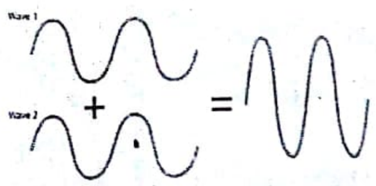
1. INTERFERENCE

Priya

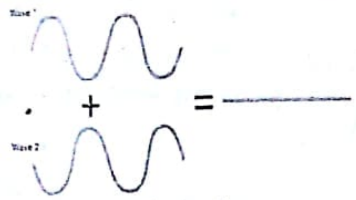
Interference:

When two or more waves are superimposed then there is a modification of intensity or amplitude in the region of superposition. This modification of intensity or amplitude in the region of super position is called **Interference.**

When the resultant amplitude is the sum of the amplitudes due to two waves, the interference is known as **Constructive interference** and when the resultant amplitude is equal to the difference of two amplitudes, the interference is known as **destructive interference.**



Constructive interference



Destructive interference

PRINCIPLE OF SUPERPOSITION:

This principle states that the resultant displacement of particle in a medium acted upon by two or more waves simultaneously is the algebraic sum of displacements of the same particle due to individual waves in the absence of the others.

Consider two waves traveling simultaneously in a medium. At any point let y_1 be the displacement due to one wave and y_2 be the displacement of the other wave at the same instant.

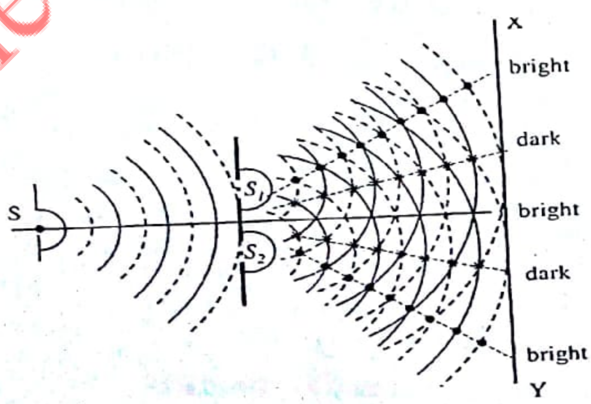
Then the resultant displacement due to the presence of both the waves is given by

$$\boxed{y = y_1 \pm y_2}$$

$+ve$ Sign has to be taken when both the displacements y_1 & y_2 are in the same direction

$-ve$ Sign' has to be taken when both the displacements y_1 & y_2 are in the opposite direction

Young's double slit experiment:



YOUNG first demonstrated experimentally the phenomenon of light. the apparatus as shown in fig.

In this experiment he allowed sun light to pass through a small pin hole S and then at some distance through two sufficiently close pin holes S_1 &S_2 in opaque card board. The interference pattern is observed on the screen. He observed few colored bright and dark bands on the screen. if sun light is replaced by

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monochromatic light. The interference pattern consists of equally spaced bright and dark bands on the screen.

Explanation on the basis of Huygens wave theory:

When monochromatic light passes through pin hole S, spherical waves spread out .we know from Huygens principle that each point on the wave front is a centre of secondary wave lets. Hence spherical waves also spread out from pin holes S_1 &S_2. The radii of these wave fronts increase as they move from S_1 &S_2 and hence they superimpose on one another.

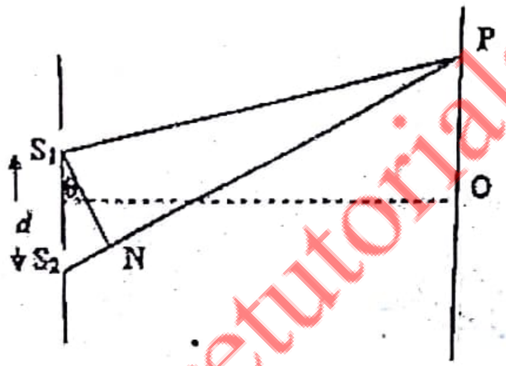
At points where Crest of one wave falls on the crest of the other wave (or trough on a trough), the resultant amplitude is the sum of the amplitudes of individual waves .hence the resultant intensity is increased. This is known as constrictive interference.

