Chapter -1

# Light and Images

Light :

Light is a electronegative wave.

## Reflection :

When a light beam stricks a boundary between two media some or all of the light may be returned back into first media, This phenomenon is called reflection of light.

AO → incident ray of light

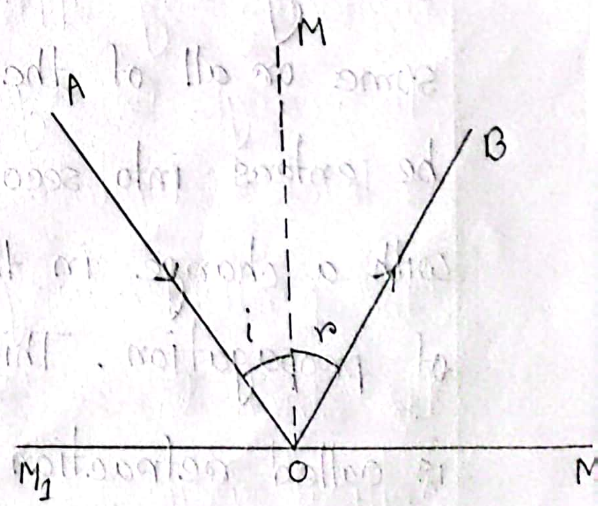
OB → reflected ray of the light

MO → Normal

$M_1OM_2$ → reflected edge

$i$ → angle of incidence

$r$ → angle of reflection.




$[i = r]$

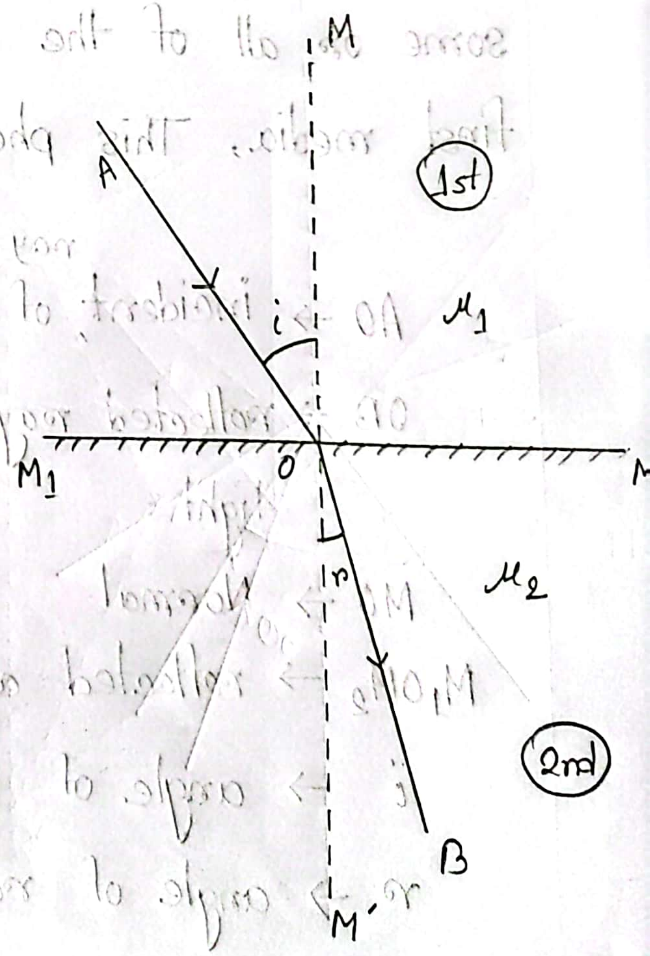
## Law of reflection :

(i) 1st law : The incident ray, reflecting ray and the normal lie in the same plane.

(ii) 2nd law : The angle of incidence is equal to the angle of reflection ($\angle i = \angle r$)

## Refraction :

When a light beam stricks a boundary between two media some or all of the light may be enters into second medium with a change in the direction of propagation. This process is called refraction of light.



## Law of refraction:

(i) 1st law: The incident ray, the refracted ray and the normal to the surface of separation at the point of incidence are coplanar.

(ii) 2nd law: The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant.

$$\mu_1 \sin i = \mu_2 \sin r$$

Snell's law, $\dfrac{\sin i}{\sin r} = \text{constant}$

## Refractive index ($\mu$):

It is defined as the ratio between the velocity of light in a vacuum (c) and the velocity of light in the medium.

$$\mu = \frac{c}{v}$$

Here, $c = n\lambda$ $\qquad$ $\lambda$ = wavelength in vacuum

$v = n\lambda_m$ $\qquad$ $\lambda_m$ = wavelength in medium

$$\therefore \mu = \frac{n\lambda}{n\lambda_m}$$

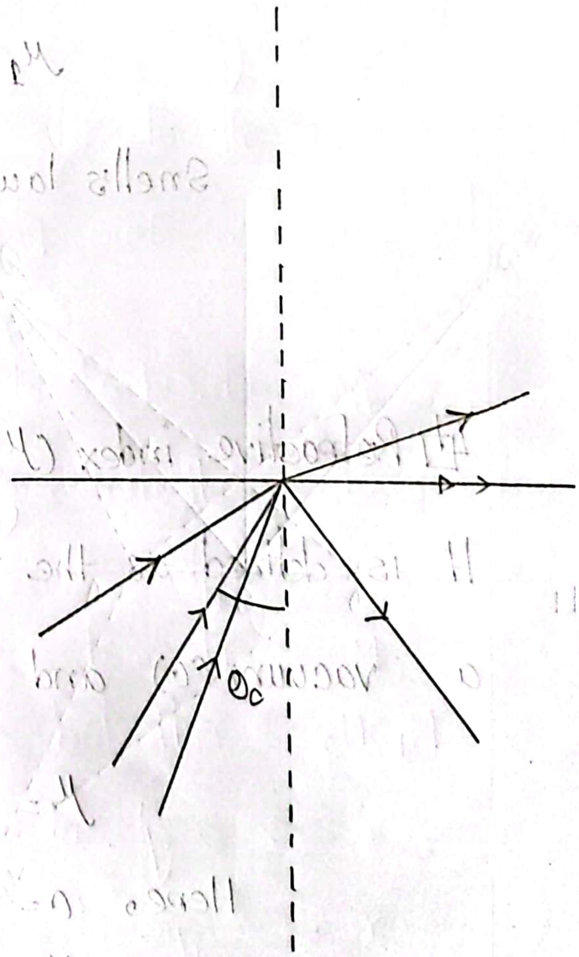
$$\Rightarrow \mu = \frac{\lambda}{\lambda_m}$$

When light is propagated from one medium to another, the frequency remains constant. Wavelength is different for different medium.

## Critical angle :

When incident ray approch an angle of 90° with normal there reflected ray approach at a fixed angle $\theta_c$ beyond no refracted light is possible.

The particular angle $\theta_c$ for which $\theta_c = 90°$ is called critical angle.



☐ Optical path :

It is defined as the product of the geometrical distance and refractive index of the medium.

Let a ray travels a distance $x$ in a medium of refractive index $\mu$. Then optical path is equal to $\mu x$.

☐ Totally internally reflection :

If the angle of incidence ($\theta$) is greater than critical angle the instead of refraction its occur totally internally reflection.

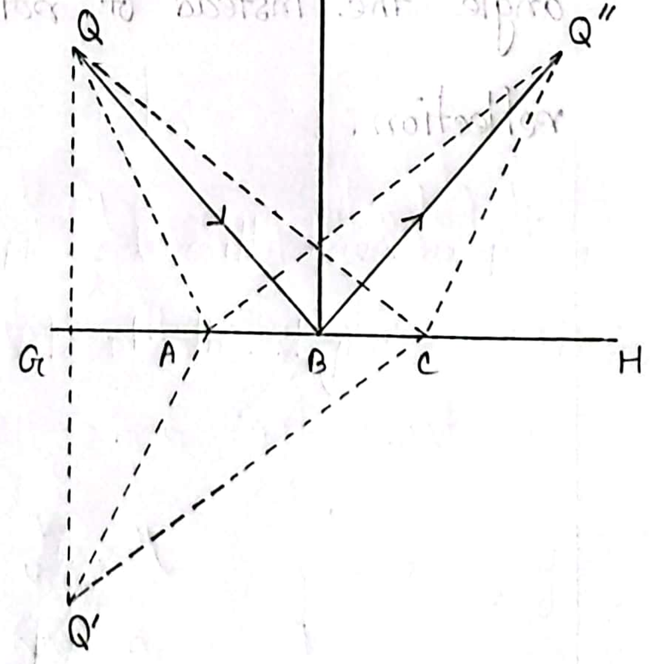
4) State and explain Fermat's principle.

Statement:

In 1658, Fermat proposed the principle of least time time for the path followed by light radiation.

"A light ray travelling from one point to another will follow a path. Such that compared with nearly paths, the time required is either a minimum or a maximum or will remain unchanged.

Explanation:




Ray of light come from 1st point Q then after reflected on a plane surface GH go to 2nd point Q" to get real paths draw perpendicular and extened equal distance on other side.

$QG = GQ'$

Consider adjacent path at point A and C. QAQ'' and QCQ'' is greater than QBQ''. QA=

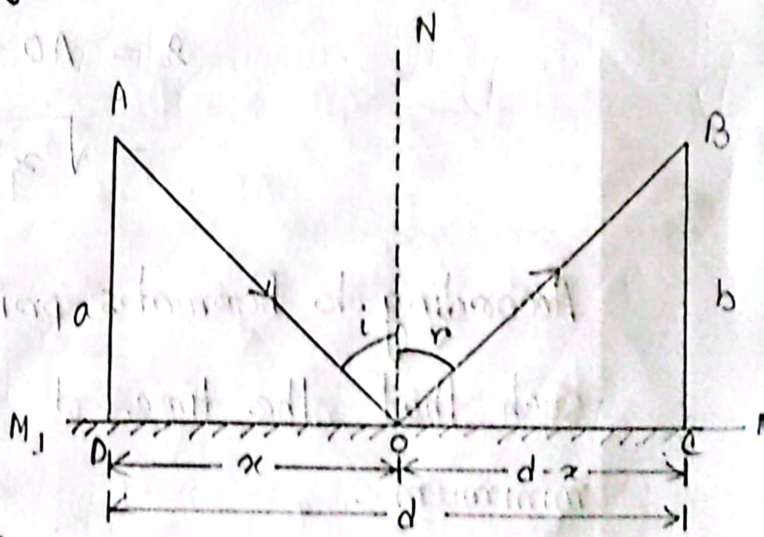
$QA = Q'A$ and $QC = Q'C$

$QAQ'' > QBQ''$ and $QCQ'' > QBQ''$

The real path QBQ'' is minimum.

## Law of reflection using Fermat's principle —

⇒ $M_1M_2$ be the plane mirror. AO be the incident ray and the OB reflected ray. ON be the normal.




The angle of incidence is $i$ and the angle of reflection is $r$.

$\therefore$ $CD = d$, $DO = x$, $OC = (d-x)$, $AD = a$, $BC = b$

From $\Delta AOD$,

$$OA^2 = OD^2 + AD^2$$

$$\Rightarrow OA = \sqrt{OD^2 + AD^2}$$

$$= \sqrt{x^2 + a^2}$$

From $\Delta BOC$,

$$OB^2 = OC^2 + BC^2$$

$$\Rightarrow OB = \sqrt{OC^2 + BC^2}$$

$$= \sqrt{(d-x)^2 + b^2}$$

Total length of the ray,

$$\lambda = AO + OB$$

$$= \sqrt{x^2 + a^2} + \sqrt{(d-x)^2 + b^2}$$

According to Fermat's principle, O will have a position such that the time of travel of the light must be minimum.

$$\frac{d\lambda}{dx} = 0$$

$$\Rightarrow \frac{d}{dx}\left[\sqrt{x^2 + a^2} + \sqrt{(d-x)^2 + b^2}\right] = 0$$

$$\Rightarrow \frac{1}{2}(x^2+a^2)^{-\frac{1}{2}}\cdot 2x + \frac{1}{2}\left[\left\{(d-x)^2+b^2\right\}^{-\frac{1}{2}}\cdot 2(d-x)(-1)\right] = 0$$

$$\Rightarrow \frac{x}{\sqrt{(x^2+a^2)}} - \frac{d-x}{\sqrt{(d-x)^2+b^2}} = 0$$

$$\Rightarrow \frac{x}{\sqrt{x^2+a^2}} = \frac{d-x}{\sqrt{(d-x)^2+b^2}}$$

$$\Rightarrow \frac{OD}{OA} = \frac{OC}{OB}$$

$$\Rightarrow \sin i = \sin r$$

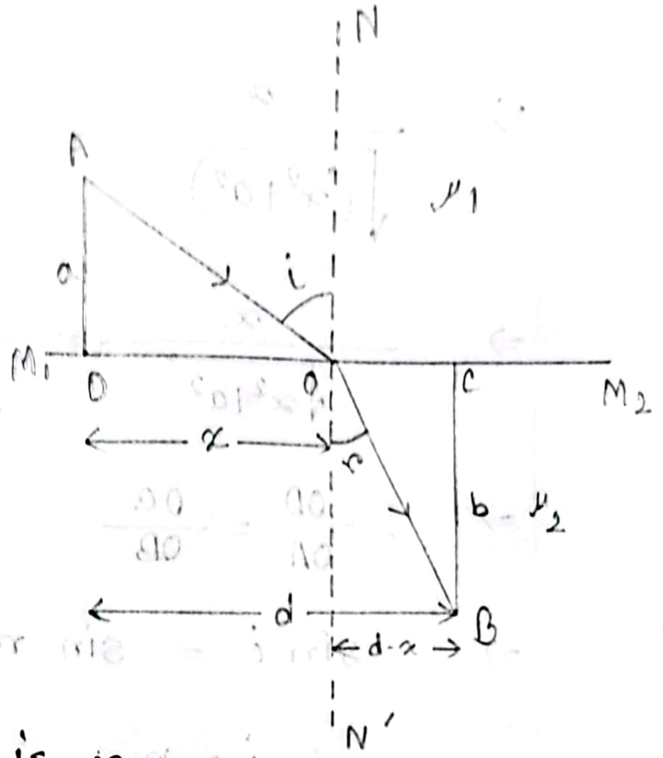
$$\therefore i = r,$$

The angle of incidence is equal to the angle of reflection and the incident ray, reflection ray and normal lie in the same plane.

