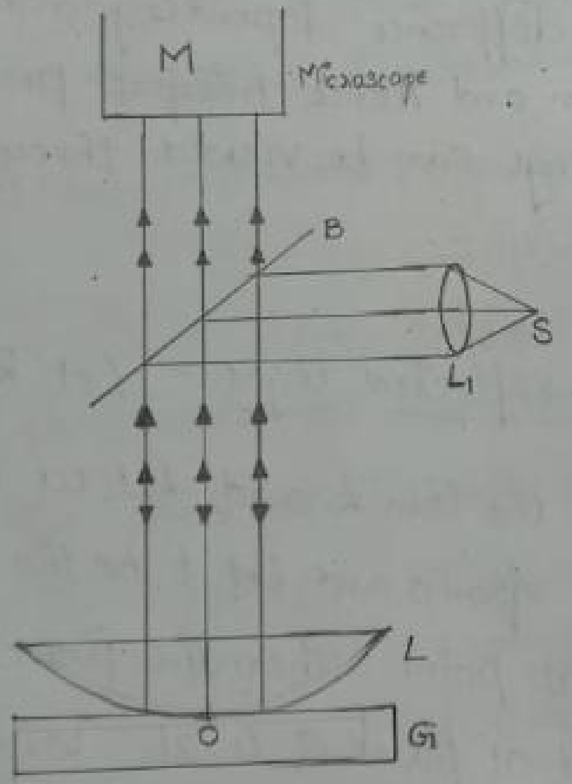
or $2\mu t \cos r = n\lambda$.

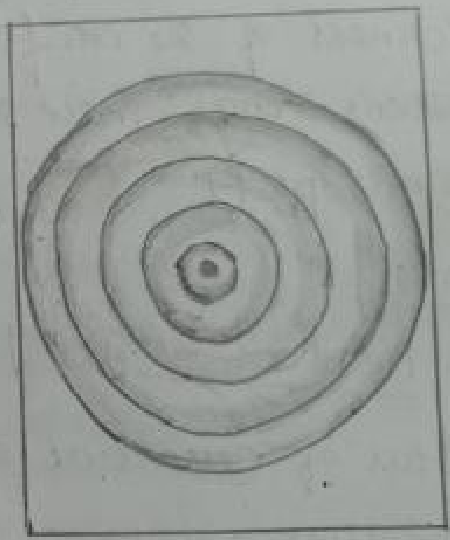
where $n = 1, 2, 3 \ldots$ etc.

(iii) If the film thickness is extremely small, when compared to λ, then $2\mu t \cos r$ can be neglected then the net path difference is $\lambda/2$. Hence destructive interference will occur and the film will appear dark.

⇒ Newton's Rings:-

Experimental arrangement:-





The Experimental arrangement for obtaining Newton's Rings is as shown in figure.

'L' is a plano convex lens of larger radius of curvature placed on an optically plane glass plate G.

The lens touches the glass plate at O. S is a mono-chromatic source of light and lens L_1 collimates the light from source S. The collimated horizontal beam of light falls on a glass plate B held at 45° inclination. The glass plate B reflects part of the light incident on it towards the air film enclosed b/w the lens L and the glass plate G. part of the light incident on the lens L is reflected back by the curved surface of the lens L and the other part transmitted & partly reflected back by the upper surface of the glass plate G. These two reflected beams have some path difference depending on the thickness of the air film and hence interfere producing Newton's ring. These rings can be viewed through a microscope M.