At points where Crest of one wave falls on the trough of the other wave (or trough on a crest), the resultant amplitude is the difference of the amplitudes of individual waves .hence the resultant intensity is decreased. This is known as destructive interference.

Thus the interference pattern consists of alternate dark and bright bands on the screen

ANALYTICAL TREATMENT OF INTERFERENCE

INTENSITY AT A POINT IN A PLANE:



Consider A monochromatic light 'S' emitting the waves , S_1 & S_2 be two narrow pin holes equidistant from source S . The waves arriving at S_1 & S_2 from S will be in phase at all times. We shall investigate the resultant intensity of light at a point P on the screen.

Let a_1 & a_2 be amplitudes of the waves from S_1 & S_2 and δ be the phase difference between the two waves reaching at point P. If y_1 & y_2 are the displacements of the two waves,

Then

$$y_1 = a_1 \sin \omega t \text{ ---------------(1)}$$

$$y_2 = a_2 \sin(\omega t + \delta) \text{ -------(2)}$$

According to the principle of superposition

The Resultant displacement $y = y_1 + y_2$

$$= a_1 \sin \omega t + a_2 \sin(\omega t + \delta)$$

$$y = a_1 \sin \omega t + a_2 \sin \omega t \cos \delta + a_2 \cos \omega t \sin \delta$$

$$y = \sin \omega t(a_1 + a_2 \cos \delta) + \cos \omega t(a_2 \sin \delta) \text{ --------------(3)}$$

Let $a_1 + a_2 \cos \delta = R \cos \theta$ -------------- (4)

$$a_2 \sin \delta = R \sin \theta \text{ ---------------------(5)}$$

Where R & θ are new constants

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$\therefore$ From equations (3),(4) & (5)

$$y = \sin\omega t . R\cos\theta + \cos\omega t . R\sin\theta$$

$$y = R\sin(\omega t + \theta) \quad \text{------(6)}$$

Where R is the resultant amplitude

the value of R can be obtained by squaring and adding equations (4)and (5) we get

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

$$R^2 = a_1^2 + a_2^2 + 2a_1a_2\cos\delta \quad \text{------(7)}$$

The resultant intensity at P is given by the square of the amplitude R.

$$I = R^2 = a_1^2 + a_2^2 + 2a_1a_2\cos\delta \quad \text{------(8)}$$

Case(1) :Condition for maximum intensity

From Eq(8) the Intensity I is maximum when

$$\cos\delta = +1$$

$$\therefore \delta = 0, 2\pi, 4\pi, ...2n\pi$$

$$\delta = 2n\pi, \text{ Where } n = 0,1,2,3......$$

$$\therefore \text{Path difference} = \frac{\lambda}{2\pi} \times phase.diff$$

$$\boxed{\therefore \text{Path difference} = \frac{\lambda}{2\pi} \times 2n\pi = n\lambda}$$

$$\boxed{\therefore I_{max} = (a_1 + a_2)^2}$$

Case (2) :Condition for minimum intensity

From Eq(8) the Intensity I is minimum when

$$\cos\delta = -1$$

$$\therefore \delta = \pi, 3\pi, 5\pi, ...(2n+1)\pi$$

$$\therefore \delta = (2n+1)\pi, n = 0,1,2,3......$$

$$\therefore \text{Path difference} = \frac{\lambda}{2\pi} \times phase.diff$$

$$\boxed{\therefore \text{Path ifference} = \frac{\lambda}{2\pi} \times (2n+1)\pi = (2n+1)\frac{\lambda}{2}}$$

$$\boxed{\therefore I_{min} = (a_1 - a_2)^2}$$

Case 3: if $a_1 = a_2$

$$I_{max} = (a+a)^2 = 4a^2$$

$$I_{min} = (a-a)^2 = 0$$

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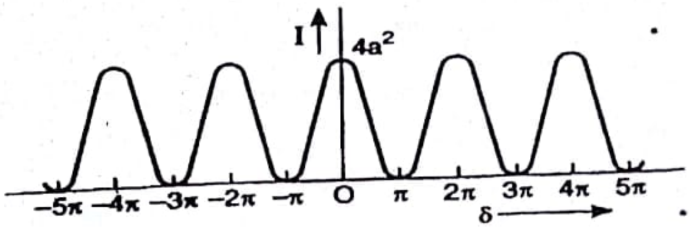
Intensity distribution curve