Snell's law of refraction using Fermat's law.

Derive the law of refraction using Fermat's law.

Let $M_1 M_2$ is the boundary separating the two media of refractive indexes $\mu_1$ and $\mu_2$. AO incident ray and OB be the refracted ray. NON′ be the normal.




The angle of incidence is $i$ and the angle of refraction is $r$.

Here, $CD = d$, $DO = x$, $OC = (d-x)$

$AD = a$ ; $BC = b$

Velocity of light $= c$

Time taken along path AOB.

$$t = \frac{l_1}{v_1} + \frac{l_2}{v_2}$$

$$= \frac{l_1}{c/\mu_1} + \frac{l_2}{c/\mu_2} \qquad \left[\because \mu = \frac{c}{v}\right]$$

$$= \frac{l_1 \mu_1}{c} + \frac{l_2 \mu_2}{c}$$

$$= \frac{1}{c}\left(l_1\mu_1 + l_2\mu_2\right)$$

$$= \frac{l}{c}$$

where, $l = l_1\mu_1 + l_2\mu_2$

$= \text{optical path}$

From $\Delta AOD$,

$$OA^2 = OD^2 + AD^2$$

$$\Rightarrow OA = \sqrt{OD^2 + AD^2}$$

$$= \sqrt{x^2+a^2} = l_1$$

From $\Delta BOC$,

$$OB^2 = OC^2 + BC^2$$

$$\Rightarrow OB = \sqrt{OC^2 + BC^2}$$

$$= \sqrt{(d-x)^2 + b^2} = l_2$$

Total length, $l = \mu_1\sqrt{x^2+a^2} + \mu_2\sqrt{(d-x)^2+b^2}$

According to the Fermat's principle, O will have a position such that the time of travel of the light must be maximum.

$$\frac{dl}{dx} = 0$$

$$\Rightarrow \frac{d}{dx}\left[\mu_1\sqrt{x^2+a^2} + \mu_2\sqrt{(d-x)^2+b^2}\right] = 0$$

$$\Rightarrow \mu_1 \frac{1}{2}(x^2+a^2)^{-\frac{1}{2}} \cdot 2x + \mu_2 \frac{1}{2}\left[\left\{(d-x)^2+b^2\right\}^{-\frac{1}{2}} \cdot 2(d-x)(-1)\right] =$$

$$\Rightarrow \frac{\mu_1 x}{\sqrt{(x^2+a^2)}} - \frac{\mu_2 (d-x)}{\sqrt{(d-x)^2+b^2}} = 0$$

$$\Rightarrow \frac{\mu_1 x}{\sqrt{x^2+a^2}} = \frac{\mu_2 (d-x)}{\sqrt{(d-x)^2+b^2}}$$

$$\Rightarrow \mu_1 \sin i = \mu_2 \sin r$$

$$\Rightarrow \frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$

This is the refractive law and also the Snell's law.

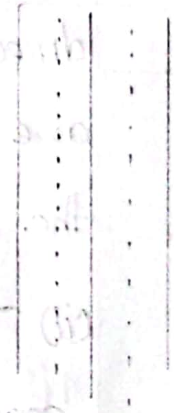
## Wave front :

Wave front is defined as the locus of all the points of the medium which are vibrating in phase and are also displaced at the same time.

If the distance of source is very small, the wave front (a).

If source is at large distance wave front is plane (b)

(a)



(b)

Example :

(i) When we drop a small stone in a pool of water circular ripples spread out from the point of stone (locus) each point of circles oscillates with same amplitude and same phase thus a circular wave front.

(ii) Plane wave front.

☐ State and explain ~~Hy~~ Huygens principle.

⇒ Statement:

(i) Every point on a wave fronts acts as a "secondary" source of disturbance. and ~~these~~ secondary wavelets spread in all directions from these new sources. The secondary wavelets are spherical and have the same frequency and velocity as the original wave.

(ii) The surface, which touches all the wavelets from the secondary sources, gives the new positions of the wave.

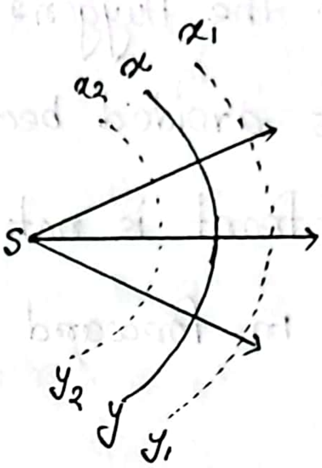
[Boi]

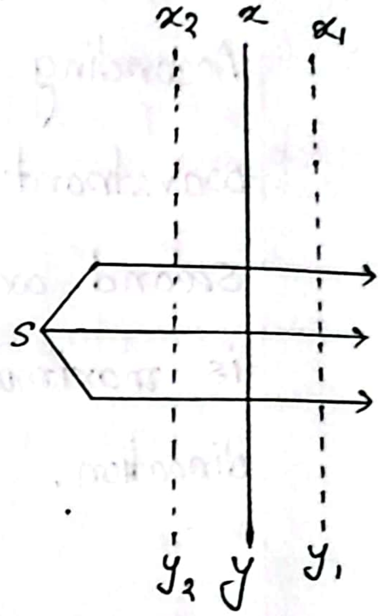
Each point of wave front is a source of secondary disturbance and the wavelets emanating from these points spread out in all directions with the speed of the wave. The envelope of these wavelets gives the shape of the new wavefronts.

Explanation :

s be the source of light in the form of waves.

After an interval of time t, all the particles of medium on the surface xy vibrates in phase. xy is portion of sphere of radius vt and centre s. xy be the primary wave front.



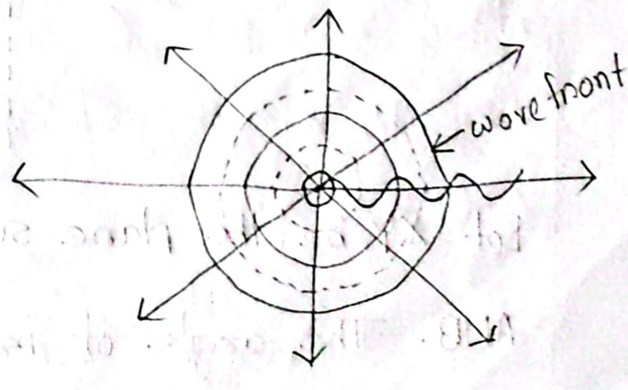




All points of primary wave front are the source of secondary wave front.

After t', secondary wave front travel a distance vt, travel to surface $x_1y_1$ and $x_2y_2$.

where, $x_1y_1$ be the forward wave front

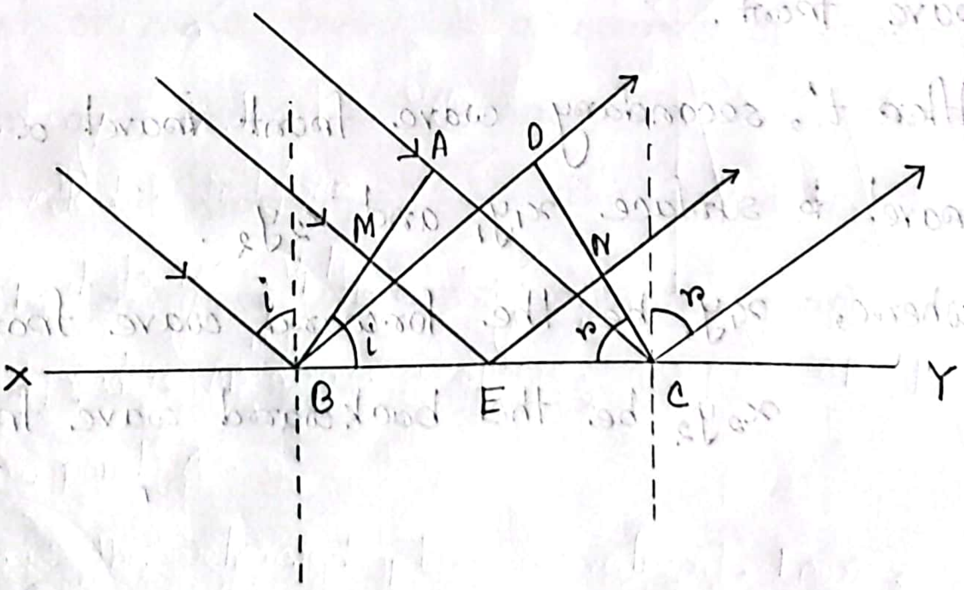
$x_2y_2$ be the backward wave front.



Limitations :

According to the Huygens the presence of backward wavefront is avoided because the amplitude of second wavefront is not uniform in all direction. It is maximum in forward direction and zero in backward direction.

⊞ Derive the law of reflection using Huygen's principle.




Let XY be the plane surface. The incident wave front AMB. The angle of ~~incident~~ incidence is $i$ and the angle of reflection is r. All particles on AB will be vibrating in phase. In the interval of time the disturbance at A goes to C. Secondary wave front from B travel a distance BD equal to AC.

The angle of reflection is r.

From $\triangle ABC$ and $\triangle DBC$,

BC is the common side of two triangle.

$$BD = AC$$

$$\angle BAC = \angle BDC = 90^\circ$$

$$\angle ABC = \angle i = \angle BCD = \angle r$$

$$\therefore \angle i = \angle r$$

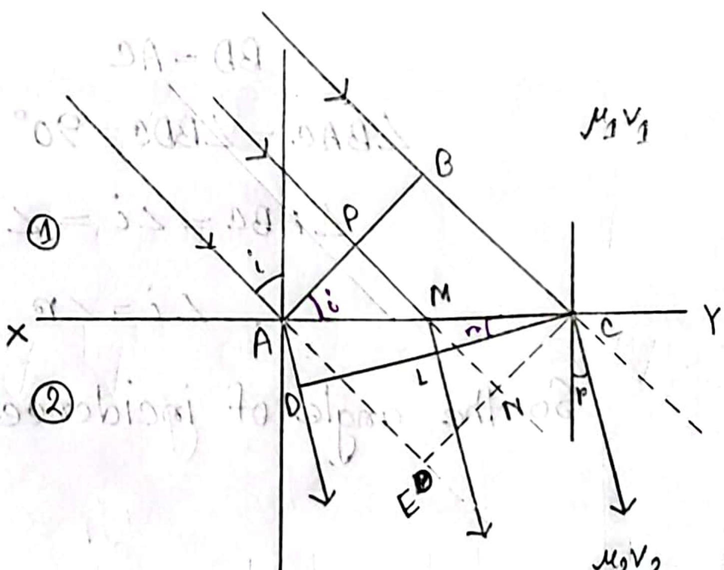
So the angle of incidence is equal to angle of reflection.

4 Derive the law of refraction using Huygens principle.

5 Derive Snell's law of refraction using Huygens principle.

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$

⇒ Let, XY represents the surface separating the media 1 and 2 of refractive indices $\mu_1$ and $\mu_2$ respectively. $v_1$ and $v_2$ are the velocities of light in the two media. APB be the incident plane wave-front.




By the time disturbance, t ① at B reaches to C.

The secondary wavefront ② from A travelled a distance $AD = v_2 t$ equal to $BC = v_1 t$.

Centre B and radius AD if we draw a sphere and tangent CD to the sphere from point C.

Then CLD is the refracted plane wavefront. From, $\Delta ACD$ and $\Delta MCL$

$$\frac{AD}{ML} = \frac{AC}{MC} \quad \text{——— (1)}$$

From $\Delta ACE$ and $\Delta MCN$,

$$\frac{AE}{MN} = \frac{AC}{MC} \text{ ——— (2)}$$

From equation (1) and (2)

$$\frac{AE}{MN} = \frac{AD}{ML}$$

$$\Rightarrow \frac{AE}{AD} = \frac{MN}{ML}$$

$$\Rightarrow \frac{BC}{AD} = \frac{MN}{ML} \text{ ——— (3)} \quad [\because AE = BC]$$

Now,

$$\frac{BC}{AD} = \frac{v_1 t}{v_2 t} = \frac{v_1}{v_2} \text{ ——— (4)}$$

$$\text{So, } \frac{BC}{AD} = \frac{MN}{ML} = \frac{v_1}{v_2} \text{ ——— (5)}$$

Let $i$ and $r$ be the angles of incidence and refraction respectively.

From $\Delta ABC$, $\sin i = \frac{BC}{AC}$

and $\Delta ACD$, $\sin r = \frac{AD}{AC}$

$$\therefore \frac{\sin i}{\sin r} = \frac{BC/AC}{AD/AC} = \frac{BC}{AD} \text{ ——— (6)}$$

Comparing equation (5) and (6)

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

$$\Rightarrow \frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \qquad \left[\because \mu = \frac{v}{c}\right]$$

$$\Rightarrow \mu_1 \sin i = \mu_2 \sin r$$

This is the snell's law of refraction.

Newton's ~~corpu~~ corpuscular theory :

Light consists of a stream of particles is called corpuscles. These corpuscles come out by light and travel in straight line with large velocity.

"A luminous body continuously emits tiny light and elastic particles called corpuscles in all directions they can travel through the interstics of the particles of matter with velocity of light and they posses the property of reflection. when these particles fall on the retina of the eye they produce the sensation of vission.

4] Characteristics of wave front :

(i) The energy of light flows perpendicular to the wavefronts

(ii) Time taken by light to travel from one position to another of the wave front is constant along the ray.

(iii) Space between a pair of wavefronts is constant along any ray.

(iv) All points are in the same phase on the same wavefront

5] Significance of Farmet principle –

Fermats principle is a remarkable and important principle in optics, which explain why light propagates along straight lines and the law of reflection and refraction. It forms the basis of geometrical optics. It is not so much a computational device as it is a concise way of thinking about the propagation of light. It is a statement about the grand scheme of things without any concern for the contributing mechanics.

## Applications :

The fundamental laws of rectilinear propagation, reflection and refraction can be derived from Fermats principle. Also the reversibility of light rays follows from Fermats law.

## Limitation :

Farmet priciple only applicable for flat surface. It is not applicable for spherical surface. Again Farmet law can only derived the law of reflection and refraction in a flat surface. , Interference, diffraction of light can not be derived by it.
Wave properties of light.