Theory :-

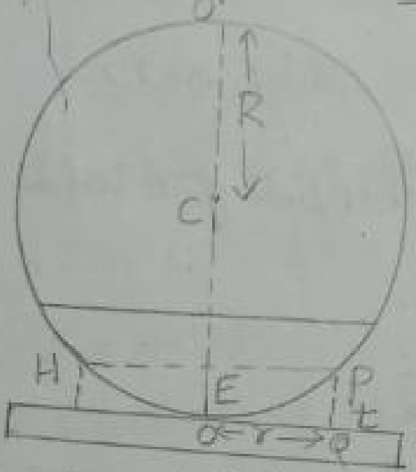
(i) Newton's rings by reflected light :- Let R be the radius of curvature of the lens L and let us choose a point P at a distance r from O and let t be the thick-ness of air film at that point. Then the path difference b/w the light reflected at P and Q is 2t. When the additional path difference due to reflection at Q is taken into account path difference b/w the two reflected beams becomes $2t + \lambda/2$. from Interference in thin films $2\mu t \cos r \pm \lambda/2 = n\lambda$ where $\mu = t$ and $r = 0$ then

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

When this path difference is $n\lambda$, constructive interference occurs. Hence the condition for bright rings is

$$2t + \lambda/2 = n\lambda. \quad \text{---} (1)$$

$$\text{(or) } 2t = (2n-1)\lambda/2 \quad \text{where } n = 1,2,3 \ldots \text{etc} \quad \text{---} (2)$$



Calculation of film thickness in terms of radius of curvature

Similarly for dark ring condition is

$$2t + \lambda/2 = (2n+1)\lambda/2. \quad \text{---} (3)$$

$$\text{i.e., } 2t = n\lambda \quad \text{---} (4)$$

Let us consider the curved surface of the lens as an arc of a circle whose centre is at C.

$$HE \times EP = OE \times EO'$$

$$\text{i.e., } r^2 = t(OO' - EO)$$

$$= t(2R - t) = 2Rt - t^2.$$

$$r^2 = 2Rt$$

$$\text{Hence } t = \frac{r^2}{2R}. \quad \text{---} (5)$$

Substituting 't' value in (2)

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

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

$$\therefore r = \sqrt{\frac{2(n-1)\lambda R}{2}}$$ where $n = 1,2,3 \ldots$ etc.

for dark rings. substituting 't' value in (4)

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

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

$$\therefore r = \sqrt{n\lambda R}$$ where $n = 0,1,2,3 \ldots$ etc.

for $n = 0$, the radius of the ring is zero which denotes the centre O. Since the lens touches the glassplate at O, the thickness of air film is zero, though at the point of contact the thickness of air is zero, the ray reflected at the air-glass interface undergoing additional phase change π (or) path change of $\frac{\lambda}{2}$. Hence it appears dark.

Determination of wavelength of Sodium light using Newton's Rings:- If the radius of curvature of lens (R) is known and by measuring the radii of the rings formed (r), we can calculate the wave length

Theory:-

Let R be the radius of curvature, λ is the wave-
- length of light used

Then the radius of n^{th} dark ring r is given by

$$r_n = \sqrt{nR\lambda}.$$

and the diameter of n^{th} dark ring is

$$D_n = 2r_n = 2\sqrt{nR\lambda} = \sqrt{4n\lambda R} \quad \text{--- (1)}$$

$$D_n^2 = 4n\lambda R.$$

Ill'ly the Diameter of $(n+m)^{th}$ dark ring is

$$D_{n+m} = 2r_{n+m} = \sqrt{4(n+m)R\lambda}$$

$$\therefore D_{n+m}^2 = 4(n+m)R\lambda. \quad \text{--- (2)}$$

Subtracting (1) from (2)

$$D_{n+m}^2 - D_n^2 = 4mR\lambda.$$

$$\boxed{\lambda = \frac{D_{n+m}^2 - D_n^2}{4mR}.}$$

If we know the wavelength λ of the given monochromatic source, then we can calculate the radius of curvature of light R.

Experimental Procedure:- Microscope is adjusted and focussed to see the dark spot at the centre of the rings sharply adjusted cross wire is made to coincide with the centre.