THEORY OF INTERFERENCE FRINGES:

...e fringes are produced on screen as shown in Fig. 1.4.

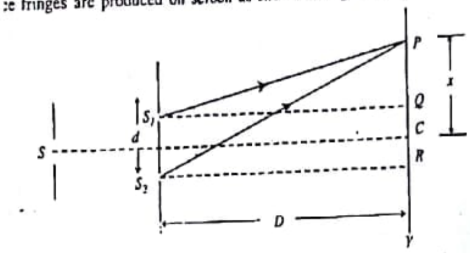


Fig. 1.4 Theory of interference fringes

Consider a monochromatic source 'S' and two pin holes S_1 & S_2 separated distance $2d$. Let a screen be placed at a distance D parallel to S_1 & S_2. The point "O on the screen is equidistant from S_1 & S_2 and path difference between the waves reaching at O is zero. Therefore O is point of maximum intensity

Consider a point P at distance x from O.

From triangle S_1PQ

$$(S_1P)^2 = (S_1Q)^2 + (PQ)^2$$

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

From triangle S_2PR

$$(S_2P)^2 = (S_2R)^2 + (PR)^2$$

$$(S_2P)^2 = D^2 + (x+d)^2$$

$$\therefore (S_2P)^2 - (S_1P)^2 = D^2 + (x+d)^2 - D^2 - (x-d)^2$$

$$(S_2P)^2 - (S_1P)^2 = (x+d)^2 - (x-d)^2$$

$$(S_2P)^2 - (S_1P)^2 = 4xd$$

$$(S_2P + S_1P)(S_2p - S_1P) = 4xd$$

As $D >> d$

$$(S_2P + S_1P) \approx 2D$$

$$\therefore \text{Path difference } (S_2p - S_1P) = \frac{4xd}{2D} = \frac{2xd}{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Case 1: Condition for bright fringe:

We know that for getting bright fringe

The path difference $= n\lambda$

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$$\therefore \frac{2xd}{D} = n\lambda$$

$$x_n = \frac{n\lambda D}{2d}$$

$$\text{For } n=1,\ x_1 = \frac{\lambda D}{2d}$$

$$\text{For } n=2,\ x_2 = \frac{2\lambda D}{2d}$$

$$\text{For } n=3, x_3 = \frac{3\lambda D}{2d}$$

$$\text{For } n=n, x_n = \frac{n\lambda D}{2d}$$

$$\therefore fringe.width(\beta) = x_2 - x_1$$

$$fringe.width(\beta) = \frac{2\lambda D}{2d} - \frac{\lambda D}{2d}$$

$$\boxed{fringe.width(\beta) = \frac{\lambda D}{}}$$

Case.2: <u>Condition for dark fringes</u>:

We know that for getting dark fringe the path difference $=(2n+1)\frac{\lambda}{2}$

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

$$x = (2n+1)\frac{\lambda}{2} \times \frac{D}{2d}$$

$$x = \frac{(2n+1)\lambda D}{4d}$$

$$x_n = \frac{(2n+1)\lambda D}{4d}$$

$$\text{For } n=1, x_1 = \frac{3\lambda D}{4d}$$

$$\text{For } n=2, x_2 = \frac{5\lambda D}{4d}$$

$$\therefore fringe.width(\beta) = x_2 - x_1$$

$$fringe.width(\beta) = \frac{5\lambda D}{4d} - \frac{3\lambda D}{4d}$$

$$\boxed{fringe.width(\beta) = \frac{\lambda D}{2d}}$$

$\therefore$ The distance between any two consecutive dark and bright fringes is same.i.e, known as fringe width (β).