## Significance of Huygens principle (Applications)

Huygens principle gives a geometrical construction for finding the position of a wave front at a future instant if its position is known at some particular instant.

Based on Huygens wave theory and Huygens principle we can explain satisfactorily reflection and refraction of light by constructing wave fronts. Adopting Fresnel's modification of Huygens principle, rectilinear propagation of light can also be explained. It served a very useful guide in explaining the phenomena of interference, diffraction and polarization.

Limitations:

Huygens construction is an incomplete concept becouse it does not explain why there are no backword going wavelets. The backwork wavelets are ~~at~~ avoided because the ~~apm~~ amplitude of second wavefornt is not uniform in all direction. It is maximum in forward direction and zero in backword direction. In 1883, Kirchhoff eliminated this defect and showed that Huygens primitive principle was a direct consequence of the differential wave equation.

# Chapter - 2

## Superposition of waves:

When two or more waves overlap, the resultant displacement at any point and at any instant may be found by adding the instantaneous displacements that would be produced at the point by the individual waves if each were present alone.

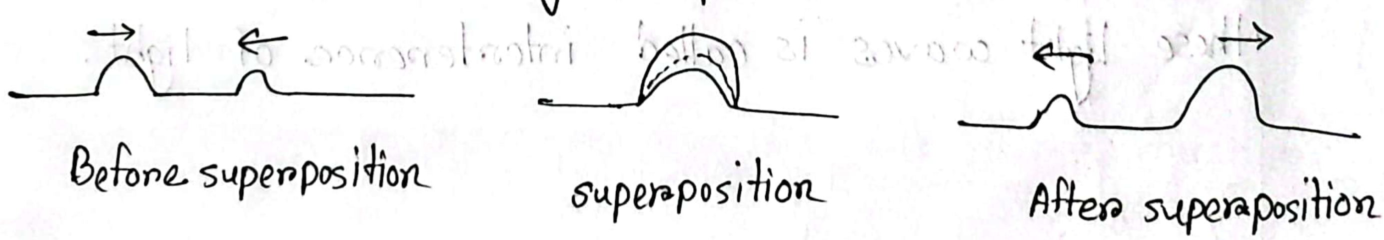
It means that the resultant is simply the sum of the disturbances.

Let two waves pass through a particle of medium.

$\Rightarrow$

When two waves of same kind meet at a point in space, the resultant displacement of that point is the vector sum of the displacements that two wave would separately produce at that point.

Let two waves pass through a particle of medium.




Let the separate displacement of the particle by individual wave be $y_1$ and $y_2$. If the two wave are incident with the same phase, then the resultant displacement of the particle,

$$y = y_1 + y_2$$

On the otherhand, If these two waves are incident on the particle in opposite phase then the resultant displacement,

$$y = y_1 \sim y_2$$

## ▣ What do you mean by interference?

## ▣ Interference:

When two or more light wave from different coherent sources meet together, then the distribution of energy due to one wave is disturbed by the other. This modification of distribution of light energy due to superposition of these light waves is called interference of light.

Write down the condition of interference :

→ (A) Condition for sustained interference –

(i) The two source of light wave must be coherent.

(ii) The two light wave from the two sources must be of the same frequency, fixed phase difference, time period. that means coherent.

(iii) The path difference between the overlaping waves must be less than the coherence length of the waves.

(iv) If the two sets of waves are plane polarized, their planes of polarization must be the same.

(B) Condition for distinct pattern :

(v) The two coherent sources must lie close to each other in order to discern the fringe pattern. If the sources are far apart, the fringe width will be very small and fringes are not seen separately.

(vi) The distance of the screen from the two source must be large.

(vii) The vector sum of the overlapping electric field vectors should be zero in the dark regions for obtaining distinct bright and dark fringes.

## Type of interference :

Two types of interference -

(i) Constructive interference
(ii) Destructive interference

(i) Constructive interference :

When both the wave are transmitted in the same phase and are superimposed on each other so the maximum ~~resultant~~ value of intensity is attained, this is called the constructive interference.

The value of resultant amplitude and intensity is maximum

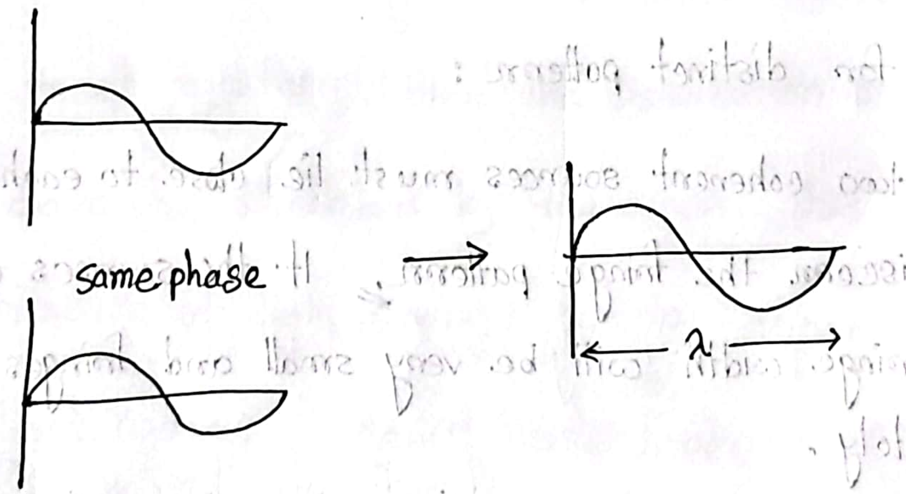
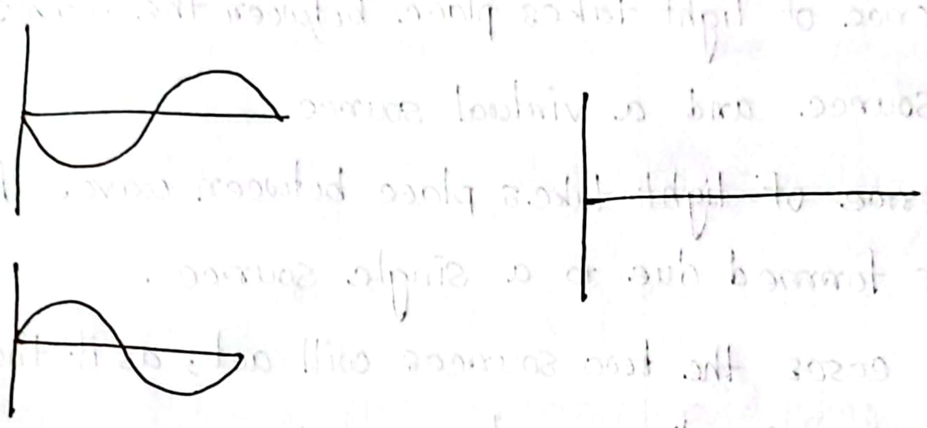



Fig. constructive interference

(ii) Distructive interference :

Whenever two waves move together in the same direction and if they meet in opposite phases at any point, the resultant intensity at this point is minimum or zero. This is called Destructive interference.



Destructive interference

⊡ Coherent source :

Two sources are said to be coherent if they emit light waves of same frequency, nearly the same amplitude and are always in phase with each other. It means that the two sources must emit radiations of the same colour (wavelength)

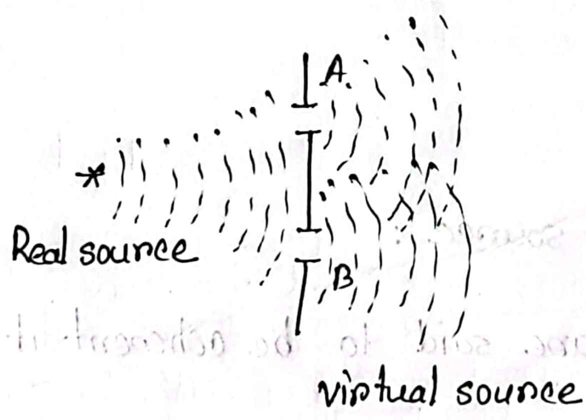
Example - Leser light.

In actual practice it is not possible to have two independent sources which are coherent. But for experimental purposes two virtual sources formed from a single source can act as coherent sources. Methods have been devised where,

(i) interference of light takes place between the waves from the real source and a virtual source.

(ii) interference of light takes place between waves from two sources formed due to a single source.

In all such cases the two sources will act, as if they are perfectly similar in all respects.




Since the wavelength of light waves is extremely small (of the order of $10^{-5}$cm), the two sources must be narrow and must also be close to each other. Maximum intensity is observed at a point where the phase difference between the two waves reaching the point is a whole number multiple of $2\pi$ or the path difference between the two waves is a whole number multiple of wavelength. For minimum intensity at a point, the phase difference between the two waves reaching the point should be an odd number multiple of $\pi$ or the path difference between the two waves should be an odd number multiple of half wavelength.

## Relation between path difference and phase difference.

If the path difference between the two waves is $\lambda$ the phase difference is $2\pi$.

Suppose for a path difference $x$, the phase difference is $\delta$

For a path difference $\lambda$, the phase difference $= 2\pi$

For a path " $x$ " " " $= \frac{2\pi x}{\lambda}$

$\therefore$ Phase difference $\delta = \frac{2\pi x}{\lambda} = \frac{2\pi}{\lambda} \times$ Path difference.

## Describe Youngs Double slit experiment:

In 1801 famous scientist Young performed an experiment to demonstrate the interference of light. In this honour this experiment is known as Young's experiment.

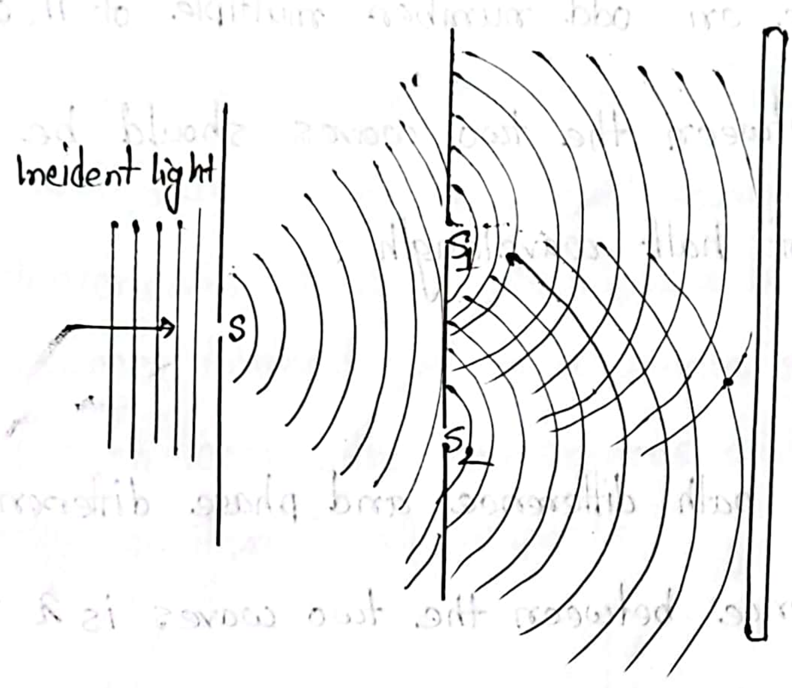



Fig.1

Fig.1 shows a plan view of the basic arrangement of the double slit experiment. The primary light ~~shour~~ source is a monocromatic source; it is generally a sodium lamp which emits yellow light of wavelength at around 5893A°.

This light is not suitabe for causing interferene because emitions from differents parts of any ordinary source are not coherent. Therefore, the monacromatic light is allowed to pass through a narrow slit at s. The light coming out of the slit originated from only a small region of the light source. and hence behaves more nearly like an ideal light source.

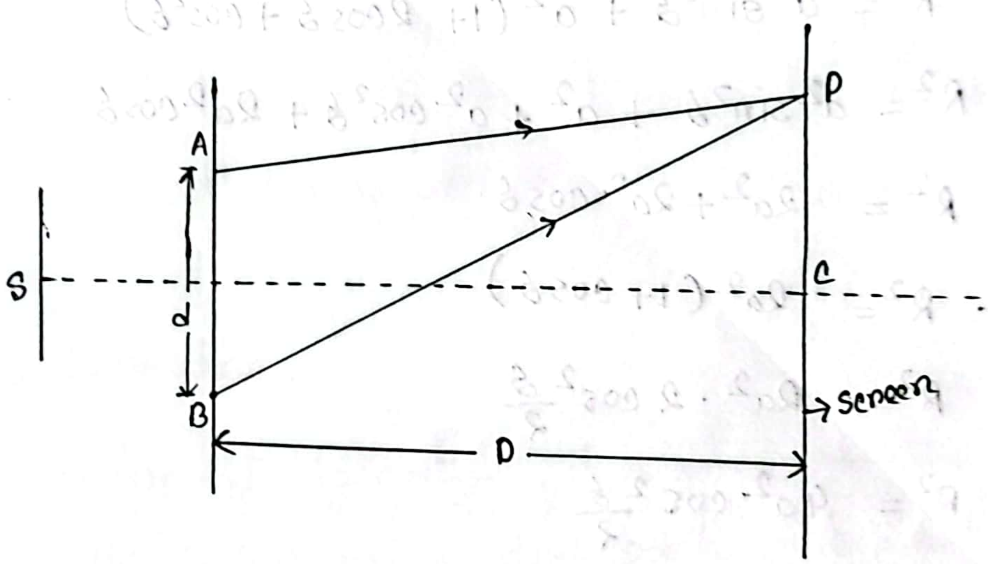
Cylindrical wavefronts are produced from the slit S, the primary light source, which fall on the two narrow closely spaced slits, $S_1$ and $S_2$ as shown in Fig.1. The slits at $S_1$ and $S_2$ are very narrow. The cylindrical waves emerging from the slits overlap. If the slits are equidistance from S, the phase of the wave at $S_1$ will be the same as the phase of the wave at $S_2$. Further, waves leaving $S_1$ and $S_2$ are therefore always in phase, Hence $S_1$ and $S_2$ act as the secondary coherent ~~sho~~ sources. The wave leaving from $S_1$ and $S_2$ interfere and produced alternate bright and dark band on the screen T.