While the microscope is moved horizontally, the vertical cross wire has to touch the dark rings tangentially and horizontal cross wire pass through the centre of the spot. We have to measure the diameters of rings of different orders to determine the wavelength of the light used. Then by counting the rings the cross wire is moved to $(n+30^{th})$ ring very slowly and carefully. Then the cross wire is moved back to $(n+25^{th})$ and corresponding reading is taken on the horizontal scale. Like wire is moved in steps of 5 rings and corresponding readings are taken and entered in to the tabular coloumn. After taking the reading for n^{th} ring,

Order of the ring	Micrometer Reading						Diameter D	D^2	$D^2_{n+m}-D^2_n$
	Left			Right					
	MSR	VC	T.R	MSR	VC	T.R			
n+30									
n+25									
n+20									
n+15									
n+10									
n+5									

on the left side, the cross wire is moved to corresponding nth ring on right side. On the right hand side for n^{th} $(n+5)$, $(n+10)$, $(n+15)$ .. $(n+30)^{th}$ ring readings are Entered in the tabular coloumn.

If we consider $m=15$, then we have to calcute.

the difference of $D_{30}^2 - D_{15}^2$ and substitute in the formula then

$$\lambda = \frac{D_{n+15}^2 - D_n^2}{4 \times 15 \times R} = \frac{D_{n+15}^2 - D_n^2}{60R}.$$

Substituting the value of R which can be measured using any standard wavelength λ of the mono-chromatic source.

Diffraction

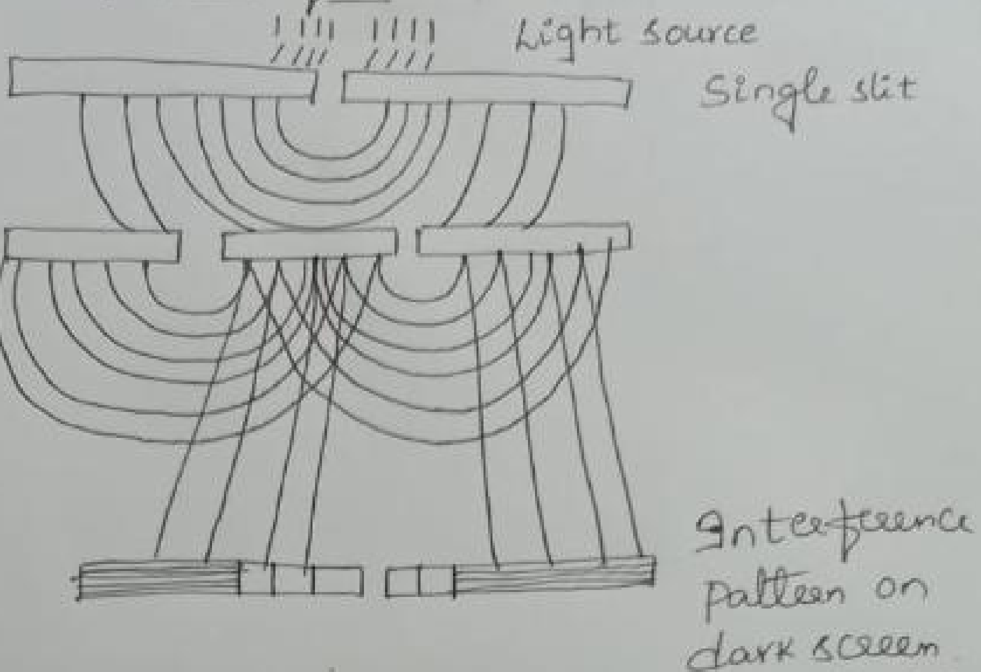
Definition:- The phenomenon of bending of light round the corners of an obstacles and spreading of light waves into geometrical shadow region of an obstacle placed in the path of light is called Diffraction

The Important condition for diffraction is the size of the obstacle must match with the wavelength of light.

Diffraction depends on Huygen's wave Theory principle

According to Huygen's wave theory, Every point on the primary wavefront acts as second source of disturbance and secondary waves are generated from those points.