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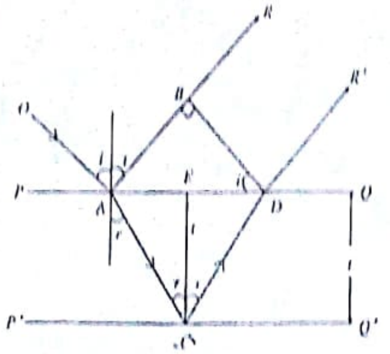
INTERFERENCE IN THIN FILMS



Consider a thin film of thickness t and refractive index μ. A ray of light OA incident on the surface at an angle i is partly reflected along AB and partly refracted into medium along AC, making an angle of refraction r .at C it is again partly reflected along CD. Similar refractions occur at E.

To find the path difference between the rays, draw DB perpendicular to AB

Then the path difference $= \mu(AC + CD) - AB$ ....(1)

From triangle ACE

$$\cos r = \frac{CE}{AC}$$

$$AC = \frac{CE}{\cos r} = \frac{t}{\cos r} \text{ ....(2)}$$

From triangle CDE

$$\cos r = \frac{CE}{CD}$$

$$CD = \frac{CE}{\cos r} = \frac{t}{\cos r} \text{ ....(3)}$$

From triangle ABD

$$\cos(90 - i) = \frac{AB}{AD}$$

$$AB = AD\cos(90 - i) = 2AE\sin i \text{ ....(4)} \qquad (\quad AD = 2AE \quad)$$

FROM triangle ACE

$$\sin r = \frac{AE}{AC} \Rightarrow AE = AC\sin r$$

$$AE = \frac{t\sin r}{\cos r} \qquad (\quad AC = \frac{t}{\cos r})$$

From Eq (4)

$$AB = \frac{2t\sin r}{\cos r} \times \sin i$$

$$AB = \frac{2t\sin r\sin i}{\cos r} \times \frac{\sin r}{\sin r}$$

$$AB = \frac{2\mu t\sin^2 r}{\cos r} \text{ ....(5)} \qquad (\quad \mu = \frac{\sin i}{\sin r})$$

On substituting the values of AC, CD & AB from Eq(2),(3)&(5) in Eq(1) ,we get

The path difference $= \mu(\frac{t}{\cos r} + \frac{t}{\cos r}) - \frac{2\mu t\sin^2 r}{\cos r}$

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

$\therefore$ The path difference $= 2\mu t\cos r$

According to the theory of reversibility, when the light ray reflected at rarer-denser interface, it introduces an extra phase difference π (or) path difference of $\frac{\lambda}{2}$

$$\boxed{\therefore \text{The actual path difference} = 2\mu t\cos r - \frac{\lambda}{2}}$$

Case.1: **condition for maximum intensity**

We know that the intensity is maximum when path difference$= n\lambda$

$\therefore$ From Eq.(6) $2\mu t\cos r - \frac{\lambda}{2} = n\lambda$

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

Case.2: **condition for minimum intensity**

We know that the intensity is minimum when path difference$= (2n+1)\frac{\lambda}{2}$

$\therefore$ from Eq.(6) $2\mu t\cos r - \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$

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

Case.3: **If the thickness of the film is very small i.e. $t \to 0$**

The path difference $= \frac{\lambda}{2}$

This is the condition for minimum intensity. So in this case the film appears black.

Production of Colors in thin films:

With monochromatic light alternate dark and bright interference fringes are obtained. With white light, the fringes obtained are colored. it is because the path difference $2\mu t\cos r - \frac{\lambda}{2}$ depends upon $\mu, t \,\&\, r$

(i) Even if t and r kept constant, the path difference will change with $\mu \,\&\, \lambda$ of light used. White light composed of various colors from violet to red. The path difference also changes due to reflection at denser medium by $\frac{\lambda}{2}$ as $\lambda_V \langle \lambda_R$.