The points where the crests due to one wave coincides with the crest due to the other, therefore, the reinforce with each other is bright and the points where the crest of one wave falls on the ~~t~~ trough of the other and they neutralize the effect of each others is dark.

## Mathematical analysis for Youngs double slit experiment:

☐ Describe the analytical treatment of interference.

Consider a monochromatic source of light S emitting waves of wavelength $\lambda$ and two narrow pinholes A and B. A and B are equidistant from S and act as two virtual coherent sources. Let a be the amplitude of the waves. The phase difference between the two waves reaching the point P, at any instant, is $\delta$




If $y_1$ and $y_2$ are the displacements.

$$y_1 = a \sin \omega t$$
$$y_2 = a \sin(\omega t + \delta)$$

$$\therefore y = y_1 + y_2 = a \sin \omega t + a \sin(\omega t + \delta)$$

$$= a \sin \omega t + a \sin \omega t \cos \delta + a \cos \omega t \sin \delta$$

$$= a \sin \omega t (1 + \cos \delta) + a \sin \delta \cos \omega t$$

Taking $a(1 + \cos \delta) = R \cos \theta$ ——(1)

and, $a \sin \delta = R \sin \theta$ ——(2)

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

$$= R\sin(\omega t+\theta) \quad \text{---} (3)$$

which represent the equation of simple harmonic vibration of amplitude R. Squaring (1) and (2) and adding,

$$R^2\sin^2\theta + R^2\cos^2\theta = a^2\sin^2\delta + a^2(1+\cos\delta)^2$$

$$\Rightarrow R^2 = a^2\sin^2\delta + a^2(1+2\cos\delta+\cos^2\delta)$$

$$\Rightarrow R^2 = a^2\sin^2\delta + a^2 + a^2\cos^2\delta + 2a^2\cos\delta$$

$$\Rightarrow R^2 = 2a^2 + 2a^2\cos\delta$$

$$\Rightarrow R^2 = 2a^2(1+\cos\delta)$$

$$\Rightarrow R^2 = 2a^2 \cdot 2\cos^2\frac{\delta}{2}$$

$$\Rightarrow R^2 = 4a^2\cos^2\frac{\delta}{2}$$

The intensity at a point is given by the square of the amplitude.

$$I = R^2$$

$$\Rightarrow I = 4a^2\cos^2\frac{\delta}{2} \quad \text{---} (4)$$

Special case:

(i) When the phase difference $\delta = 0, 2\pi, 2(2\pi), \ldots n(2\pi)$

or the path difference $x = 0, \lambda, 2\lambda \ldots n\lambda$.

$$I = 4a^2$$

Intensity is maximum when the phase difference is a whole number multiple of $2\pi$ or the path difference is a whole number multiple of wave length.

(ii) When the phase difference $\delta = \pi, 3\pi \ldots (2n+1)\pi$ or the path difference $x = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2} \ldots (2n+1)\frac{\lambda}{2}$.

$$I = 0$$

Intensity is minimum when the path difference ~~$\delta = \pi, 3\pi$~~ is an odd number multiple of half wavelength.

(iii) Energy distribution :

From the equation $I = 4a^2\cos^2\frac{\delta}{2}$, it is found that the intensity at bright points is $4a^2$ and at dark points it is zero. According to the law of conservation of energy, the energy cannot be destroyed

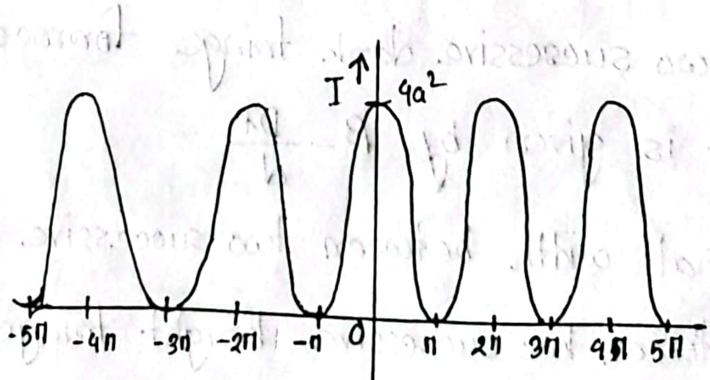



Fig. 2

Here also the energy is not destroyed but only ~~transm~~ transferred from the points of minimum intensity to the points of maximum intensity. For at bright points, the intensity due to the two waves should be $2a^2$ but actually it is $4a^2$. As shown in Fig.2 the intensity varies from 0 to $4a^2$, and the average is still $2a^2$. It is equal to the uniform intensity $2a^2$ which will be present in the absence of the interference pheonomenon due to the two waves.

Therefor the interference fringes is in accordance with the law of conservation of energy.

☐ Deduce / Obtain the fringe width, $\beta = \frac{D\lambda}{d}$.

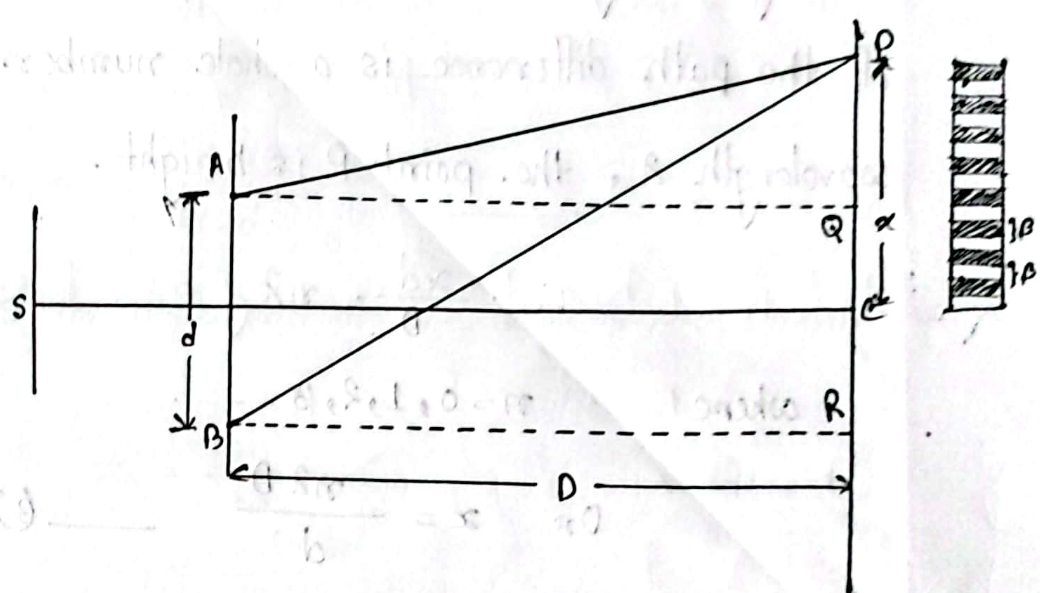
☐ Prove that $\beta = \frac{D\lambda}{d}$

☐ Prove that the distance between two successive bright fringe / two sucessive dark fringe formed in Young's experiment is given by $\beta = \frac{D\lambda}{d}$

☐ Prove that width between two successive dark fringe = width between two successive bright fringe.

☐ Describe the theory of interference ~~of~~ fringes.

⇒ Consider a narrow monochromatic source S and two pinholes. A and B equidistant from S. A and B act as two coherent sources separated by a distance d. Let a screen be placed at a distance D from the coherent source. The point C on the screen is equidistant from A and B. Therefore the path difference between the two waves is zero. Thus the point C has maximum intensity.




Consider a point P at a distance x from C. The waves reach at the point P from A and B.

Here, $PQ = x - \frac{d}{2}$ , $PR = x + \frac{d}{2}$

$$(BP)^2 - (AP)^2 = \left[D^2 + \left(x + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(x - \frac{d}{2}\right)^2\right]$$

$$\Rightarrow (BP)^2 - (AP)^2 = 2xd$$

$$\Rightarrow (BP + AP)(BP - AP) = 2xd$$

$$\Rightarrow BP - AP = \frac{2xd}{BP + AP}$$

But $BP = AP = D$ (Approximately)

$\therefore$ Path difference $= BP - AP = \frac{2xd}{2D} = \frac{xd}{D}$ ——— (1)

Phase difference $= \frac{2\pi}{\lambda}\left(\frac{xd}{D}\right)$ ——— (2)

(i) Bright fringe:

If the path difference is a whole number multiple of wavelength $\lambda$, the point P is bright.

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

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

Or $x = \frac{n\lambda D}{d}$ ——— (3)

This equation gives the distances of the bright fringes from the point C. At C, the path difference is zero and a bright fringe is formed.

When $n = 1$, $x_1 = \frac{\lambda D}{d}$

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

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

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

Therefore the difference between any two consecutive bright fringes,

$$x_2 - x_1 = \frac{2\lambda D}{d} - \frac{\lambda D}{d} = \frac{\lambda D}{d} \quad \text{——(4)}$$

(ii) Dark fringes :

If the path difference is an odd number o'multiple of half wavelength, the P point is dark.

$$\frac{xd}{D} = (2n+1)\frac{\lambda}{2} \quad \text{where } n = 0, 1, 2, 3 \ldots$$

$$x = \frac{(2n+1)\lambda D}{2d} \quad \text{——(5)}$$

This equation gives the distances of the dark fringes from the point C.

When , $n = 0 \qquad x_0 = \frac{\lambda D}{2d}$

$n = 1 \qquad x_1 = \frac{3\lambda D}{2d}$

$n = 2 \qquad x_2 = \frac{5\lambda D}{2d}$

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

The distance between any two consecutive dark fringes,

$$x_2 - x_1 = \frac{5\lambda D}{2d} - \frac{3\lambda D}{2d} = \frac{\lambda D}{d}.$$

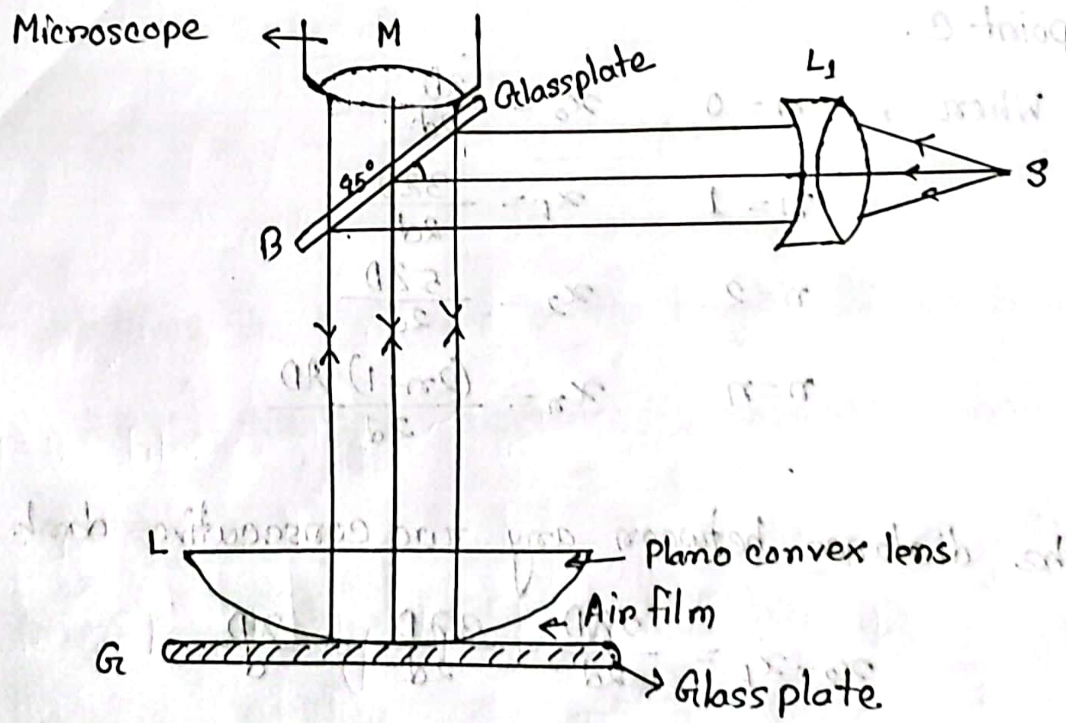
Q. Define Newton's rings.

Newton's ring is a phenomenon in which an interference pattern is created by the reflection of light between two surface ; a spherical surface and an adjacent touching flat surface.

It is named after Isaac Newton, who investigated the effect in his 1704 treatise optics.

Q. Explain how Newton's ring are formed.

⇒



"Newtons rings are formed as a result of interference between the light waves reflected from the top and bottom surfaces of the air film formed between the lens and the glass plate. When a ray is incident on the surface of the lens, it is reflected as well as refracted."

When a plano-convex lens of long focal length is placed on a plane glass plate, a thin ~~A~~ film of air is enclosed between the lower surface of the lens and the upper surface of the plate. The thickness of the air film is very small at the point of contact and gradually increases from the centre outwards. The fringes produced with monochromatic light are circular. The fringes are concentric circles, uniform in thickness and with the point of contact as the centre. When viewed with white light, the fringes are coloured. With monochromatic light, bright and dark circular fringes are produced in the air film.

S is a source of monochromatic light at the focus of the lens $L_1$. A horizontal beam of light falls on the glass plate B at 45°. The glass plate B reflects a part of the incident light towards the air film enclosed by the lens L and the glass plate G. The reflected beam from the air film is viewed with ~~m~~ a microscope. Interference takes place and dark and bright circular fringes are produced. This is due to the interference between the light reflected from the lower surface of the lens and the upper surface of the glass plate G.

Q. Why Newton's ring are circular?

⇒ The optical path difference between two light rays reflected from the thin film used in Newton's ring experiment is given by,

$$A = 2\mu t \cos(r+\theta) \pm \frac{\lambda}{2}$$

Condition of max. and min. depend on $\mu$, $r$, $\theta$, $\lambda$ and $t$. As the thickness of the film created is constant along the circle. the interference pattern will be circular. The light passing through the lens of equal intensity depends upon the thickness of the air gap between the lens and the glass plate.