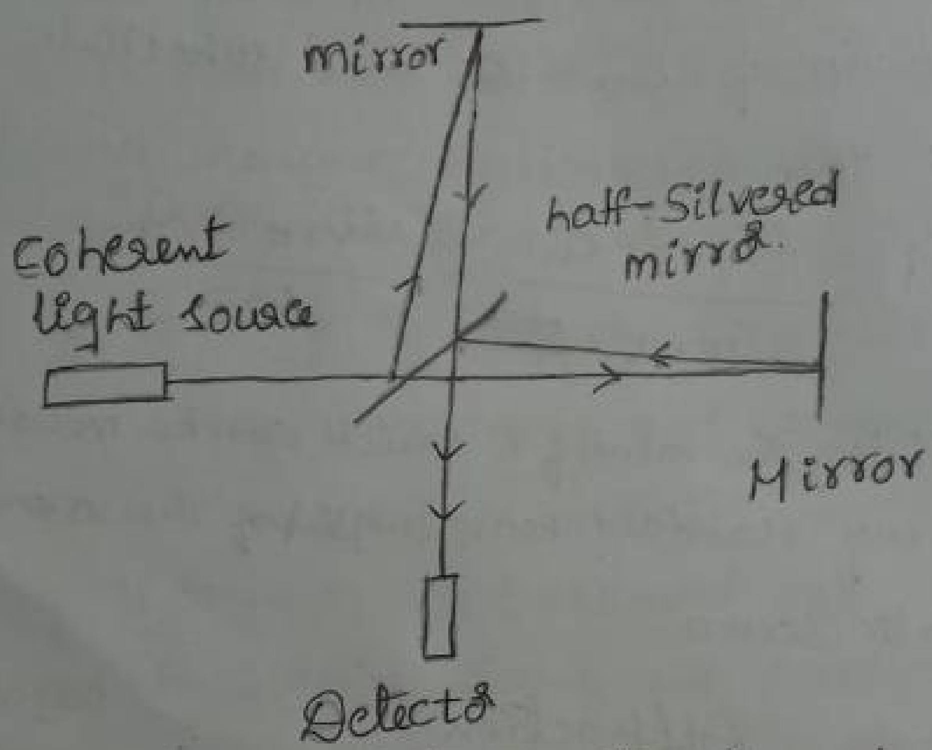
Division of wave front:-



Young's double slit Experment :- Example for wave front divesion. Two coherent waves are obtained by dividing the wavefront, origina-ting from a common source. This is done by use of mirrors, biprisms (or) lenses. This class Interference requires esentially a point source (or) a narrow slit source.

The Instruments used to obtain Interference by division of wave front are the Young's double slit Experiment, Fresnel biprism, Fresnel mirrors, Llyod's mirror etc. Here diffraction effects highly reduced.

Division of Amplitude:-



Michelson's Interferometer - Example for amplitude division, Newton's Rings Experiment.

Two coherent waves are obtained by dividing the amplitude of a beam originating from a common source. This is done either by partial reflection (or) refraction. These coherent beams travel different paths and are then brought to gether to produce Interference.

The Interference in thinfilms, Newton's rings. and Mechelson's Interferometer are Examples of Interference due to diviscon of Amplitude.

→ <u>Colours of Thin films</u>:- When a thin film is Exposed to a white light such as sunlight, beautiful colours appear in the reflected light. Let us see the Examples of soap bubble and thin oil layer.

In the case of soap bubble, let us assume the thickness of the film 't' is a constant. Then in formula, $2\mu t \cos r$, μ and 'r' are variables since white light has varying λ value, μ also varies with λ. Also due to curved nature of bubble, even if ||el rays are incident, Angle of Incidence varies for different points on the bubble and hence angle of refraction 'r' also varies.

Hence $2\mu t \cos r = (2n+1)\frac{\lambda}{2}$ varying the values of μ and 'r' can satisfy the condition for constructive Interference for a particular wave length 'λ' only. So the point will appear as bright in that particular colour.

In a similar way different points satisfy the condition for constructive Interference for different colours and hence appeared multi-different colours.

Now Incase of thin layer of oil film floating on water, then the film is flat, when ||el rays such as sunlight is Incident, the angle of Incidence 'i' and hence angle of refraction 'r' will remains constant. But for different λ values, μ varies and also hence thickness of the film 't' may not be constructive Interference constant through out the film. Hence different points on the film satisfy the condition for constructive Interference for different colours depending on the values of μ and t and hence appeared multi-coloured.