(ii) If the thickness of the film varies with uniformly, if at beginning it is thin, which will appear black. as path difference varies with thickness of the film, it appears different colors with white light.

(iii) If the angle of incidence changes, the angle of refraction is also changes, so that with white light, the film appears various colors when viewed from different directions.

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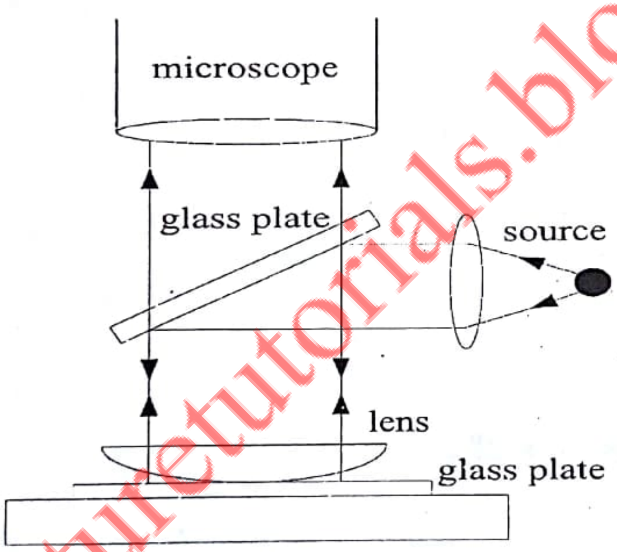
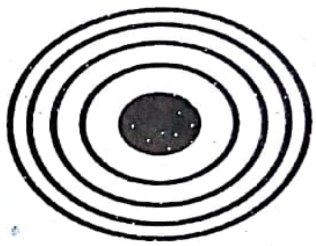
NEWTON'S RING EXPERIMENT

A Plano convex lens(L) having large focal length is placed with its convex surface on the glass plate(G_2).a gradually increasing air film will be formed between the plane glass plate and convex surface of Plano convex lens. The thickness of the air film will be zero at the point of contact and symmetrically increases as we go radially from the point of contact.

A monochromatic light of wavelength 'λ' is allowed to fall normally on the lens with the help of glass plate (G_1) kept at 45^0 to the incident monochromatic beam. A part of the incident light rays are reflected up at the convex surface of the lens and the remaining light is transmitted through the air film. Again a part of this transmitted light is reflected at on the top surface of the glass plate (G_1).both the reflected rays combine to produce an interference pattern in the form of alternate bright and dark concentric circular rings, known as Newton rings. The rings are circular because the air film has circular symmetry. These rings can be seen through the travelling microscope.



(a)


(b)

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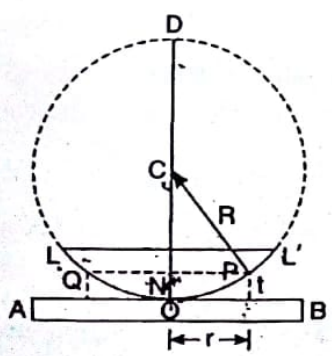
THEORY



Consider a Plano convex lens is placed on a glass plate. Let R be the radius of curvature and r be the radius of NEWTON ring, corresponding to constant film thickness.

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As one of the rays suffers reflection at denser medium, so a further phase changes of π or path difference of $\frac{\lambda}{2}$ takes place.

The path difference between the rays are $=2\mu t \cos r + \frac{\lambda}{2}$ ---------------------------- (i)

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

$\therefore$ **Path difference** $= 2t + \frac{\lambda}{2}$

AT THE POINT OF CONTACT

The thickness of the air film t=0, μ=1 & for normal incidence r = 0.

Then the path difference $= \frac{\lambda}{2}$.

if the Then the path difference $= \frac{\lambda}{2}$ then the corresponding phase difference is π.so that gives a dark spot is formed at the centre.