The path difference between the reflected ray and incident ray depends upon the thickness of the air gap between lens and the base. As the lens is symmetic along its axis, the thickness is constant along the circumference of a ring of a given radius. Hence Newton's rings are circular. Reflection of light depend on the thickness of air flim between planoconvex lense and glass plate. এবং Point of contact থেকে একই নির্দিষ্ট দূরত্বে অবস্থিত বিন্দুর thicness সমান। ~~which give the radius of a cir.~~ এই thickness constant হওয়ায় গোলাকার circle view

□ Why centre of the Newton ring is dark?

⇒ The centre of the ring ~~dark~~ in Newton's Rings experiment with reflected light is dark because at the point of contact the path difference is zero but optical path is not zero. One of the ~~ray in the~~ centre interfering ray is reflected ~~so~~ from the ~~plane surface~~ of the air film suffers a phase difference of 180°. so the effective ~~ph~~ path difference become $\lambda/2$. Thus the condition of minimum intensity is created. Hence the centre of the ring pattern is ~~zero~~ dark.

## Application of Newton's ring -

1. Determination of wavelength of light / monocromatic light.

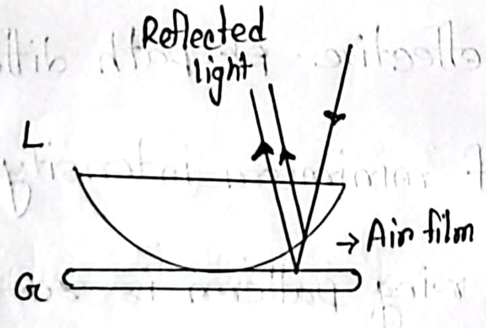
$$\lambda = [r_{m+n}^2 - r_n^2] / mR$$

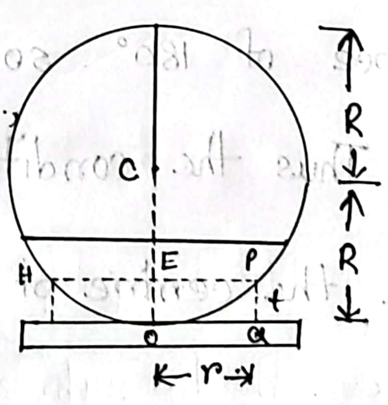
2. Determination of radius of curvature of a plan convex lens.

3. Used to measure refractive index of material,

$$\mu = r_n^2 / r_n'^2$$

## Newton's ring by reflected light:




Suppose the radius of curvature of the lens is R and the air film is of thickness t at a distance of OQ = r from the point of contact O.

Here the interference is due to reflected light. Therefore for bright rings,

$$2\mu t\cos\theta = (2n-1)\lambda/2 \quad \text{——(1)}$$

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

Here $\theta$ is small, $\cos\theta = 1$

For air $\mu = 1$

$$\therefore \; 2t = (2n-1)\lambda/2 \quad \text{——(2)}$$

For dark rings,

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

Or, $2t = n\lambda$ ——(3)

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

From fig. $EP \times HE = OE \times (2R - OE)$

But $EP = HE = r$, $OE = PQ = t$

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

Again $(2R - t) = 2R$ (approximately)

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

$$\Rightarrow t = \frac{r^2}{2R}$$

Substituting the value of $t$ in equation (11) and (3)

For bright rings,

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

$$r = \sqrt{\frac{(2n-1)\lambda R}{2}} \quad \text{——— (4)}$$

For dark rings,

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

$$r = \sqrt{n\lambda R} \quad \text{——— (5)}$$

When $n=0$ the radius of the dark ring is zero and the radius of the bright ring is $\sqrt{\frac{\lambda R}{2}}$. Therefore the centre is dark. Alternately dark and bright rings are produced.

Result:

The radius of the dark rings is proportional to (i) $\sqrt{n}$, (ii) $\sqrt{\lambda}$ and (iii) $\sqrt{R}$. Similarly radius of the bright rings is proportional to (i) $\sqrt{\frac{2n-1}{2}}$, (ii) $\sqrt{\lambda}$ and $\sqrt{R}$.

If D is the Diameter of the dark ring,

$$D = 2r = 2\sqrt{n\lambda R} \quad \text{——— (6)}$$

For central dark ring $n = 0$,

$$D = 2\sqrt{n\lambda R} = 0$$

This corresponds to the centre of Newtons rings. While counting the order of the dark ring 1, 2, 3 etc. the central ring is not counted.

Therefore the 1st dark ring, $n = 1$

$$D_1 = 2\sqrt{\lambda R}$$

For 2nd, $n = 2$,

$$D_2 = 2\sqrt{2\lambda R}$$

and for $n$th dark ring,

$$D_n = 2\sqrt{n\lambda R}$$

Take the case of 16th and 9th rings,

$$D_{16} = 2\sqrt{16\lambda R} = 8\sqrt{\lambda R}$$

$$D_9 = 2\sqrt{9\lambda R} = 6\sqrt{\lambda R}$$

The difference in diameters between 16th and 9th dark rings,

$$D_{16} - D_9 = 8\sqrt{\lambda R} - 6\sqrt{\lambda R} = 2\sqrt{\lambda R}$$

Similarly the difference between 4th and 1st ring

$$D_4 - D_1 = 4\sqrt{\lambda R} - 2\sqrt{\lambda R} = 2\sqrt{\lambda R}$$

Therefore the fringe width decreases with the order of the fringe and the fringes got closer with increase in their order.

For bright rings,

$$r^2 = \frac{(2n-1)\lambda R}{2} \qquad \text{———} (7)$$

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

$$r_n = \sqrt{\frac{(2n-1)\lambda R}{2}} \qquad \text{———} (9)$$

In equation (7) substituting $n = 1, 2, 3 \ldots$ (number of ring) the radii of the 1st, 2nd and 3rd -- of brigh ring can be obtained directly.

## Determination of wavelength / Wavelength of sodium light using Newtons rings —

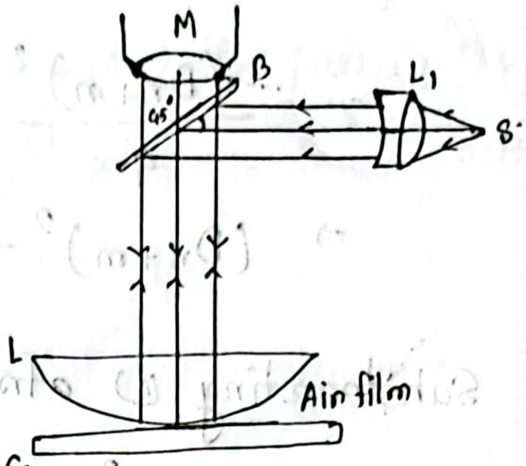



Fig. 1

From fig. 1 S is a source of sodium light. A parallel beam of light from the lens $L_1$ is reflected by the glass plate B inclined at an angle of $45°$ to the horizontal. L is a plano-convex lens of large focal length. Newton's rings are viewed through B by the travelling microscope M focussed on the air film. Circular bright and dark ring are seen with the centre dark. With the help of travelling microscope, measure the diameter of nth dark ring.

Suppose the diameter of the nth ring $= D_n$

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

But $r_n = \frac{D_n}{2}$

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

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

Measure the diameter of the n+mth dark ring.

Let it be $D_{n+m}$

$$\therefore \frac{(D_{n+m})^2}{4} = (n+m)\lambda R$$

$$\Rightarrow (D_{n+m})^2 = 4(n+m)\lambda R \quad \text{——— (ii)}$$

Substracting (i) from (ii)

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

$$\therefore \lambda = \frac{(D_{n+m})^2 - (D_n)^2}{4mR}$$

[Wavelength determination যদি ৮ মার্কের আসে তো reflected light এর calculation সহ আর তা না হলে ~~sa~~ শুধু determination of wavelength]

☐ Describe Michelson-Morley experiment and explain the significance of results.

⇒ ~~To~~ The experiment was performed by Michelson and Morley to determine the relative velocity of light with respect to earth.

Experimental arrangement:

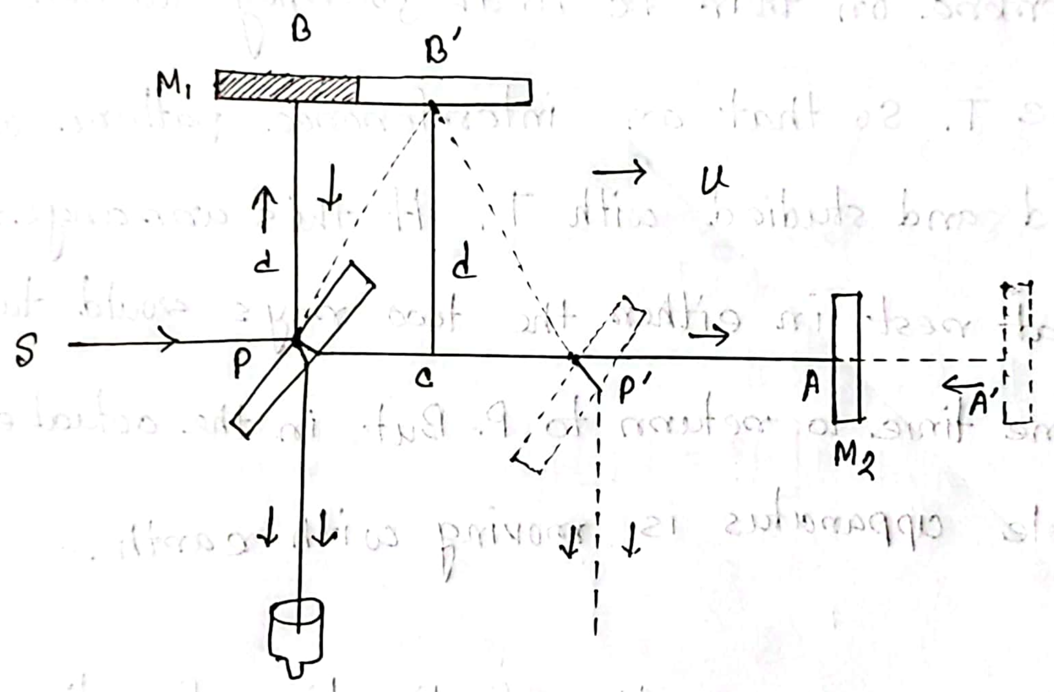



Fig. Michelson - Morley apparatus

Let us suppose that a beam of light from a monocromatic source S falls upon a ~~semi~~ glass plate P ~~pala~~ placed at 45° to the beam and is partly reflected and partly transmitted. The reflected portion travel in a direction at right angles to that of initial beam falls normally at B on a Mirror $M_1$ by which it is reflected back to P. The transmitted ~~poo~~ portion travel along the direction of the initial beam falls normally at A on another mirror $M_2$ and is reflected back to P. The two rays thus return to P interfere on their ~~fe~~ final journey towards the telescope T. So that an interference pattern can be observed and studied with T. If this arrangement were at rest in either the two rays would take the same time to return to P. But in the actual experiment the whole apparatus is moving with earth.

Let us suppose the motion of direction of motion of earth coincides with the direction of the initial beam. Thus the path of the ~~initial b~~ two rays and the time taken on their journey will no longer the equal.

Let c be the velocity of light, v be the velocity of the earth. Let $PA = PB = d$, The ray reflected from P and moving transversely will strike the mirror $M_1$ not at B but at B′ due the motion of earth. If t be the time taken by the ray starting from P to reach $M_1$ then

$$PB' = ct$$
$$BB' = vt$$

The total path of the rays until it comes ~~bat~~ back to the plate is $PB'P'$, $PP'$ being equal to $2PC = 2BB'$

Also, $PB'P' = PB' + B'P'$
$= 2PB'$ ~~sine~~ [since $B'P = B'P'$]

$$(PB')^2 = (PC)^2 + (CB')^2$$

i.e; $c^2t^2 = v^2t^2 + d^2$ [$CB' = PB$]

$$\therefore t = \frac{d}{[c^2 - v^2]^{1/2}}$$

If $t_1$ is the total time taken by the ray to travel the whole path $PB'P'$, then,

$$t_1 = 2t = \frac{2d}{[c^2 - v^2]^{1/2}}$$

$$= \frac{2d}{c}\left[1 + \frac{v^2}{2c^2}\right] = \frac{2d}{c} + \frac{2dv^2}{2c^3}$$

The ray transmitted through P and moving longitudinally towards $M_2$ has a velocity $(c-v)$ relative to the apparatus from P to A and $(c+v)$ on the return journey from A' to P' assuming that other to be at rest. If $t_2$ is the total time taken by this ray get back to the plate,

$$t_2 = \frac{d}{c-v} + \frac{d}{c+v}, \quad [\text{since } PA = P'A' = d]$$

$$\Rightarrow t_2 = \frac{2cd}{c^2 - v^2}$$

$$\therefore t_2 = \frac{2d}{c}\left(1 + \frac{v^2}{c^2}\right) = \frac{2d}{c} + \frac{2dv^2}{c^3}$$

Hence the time difference between the time to travel of the longitudinal and transvers ray is,

$$t_2 - t_1 = \frac{2\cancel{d}}{\cancel{c}} \cdot \frac{v^2}{\cancel{2}c^2} \quad \frac{dv^2}{c^3}$$

And effective optical path difference between the two ray is,

$$\delta = \frac{c(t_2 - t_1)}{\lambda} = \frac{dv^2}{c^2\lambda} \text{ wavelength.}$$

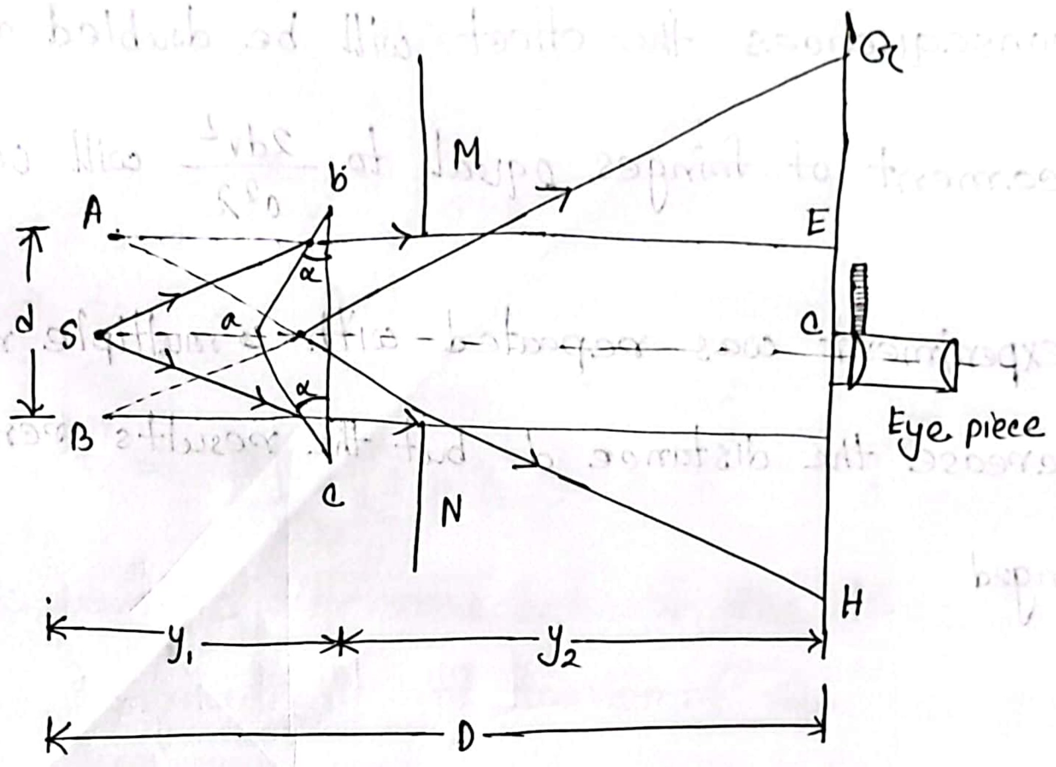
$\lambda$ being the wavelength of the light used. The interference pattarn, would accordingly be shifted by the motion through $dv^2/c^2\lambda$ fringes.

If the whole apparatus is turned through 90° the difference in path will be in the opposite directions and consequences the effect will be doubled and displacement of fringes equal to $\frac{2dv^2}{c^2\lambda}$ will occur.

The experiment was repeated with multiple mirrors to increase the distance d but the results remains unchanged.

## Biprism

Fresnel used a biprism to show interference phenomenon. The biprism abc consists of two acute angled prism placed base to base. Actually, it is constructed as a single prism of obtuse angle of about 179°. Acute angle a on both sides is about 30′/ ½°. The prism placed with it refracting edge parallel to the line source S(slit) such that Sa is normal to the face bc of the prism. When light falls from S on the lower portion of the biprism it is bent upwards and appears to come from the virtual source,




B similarly light falling from S on the upper portion of the prism is bent downwards and apears to come from the virtual source A. Therefore A and B act as two coherent sources. Suppose the distance between A and B = d. If a screen is placed at C. interference frienges equal width are produced between E and F but beyond E and F fringes of large width are produced which are due to diffraction. MN is a stop to limit the rays. To observe the fringes, the screen can be replaced by an eye piece or a low power microscope and fringes are seen in the field of view. If the point C is at the principal focus of the eye piece, the fringes are observed in the field of view.

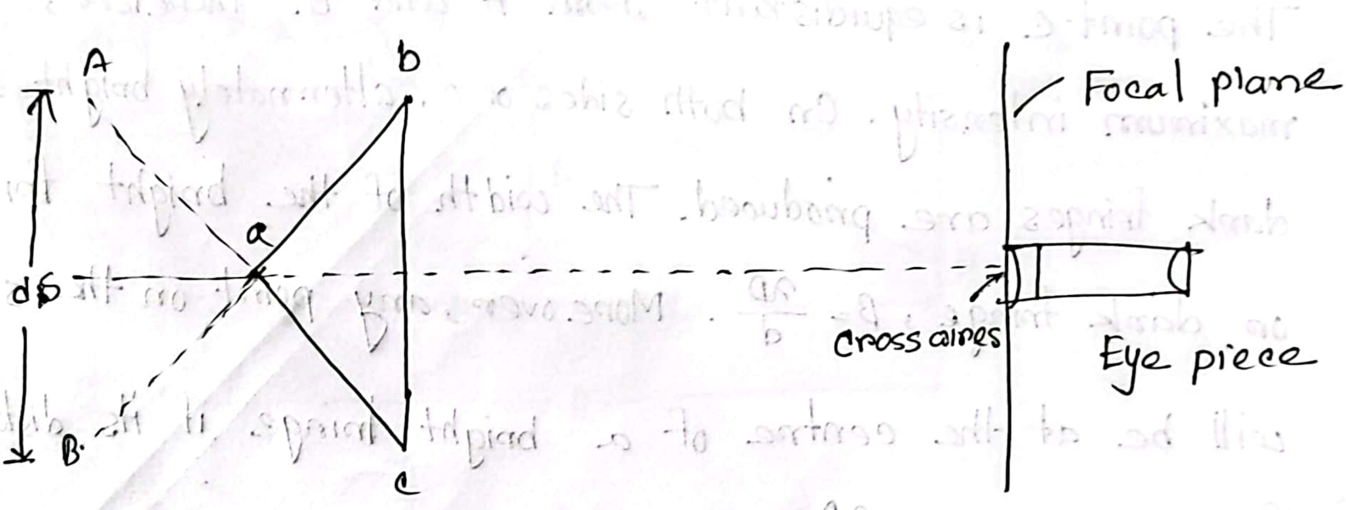
Theory:

The point C is equidistant from A and B. Therefore, it has maximum intensity. On both sides of C, alternately bright and dark fringes are produced. The width of the bright fringes or dark fringe, $\beta = \frac{\lambda D}{d}$. Moreover, any point on the screen will be at the centre of a bright fringe if its distance from C is $\beta = \frac{n\lambda D}{d}$, where $n = 0, 1, 2, 3 ----$. The point will be at the centre of a dark fringe if its distance from C is $\frac{(2n+1)\lambda D}{2d}$ where $n = 0, 1, 2, 3 --$.

Determination of wavelength of light:

Fresnel's biprism can be used to determine the wavelength of a given source of monocromatic light.

A fine virtical slit S is adjusted just close to a source of light and the refracting edge is also set parallel to the slit S such that be is horizontal.




They are adjusted on an optical bench. A micrometer eye piece is placed on the optical bench at some distance from the prism to view the fringes in its focal plane at its cross wire.

Let us suppose the distance between the

source and the eye piece = D. and distance between two virtual source A and B = d. ~~Then the wave~~ And fringe width is $\beta$. then the wavelength is,

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

# Diffraction

☐ What do you mean by diffraction?

☐ Define diffraction.

Bending of light near the edges of an obstacle or slit and spreading into the region of geometrical shadow is known as diffraction of light.

or,

~~Diffraction is the slight bending depends on the relative size of the~~

or,

Diffraction is the slight bending of light as it passes around the edge of an object. The amount of bending depends on the ~~edge of an object~~ relative size of the wavelength of light to the size of the opening. If the opening is much larger than the light's wavelength, the bending will be almost unnoticeable

☐ Type of diffraction:

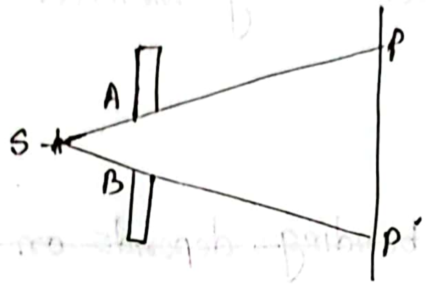
There are two types of diffraction:

(1) Fresnel diffraction

(2) Fraunhofer diffraction.

(1) Fresnel diffraction :

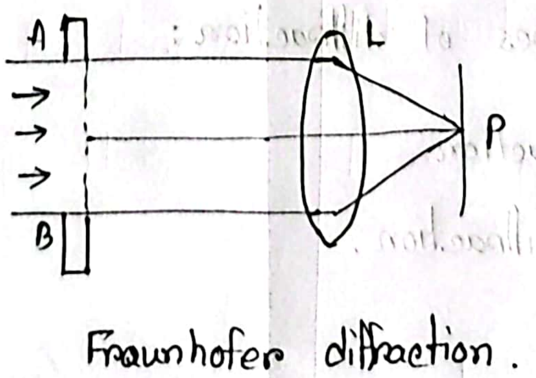
When source of light or the screen on which the diffraction pattern is observed or both are effectively at finite distance from the aperture causes the diffraction of light is called Fresnel diffraction.




Fresnel diffraction

(2) Fraunhofer diffraction :

When the source of light or the screen on which the diffraction pattern is observed or both are effectively at infinite distance from the aperture causes the diffraction of light is called Fraunhofer diffraction.




Fraunhofer diffraction.

## Distinguish between Fresnel and Fraunhofer diffraction –

| Fresnel | Fraunhofer |
|---|---|
| 1. The source or the screen or both are at finite distances from the aperture or obstacle causing diffraction. | 1. The source or the screen or both are at infinite distances from the aperture or obstacle causing the diffraction |
| 2. Observation of Fresnel diffraction does not required any lense. | 2. More than one lens is required to occur the diffraction. |
| 3. Incident wavefront will be spherical or cylindrical. | 3. Incident wavefront ~~with~~ will be always plane. |
| 4. It is difficult to treat theoritically. | 4. It is difficult to treat experimentally. |
| 5. Fresnel diffraction is observed on spherical surfaces. | 5. Observed in flat surface. |
| 6. This diffraction is also known as Near field diffraction | 6. Far field diffraction |
| 7. The diffraction pattern formed in this type of diffraction change if we move downstream of the diffraction. The shape as well as the intensity of the diffraction also changes. | 7. do no change, they are constant throughout the pattern and the shape as well as the intensity of the diffraction remains constant. |

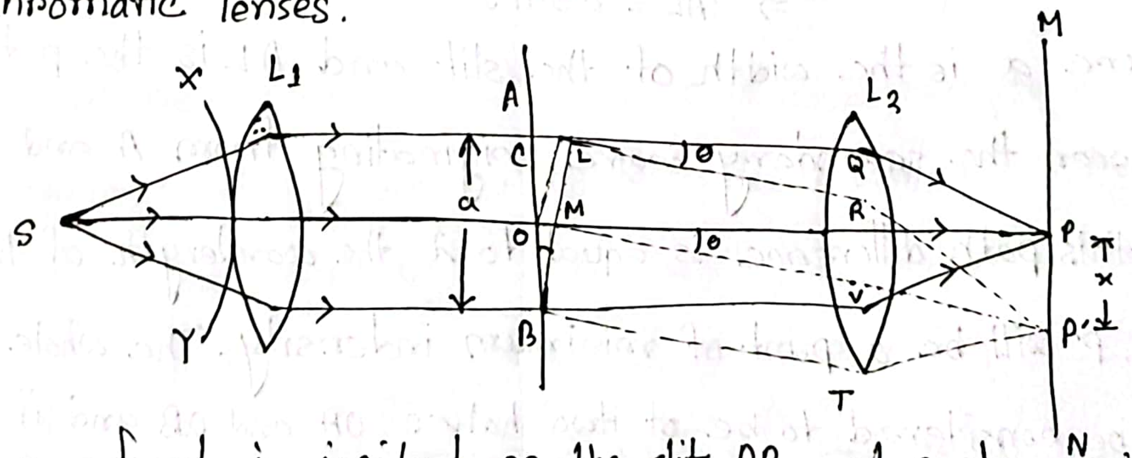
## Distinguish between interference and diffraction-

| Parameter | Interference | Diffraction |
|---|---|---|
| Definition | 1. When two wave from different coherent sources meet togather, their distribution of energy due to one wave is disturbed by the others. This modification of distribution of light energy due to super position of two light wave is called interference. | |
| Occurrence | It occurs ~~because of~~ due to the light waves superposition that is from two sources. | It occurs because of the secondary wavelengths superposition. |
| Width of fringes | Equal | Unequal. |
| Intensity of fringes | Same fringe intensity for all the fringes. | Not same for all the fringes. |
| Obstacle or slit | There is not a requirement for it. | Slit or obstacle is required |
| Fringe spacing | Uniform in case of interference | Not - uniform in case of diffraction |
| Wave propagation direction | It does not change after a superposition. | It changes after diffraction. |
| Contrast between maxima Minima | contrast between maxima and minima is certainly good | poor. |

## [2] Fraunhofer diffraction at a single slit:

To obtain a Fraunhofer diffraction pattern the incident wavefront must be plane and diffracted light is collected on the screen without the help of lense. Thus the source of light should either be at a large distance from the slit or a collimating lens must be used.

S is a narrow slit perpendicular to the plane of the paper and illuminated by monochromatic light. $L_1$ is the collimating lens and AB is a slit of width a. XY is the incident spherical wavefront. The light passing through the slit AB is incident on the lens $L_2$ and the final refracted beam is observed on the screen MN. The screen is perpendicular to the plane of the paper. The line SP is perpendicular to the screen, $L_1$ and $L_2$ are achromatic lenses.




A plane wavefront is incident on the slit AB and each point on this wavefront is a source of secondary disturbance. The secondary waves travelling in the direction parallel to OP viz. AQ AQ and BV come to focus at P and a bright central image is observed. The secondary waves from points equidistant from O and situated in the upper and lower halves OA and OB of the wavefront travel the same distance in reaching P and hence the path difference is zero. The secondary waves reinforce one another and P will be a point of maximum intensity.

Now consider the secondary waves travelling in the direction AR, inclined at an angle $\theta$ to the direction OP. All the secondary wave travelling in this direction reach the point P' on the screen. The point P' will be of maximum or minimum intensity depending on the path difference of the wavefront. Draw OC and BL perpendiculars to AR.

Then in the $\Delta ABL$,

$$\sin\theta = \frac{AL}{AB} = \frac{AL}{a}$$

$$\Rightarrow \quad AL = a\sin\theta$$

where a is the width of the slit and AL is the path difference between the secondary wave originating from A and B.

If this path difference is equal to $\lambda$ the wavelength of light used then P' will be a point of minimum intensity. The whole wavefront can be considered to be of two halves OA and OB and if the path difference between the secondary waves from A and B is $\lambda$, then path difference between A and O will be $\lambda/2$. Similarly OB $= \lambda/2$.

Thus, destructive interference takes place and the point P' will be of minimum intensity. If the direction of the secondary waves is such that $AL = 2\lambda$, then also the point where they meet the screen will be minimum intensity. This is so because the secondary waves from the corresponding points of the lower half, differ in path by $\lambda/2$ and this again gives the position of minimum intensity.