For bright ring

$$2t + \frac{\lambda}{2} = n\lambda$$

$$2t = (2n-1)\frac{\lambda}{2} \quad \text{------------------------------------- (ii)}$$

For Dark ring

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

$$2t = n\lambda \quad \text{--- (iii)}$$

In the above fig, from the property of the circle

$$NP \times NQ = NO \times ND$$

$$r \times r = 2t \times (2R - t)$$

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

As t is small, t^2 is very small. So t^2 is neglected.

$$\therefore \; r^2 = 2Rt$$

$$t = \frac{r^2}{2R} \Rightarrow t = \frac{D^2}{8R} \quad \text{------------------------ (iv)}$$

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Thus for bright ring

From Eq (ii) & (iv)

$$\frac{2D^2}{8R} = (2n-1)\frac{\lambda}{2}$$

$$\boxed{D_n^2 = 2(2n-1)\lambda R} \text{ -- (v)}$$

Thus for dark ring

From Eq. (iii) & (iv)

$$\frac{2D^2}{8R} = n\lambda$$

$$D_n^2 = 4Rn\lambda \text{ .... (vi)}$$

$$\boxed{D_n^2 = 4Rn\lambda}$$

Determination of wave length of monochromatic light

From Eq(vi) $D_n^2 = 4Rn\lambda$

For $n = m$, $D_m^2 = 4Rm\lambda$

$$\therefore\ D_m^2 - D_n^2 = 4Rm\lambda - 4Rn\lambda$$

$$= 4R\lambda(m-n)$$

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

This is the expression for wave length of monochromatic light.

Determination of refractive index of a liquid

The experimental set up as shown in fig. is used to find the refractive index of a liquid.

To find the refractive index of a liquid, the plane glass plate and Plano convex lens set up is placed in a small metal container. The diameter of n[th] and m[th] dark rings are determined, when there is air between Plano convex lens and plane glass plate.

Then we have,

$$D_m^2 - D_n^2 = 4Rm\lambda - 4Rn\lambda$$

$$= 4R\lambda(m-n) \text{ ....(vii)}$$

Now the given liquid whose refractive index (μ) is to be introduced in to the space between Plano convex lens and plane glass plate without disturbing the experimental set up.

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Then the diameters of Newton's rings are changed. Now the diameter of n^{th} and m^{th} dark rings are measured.

Then

$$D_m^{1^2} - D_n^{1^2} = \frac{4R(m-n)\lambda}{\mu} \quad \text{..(vii)}$$

Therefore from (vii) & (viii)

$$\mu = \frac{D_m^2 - D_n^2}{D_m^{1^2} - D_n^{1^2}}$$

CONDITIONS TO GET STATIONARY INTERFERENCE FRINGES

1. The two sources should be coherent.
2. The two sources must emit continuous waves of the same wavelength and same frequency.
3. The distance between the two sources (d) should be small.
4. The distance between the sources and the screen (D) should be large.
5. To view interference fringes, the back ground should be dark.
6. The amplitude of interfering waves should be equal.
7. The sources must be narrow, i.e., they must be extremely small.
8. The source must be monochromatic source.

CONCEPT OF COHERENCE

The two sources which maintain zero or constant phase relation between themselves are known as coherence sources, the phenomenon is known as coherence.

The two waves are said to be coherent, their waves have same wavelength and constant phase difference. Such waves on superposition give rise to interference pattern.i.e, bright and dark fringes are formed. If the phase difference changes with time, two sources are known as incoherent sources.

There are two independent concepts of coherence:

(i) Temporal coherence

(ii) Spatial coherence

(i) Temporal coherence: If the phase difference between the two fields is constant during the period, then the wave said to have temporal coherence.

(ii) Spatial coherence: if the phase difference for any two fixed points is in a plane normal to the wave propagation dose not vary with time, then the wave is said to be spatial coherence.

Temporal coherence is a characteristic of single beam of light where as spatial coherence concerns the relationship between two separate beams of light.

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INTERFEROMETRY

Interferometry is a technique in which waves are superimposed in order to exact information about the waves.

INTERFEROMETER

The instruments based on the principle of interference of light are called interferometer. These are used to make a exact measurement of wavelength, distances, refractive indices and resolution of spectral lines.

BASIC PRINCIPLE INVOLVED IN INTERFEROMETERS

When a beam of light is incident on a beam splitter (or) half-transparent mirror, the incident light beam splits into two beams. One is directed towards a fixed mirror and other is transmitted towards a movable mirror. The two beams reflected from these mirrors are thus recombined and produce interference pattern due to phase (or) path between them.

CONSTRUCTION OF INTERFEROMETER

To construct any interferometer, the following requirements are used.

1. A light source
2. Beam splitter
3. Compensator
4. Mirrors
5. Detector

1. **Light source:** We can use different light sources but the selection of proper light source depends on the results to be obtained by the interferometer.
   Ex: sodium vapor lamp, Mercury vapor lamp and laser (or) LED.

2. **Beam splitter:** The beam splitter is a partially silvered glass plate and it splits an incident beam of light into two beams by division of amplitude.

3. **Compensator:** Its working is to compensate the difference in path length between the two light beams from the mirrors. It is made up of same quality of glass with same thickness and orientation of the beam splitter.

4. **Mirrors:** It consists of two optically plane polished mirrors, one is held fixed and the other movable, which are held perpendicular to each other. Its function is to vary the path length of light beams reflected from it in order to get the desired interference pattern.

5. **Detectors:** It is a camera (or) Telescope to detect and obtain the interference pattern.

MICHELSON INTRFEROMETER

Interferometer first designed by Albert Michelson in 1881.It is used to accurate measurement of

1. Wavelength of monochromatic light source.
2. Refractive index and thickness of various thin transparent materials and etc…..

PRINCIPLE:

The amplitude of light beam from the source is divided into two parts of equal intensities by partial reflection & refraction. These beams are sent in to two directions at right angles and brought to gather after reflection from plane mirror to produce interference fringes.

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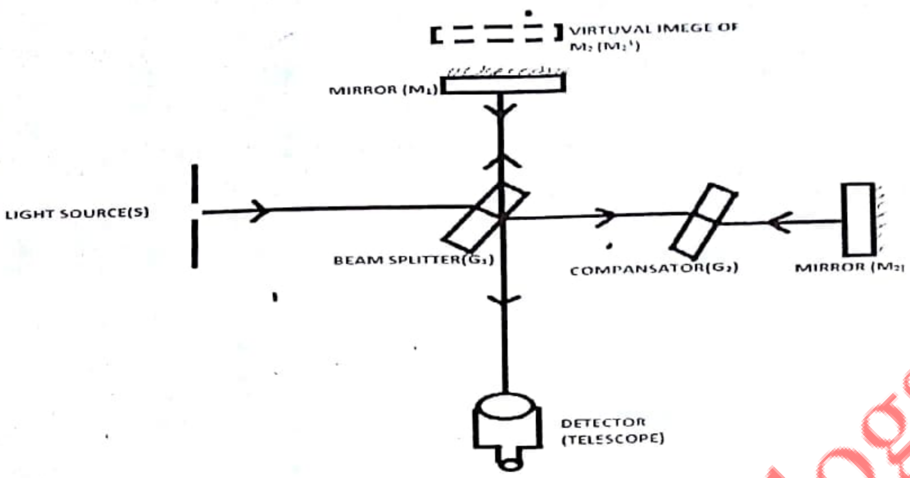
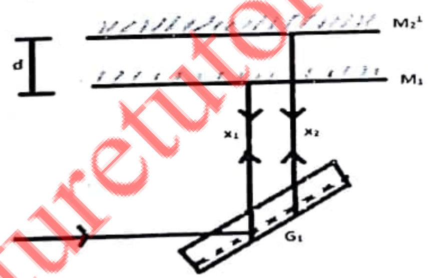
CONSTRUCTION:

It consists of two highly polished mirrors M_1 and M_2 placed at right angles to each other and two plane parallel glass plates G_1 and G_2 of same thickness. The plate G_1 is half silvered at back. So that incident beams is divided into a reflected and refracted beams of equal intensity. Glass plates G_1 and G_2 are held at parallel and inclined at 45^0 and 'T' is a telescope which receives the reflected lights from M_1 and M_2.