In general, $a \sin\theta_n = n\lambda$

$$\Rightarrow \sin\theta_n = \frac{n\lambda}{a}$$

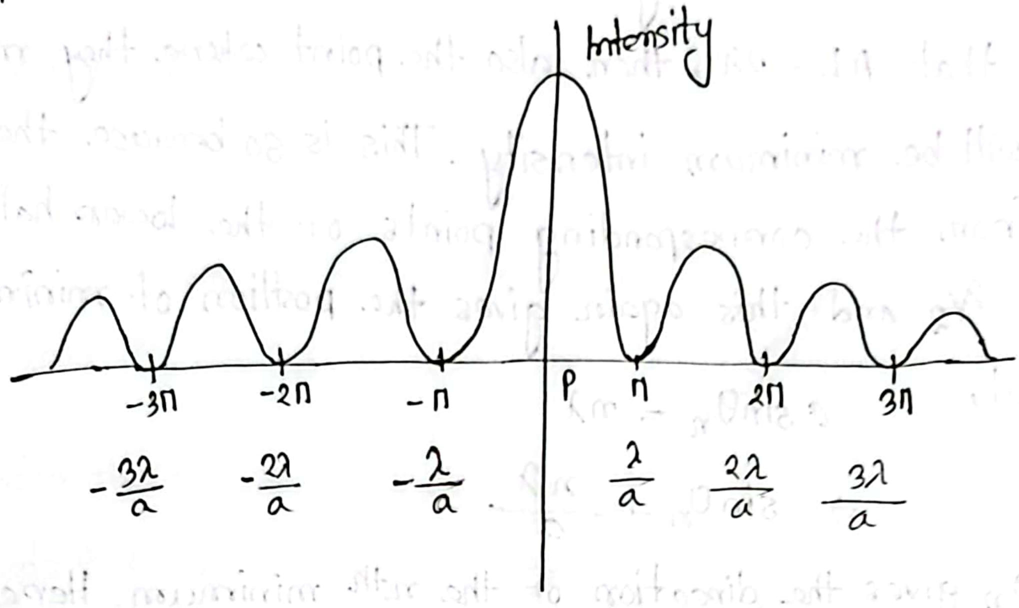
where $\theta_n$ gives the direction of the nth minimum. Here $n$ is an integer.

If, however, the path difference is odd multiples of $\lambda/2$, the direction of the secondary maxima can be obtained. In this case,

$$a \sin\theta_n = (2n+1)\lambda/2$$

$$\Rightarrow \sin\theta_n = \frac{(2n+1)\lambda}{2a} \qquad n = 1, 2, 3 \ldots$$

Thus, the diffraction pattern due to a single slit consists of a central bright maximum at P followed by secondary maxima and minima on both sides. The intensity distribution on the screen is given in Fig. 1. P corresponds to the position of the central bright maximum and the points on the screen for which the path difference between the points A and B is $\lambda$, $2\lambda$ etc. corresponds to the positions of secondary minima. The secondary maxima are of much less intensity. The intensity falls off rapidly from the point P outwards.




If the lens $L_2$ is very near the slit or the screen is far away from the lens $L_2$ then,

$$\sin\theta = \frac{x}{f} \quad \text{——— (1)}$$

where f is the focal length of the lens $L_2$

But $\sin\theta = \frac{\lambda}{a}$

$$\therefore \frac{x}{f} = \frac{\lambda}{a}$$

$$\Rightarrow x = \frac{f\lambda}{a} \quad \text{——— (2)}$$

where $x$ is the distance of the secondary minimum from the point P. Thus, the width of the central maximum $= 2x$

$$2x = \frac{2f\lambda}{a} \quad \text{——— (3)}$$

The width of the central maximum is proportional to $\lambda$, the wave length of light. With red light (longer wavelength), the width of the central maximum is more than with violet light (shorter wavelength). With a narrow slit, the width of the central maximum

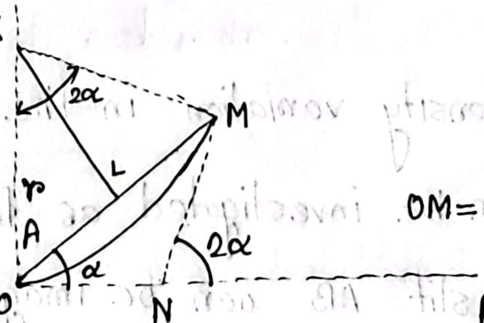
maximum is more. The diffraction pattern consists of alternate bright and dark bands with monochromatic light. With white light the central maximum is white and the rest of the diffraction bands are coloured. From equation (11), if the width a of the slit is large, $\sin\theta$ is small and hence $\theta$ is small. The maxima and minima are very close to the central maximum at P. But with a narrow slit, a is small and hence $\theta$ is large. This results a distinct diffraction maxima and minima on both the sides of P.

☐ Deduce / Derive the expression for intensity of Fraunhofer diffraction due to single slit.

☐ Intensity distribution in the diffraction pattern due to a single slit —

The intensity variation in the diffraction pattern due to a single slit can be investigated as follows. The incident plane wavefront on the slit AB can be imagined to be divided into a large number of infinitesimally small strips. The path difference between the secondary waves emanating from the extreme points A and B is $a\sin\theta$ where a is the width of the slit and $\angle ABL = \theta$.

For a parallel beam of incident light, the amplitude of vibration of the waves from each strip can be taken to be the same. As one considers the secondary waves in a direction inclined at an angle $\theta$ from the point B upwards, the path difference change and hence the phase difference also increases. Let $\alpha$ be the phase difference between the secondary waves from the points B and A. of the slit. As the wavefront is divided into a large number of strips, the resultant amplitude due to the individual small strips can be obtained by the vector polygon method. Here amplitude are small and the phase difference increases by infinetesimally small amounts from strip to strip. Thus, the vibration polygon coincides with the circular arc OM. OP gives the direction of the initial vector and NM the direction of the final vector due to the secondary waves from A. K is the centre of the circular arc.



$$\angle MNP = 2\alpha$$

$$\therefore \angle OKM = 2\alpha$$

In the $\Delta OKL$,

$$\sin\alpha = \frac{OL}{r} \; ; \; OL = r\sin\alpha$$

where $r$ is the radius of the circular arc

$$\therefore \text{Chord } OM = 2OL = 2r\sin\alpha \qquad \text{———(1)}$$

The length of the arc OM is ~~t~~ proportional to the width of -

$$\therefore \text{Length of the arc } OM = ka$$

where, k is a constant and a is the width of the slit.

$$\text{Also,} \qquad 2\alpha = \frac{\text{Arc } OM}{\text{radius}} = \frac{ka}{r}$$

$$\Rightarrow 2r = \frac{ka}{\alpha} \qquad \text{———(2)}$$

Substituting this value of $2r$ in equation (1),

$$\text{Chord } OM = \frac{ka}{\alpha}\sin\alpha$$

~~⇒ A = A~~

But $OM = A$ where A is the amplitude of the resultant.

$$A = (ka)\frac{\sin\alpha}{\alpha}$$

$$\Rightarrow A = A_0 \frac{\sin\alpha}{\alpha} \qquad \text{———(3)}$$

Thus the resultant amplitude of vibration at a point on the is given by $A_0 \frac{\sin\alpha}{\alpha}$ and the intensity $I$ at the point is gi

$$I = A^2 = A_0^2 \frac{\sin^2\alpha}{\alpha^2} = I_0\left(\frac{\sin\alpha}{\alpha}\right)^2 \qquad \text{———(4)}$$

The intensity at any point on the screen is proportional to $\left(\frac{\sin\alpha}{\alpha}\right)^2$. A phase difference of $2\pi$ corresponds to a path difference of $\lambda$. Therefore a phase difference of $2\alpha$ is given by,

$$2\alpha = \frac{2\pi}{\lambda} a\sin\theta \quad \text{———} (5)$$

where $a\sin\theta$ is the path difference between the secondary waves from A and B

$$\alpha = \frac{\pi}{\lambda} a\sin\theta \quad \text{———} (6)$$

Thus, the value of $\alpha$ depends on the angle of diffraction $\theta$.

The value of $\frac{\sin^2\alpha}{\alpha^2}$ for ~~diffracte~~ different values of $\theta$ gives the intensity ~~distribution~~ at the point under consideration.

Condition for minimum:

If $\theta_n$ be the angle of diffraction for the $n^{th}$ minimum on either sides of the point then,

$$a\sin\theta_n = n\lambda \quad n = 1, 2, 3 - - .$$

Condition for maximum:

If $\theta_n$ be the angle of diffraction for the $n^{th}$ maximum on either sides of the point then,

$$a\sin\theta_n = (2n+1)\lambda/2$$

## 4 Intensity pattern for Fraunhofer diffraction at a double slit:

As shown in the figure.1 AB and CD are two rectangular slits parallel to one another and perpendicular to the plane of the paper. The width of each slit is a and the width of the opaque portion is b. L is a collecting lens and ~~MA~~ MN is a screen perpendicular to the plane of the paper. P is a point on the screen such that OP is perpendicular to the screen. Let a plane wavefront be incident on the surface of XY. All the secondary waves travelling in a direction parallel to OP come to focus at P. Therefore, P corresponds to the position of the central bright maximum.

☒ Define grating, plane diffraction grating, grating constant.

## Grating :

A diffracting grating is an optical element that divides (disperses) light composed of lots of different wavelengths (e.g. white light) into light components by wavelength.

## Plane diffraction grating:

A plane diffraction grating is an arrangement which is equivalent in action to large number of parallel and equidistance slits of same width.

Construction —

It is constructed by rulling equidistance parallel lines on a transparent material ~~by~~ such as glass plate by means of a fine diamond point worked with a rulling engine. The ruled line act as opeque wires and thus light can not pass through them. Light passes through the space in between the lines. Thus the's ~~lines~~ space act as multiple line.

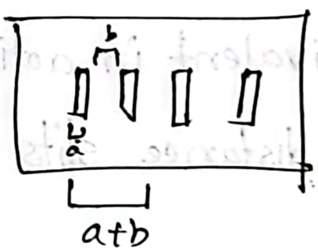
## Grating constant:

For a diffraction grating, the grating constant is the number of lines or slit per unit length (eg per lines per cm).

The distance between grating lines is $1/\text{grating constant}$.

If the width of each slit is a and opaque spacing between two consequtive slits is b. (a+b) is called grating element, ~~or grating constant~~

$$\frac{1}{N} = (a+b)$$




N is grating constant.

## Resolving power:

- Resolving power of an optical instrument is defined as the ratio of the wavelength of a spectral of the least difference in wavelength of the next spectral line that can just be seen as ~~sper~~ separated line.

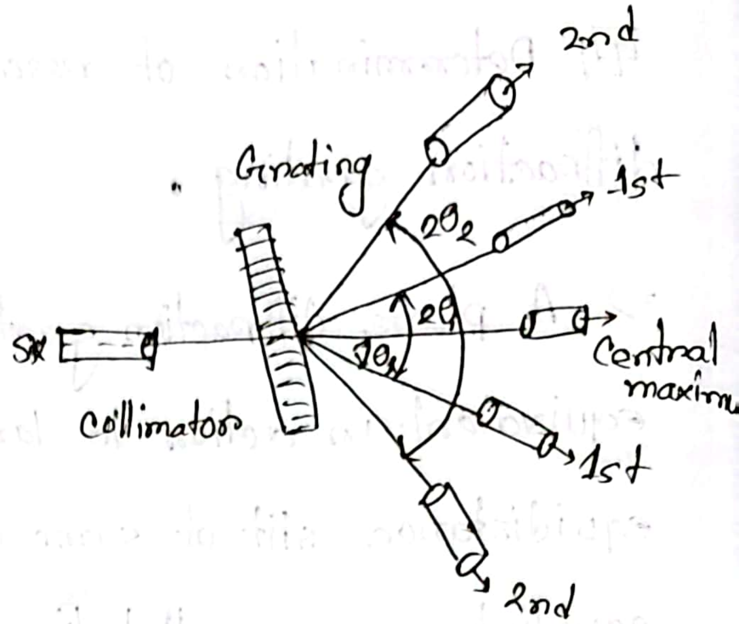
## Determination of resolving power of a plane diffraction grating.

⇒ A plane diffraction grating is an arrangement whic equivalent in action to large number of parallel and equidistance slit of same width. It is constructed by equidistance parallel lines on a transparent materic as glass plate by means of fine diamond point work. with a rulling engine.

When a beam of monocromatic light of wavelength coming out of the collimator of a spectrometer a plane diffraction grating placed vertically of the prisr table, a series of diffraction grating image of t collimator slit will be seen on both sides of the direct If $\theta$ be the deviation which form n'th image, a the slit width and b be the line width it can be written as,

$$(a+b)\sin\theta = n\lambda \quad \text{——— (1)}$$

since $(a+b) = \frac{1}{N}$ where $N$ is the grating constant that is the number of lines on rulling per ~~secon~~ cm of the grating surface.




$$\sin\theta = Nn\lambda$$

$$\Rightarrow \quad N = \frac{\sin\theta}{n\lambda} \quad \text{—— (2)}$$

Now resolving power is the ration of the wavelength of a spectral of the least difference in wavelength of the next spectral line that can just be seen as ~~sp~~ separated line. Let us suppose two spectral lines of wavelength $\lambda$ and $(\lambda + d\lambda)$ respectively. If two spectral line can just be seen ~~spe~~ separated by using a plane diffraction grating. then it equal to $\lambda/d\lambda$ where $d\lambda$ is the difference of wavelength between the spectral lines.