WORKING:

Light from the monochromatic source falls on the half silvered glass plate G_1, it is divided in to two parts. One is reflected ray which travels towards M_1 and other is refracted ray which travels towards M_2. The rays normally falls on mirrors M_1 and M_2 and reflected back along their original path. These reflected rays again meet at the semi silvered surface of G_1 and enter in to the telescope these two beams produce interference under suitable conditions.



If the distance $OM_1=x_1$ and $OM_2^1=x_2$, then the path difference between interfering rays is given by

$$\Delta=2(x_2-x_1)=2d.$$

But the reflected beam from M_2 i.e. at the rarer-denser medium.

$$\Delta=2d+\lambda/2.$$

If we look obliquely

$$\Delta=2d\cos r+\lambda/2$$

TYPES OF FRINGES

1. **Circular fringes:**

If M_1 and M_2 are exactly perpendicular then the reflected surfaces M_1 and M_2^1 are parallel. The virtual air film between M_1 and M_2^1 is of constant thickness is enclosed between them.

For a given value of d,n,λ and the angle r will be constant. Hence the loci of constant r are concentric circles, circular fringes are obtained.

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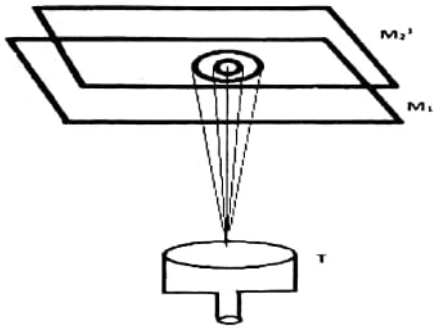
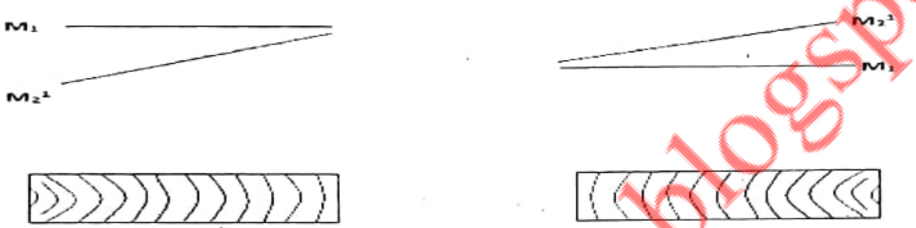
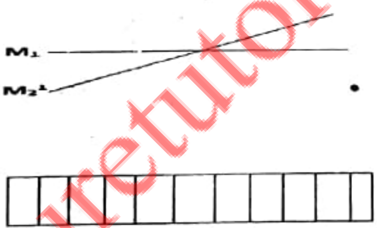


2. **Localized fringes:**

If the mirror M_2 is not exactly perpendicular to mirror M_2 (or) the mirror M_1 is and mirror M_2^1 are inclined, the air film enclosed between them is wedge-shaped then we observed curved fringes as shown in fig.



When the two mirrors are M_1 and M_2^1 intersect in the middle, straight fringes are observed as shown in fig.



DETERMINATION OF WAVELENGTH OF MONOCHROMATIC LIGHT:

Michelson's interferometer set for circular fringes with central bright spot. Then the path difference is equal to $n\lambda$.

i.e. $2d = n\lambda$.

$$\lambda = \frac{2d}{n}.$$

DETERMINATIONOF THICKNESS OF A THIN GLASS PLATE:

A thin plate is introduced in one of the interfering rays and interferometer set for localized fringes of white light.

Let 't' be the thickness and 'μ' be the refractive index of the glass plate. This thin film causes the additional path difference between the two interfering beams.

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∴ Therefore

$$2(\mu-1)\,t = n\lambda.$$

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

Thin film:- The film whose size is in the order of one wavelength (5500 A°) is know as Thin film.

Ex:- soap bubble layer, oilished paper.

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