The resolving power of a plane diffraction grating can also be expressed as,

$$R = \lambda / d\lambda = Nn$$

where N is the total number of rullings on grating surface. Now; if $l$ is the effective length of the grating surface, the equation of resolving power is,

$$R = nNl$$

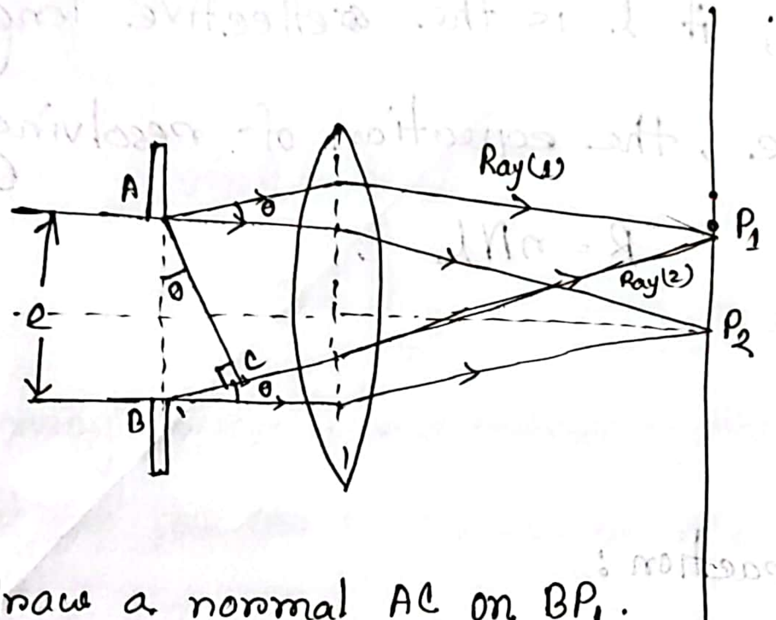
## Crystal diffraction:

The phenomenon by which x-rays are reflected from the atom in a crystalline solid is called crystal diffraction.

The diffracted x-rays generate a pattern that reveals structural orientation of each atom in a given compound.

## Single slit :

Let a monocromatic parallel beam of light be incident on the slit AB of width e. The primary wave travelling in the same direction as the incident in the same direction and as the incident light come to focus at the point $P_2$ and the secondary ~~angle~~ wave travelling at an angle $\theta$ come to focus at $P_1$.




Let us draw a normal AC on $BP_1$.

Then $\angle ACB = 90^\circ$ and $\angle BAC = \theta$. By this we can see that $AP_1 = CP_1$.

Now Path difference, $BP_1 - AP_1 = BC + CP_1 - AP_1$

$= BC + AP_1 - AP_1$

$= BC = e\sin\theta$

The phase difference, $= \frac{2\pi}{\lambda} e \sin\theta$

If $n$ number of total vibration exists in between AB then.

$$\delta = \frac{1}{n}\frac{2\pi}{\lambda}(e \sin\theta) \quad \text{——— (1)}$$

From the theory of $n$ Harmonic vibration, equation for resultant amplitude.

$$R = \frac{a \sin \frac{n\delta}{2}}{\sin \delta/2}$$

$$\Rightarrow R = \frac{a \sin \frac{n}{2}\frac{1}{n}\frac{2\pi}{\lambda}(e\sin\theta)}{\sin \frac{1}{2}\frac{1}{n}\frac{2\pi}{\lambda}(e\sin\theta)}$$

$$\Rightarrow R = \frac{a \sin(\pi/\lambda \, e\sin\theta)}{\sin \frac{1}{n}(\pi/\lambda \, e\sin\theta)}$$

Let consider,

$$\pi/\lambda \, e\sin\theta = \alpha$$

$\therefore$ Resultant amplitude, $R = \dfrac{a \sin\alpha}{\sin \frac{\alpha}{n}}$ ——— (2)

If $\frac{\alpha}{n}$ is very small then, $\sin\frac{\alpha}{n} \approx \frac{\alpha}{n}$

$$\therefore \quad R = \frac{a \sin\alpha}{\frac{\alpha}{n}}$$

$$\Rightarrow R = \frac{an \sin\alpha}{\alpha}$$

$$\Rightarrow R = A\frac{\sin\alpha}{\alpha} \quad \text{——— (3)}$$

Here, $A = na$ is near amplitude due to using single slit.

Now,

$$\text{Intensity} = (\text{Amplitude})^2$$

$$\therefore \quad I = A^2 \frac{\sin^2\alpha}{\alpha^2} \quad \text{———} (4)$$

$$\text{where,} \quad \alpha = \frac{\pi}{\lambda} e \sin\theta \quad \text{———} (5)$$

Condition for minima:

I will be minimum i.e; $I = 0$ if and only if,

$$\sin\alpha = 0 \qquad \{\alpha \neq 0 \, ; \, A \neq 0\}$$

$$\Rightarrow \sin\alpha = \sin n\pi$$

$$\Rightarrow \alpha = \pm n\pi \qquad \text{where } n = 1, 2, 3 \ldots$$

Hence positions for minimum $\pm\pi, \pm 2\pi, \pm 3\pi \ldots$

Again from (5),

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

$$\Rightarrow \pm n\pi = \frac{\pi}{\lambda} e \sin\theta$$

$$\Rightarrow \pm n\lambda = e \sin\theta$$

This is the condition for minima.

Condition for central maximum :

For central maximum I should be maximum. i;e; I = ∞

I will be infinite if and only if, $\alpha = 0$ as $A \neq 0$ and sin

That means only $\alpha = 0$ gives the central maximum.

$$\therefore \cancel{I = \frac{A^2 \sin^2\alpha}{}}$$

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

Here, $\pi \neq 0$ ; $\lambda \neq 0$ ; $e \neq 0$ ~~then~~ so if $\theta = 0$ then we will get central maximum.

From equation (4) by putting $\alpha = 0$ ,

$$\lim_{\alpha \to 0} \frac{\sin\alpha}{\alpha} = 1$$

$$\therefore I_{max} = I_0 = A^2$$

Condition for secondary maxima :

I will be maximum if and only if,

$$\sin\alpha = \pm 1 \qquad \{\alpha \neq 0 ; A \neq 0\}$$ From equation(

$$\Rightarrow \sin\alpha = \sin (2n+1) \frac{\pi}{2}$$

$$\Rightarrow \alpha = (2n+1) \frac{\pi}{2}$$

Hence position for maximum $3\pi/2, 5\pi/2, 7\pi/2 \ldots$

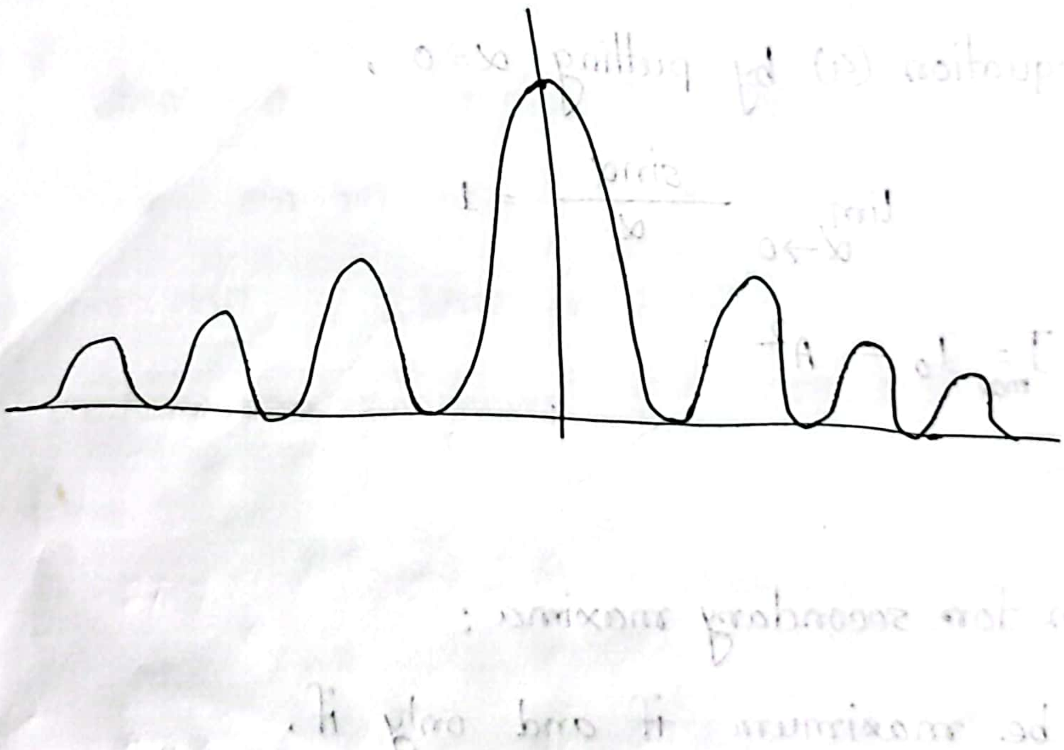
Again from equation (5),

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

$$\Rightarrow (2n+1)\frac{\pi}{2} = \frac{\pi}{\lambda} e \sin\theta$$

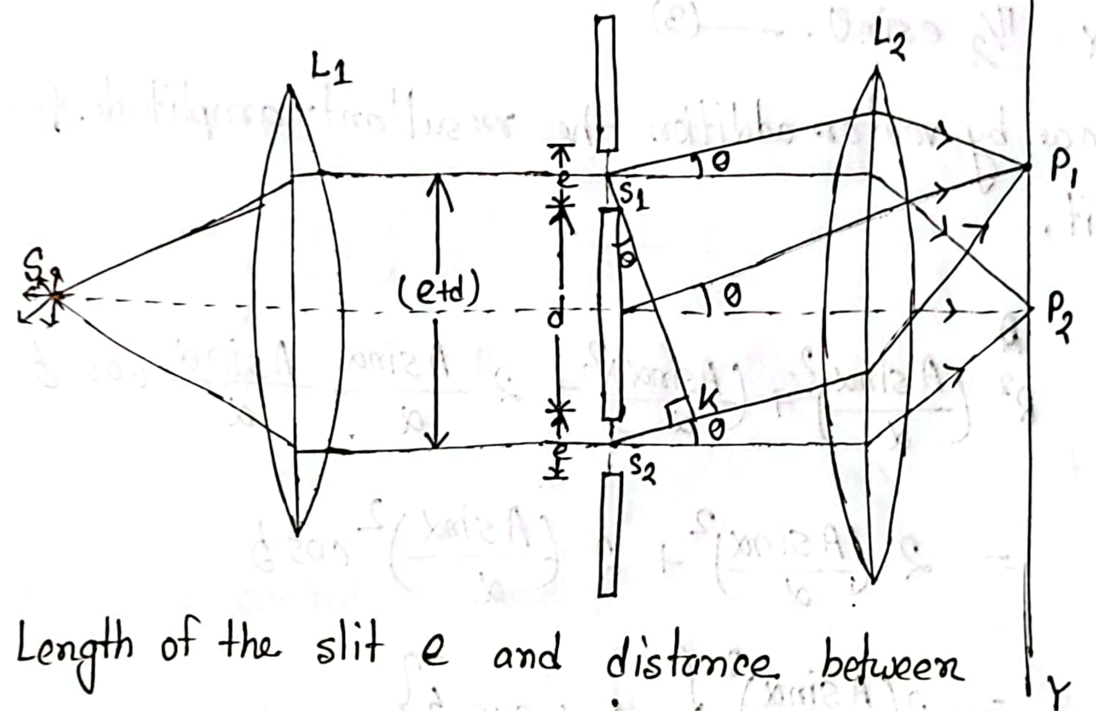
$$\Rightarrow e \sin\theta = (2n+1)\frac{\lambda}{2}$$

This is the condition for secondary maxima.



Double slit :

Let a monocromatic light beam from a source S passing through a plano convex lens $L_1$ incident on two slits $S_1$ and $S_2$ respectively. Then light get diffracted an angle $\theta$ and this light wave super imposed and we get an pattern $P_1$ on the screen.




Here, Length of the slit e and distance between two slit is d. Total distance between two light ray passing through $S_1$ and $S_2$ is $(e+d)$.

Let draw an normal $S_1k$ on $S_2P_1$ Then $\angle S_1kS_2 = 90^\circ$ and $\angle kS_1S_2 = \theta$ and $S_1P_1 = kP_1$.

The path difference; $\Delta x = S_2P_1 - S_1P_1 = S_2k + kP_1 - S_1P_1$

$= S_2k + kP_1 - kP_1$

$$\Delta x = S_2K = (e+d)\sin\theta \quad \text{——— (1)}$$

Phase difference, $\delta = \frac{2\pi}{\lambda}(e+d)\sin\theta$ ——— (2)

Here it is noted that in case of double slit, it has two single slit and for each single slit from the single slit diffraction theory the resultant amplitude, $\frac{A\sin\alpha}{\alpha}$ where

$\alpha = \frac{\pi}{\lambda} e\sin\theta$. ——— (3)

Now by vector addition the resultant amplitude for double slit,

$$R^2 = \left(\frac{A\sin\alpha}{\alpha}\right)^2 + \left(\frac{A\sin\alpha}{\alpha}\right)^2 + 2\,\frac{A\sin\alpha}{\alpha}\,\frac{A\sin\alpha}{\alpha}\cos\delta$$

$$= 2\left(\frac{A\sin\alpha}{\alpha}\right)^2 + 2\left(\frac{A\sin\alpha}{\alpha}\right)^2\cos\delta$$

$$= 2\left(\frac{A\sin\alpha}{\alpha}\right)^2\left\{1+\cos\delta\right\}$$

$$= 2A^2\left(\frac{\sin\alpha}{\alpha}\right)^2 2\cos\frac{\delta}{2}$$

$$= 4A^2\left(\frac{\sin\alpha}{\alpha}\right)^2\cos\frac{1}{2}\,\frac{2\pi}{\lambda}(e+d)\sin\theta$$

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

Let $\pi/\lambda\,(e+d)\sin\theta = \beta$

$$\therefore R^2 = 4A^2\left(\frac{\sin\alpha}{\alpha}\right)^2\cos^2\beta \quad \text{——— (4)}$$

In equation (4) $\left(\frac{\sin\alpha}{\alpha}\right)^2$ represents the diffraction ~~patt~~ and $\cos^2\beta$ represents interference. Because here two waves coming from two slit and superimposed with each other and meet at $P_1$. That means resultant intensity has both the effect of diffraction and intensity.

The resultant intensity due to double slit,

$$I = R^2 = 4A^2\left(\frac{\sin\alpha}{\alpha}\right)^2\cos^2\beta \quad \text{——— (5)}$$

where $\beta = \pi/\lambda\,(d+e)\sin\theta$

① Condition for central maxima :

From equation (5) it is clear that the central maxima in direction ~~$\beta=0$ as~~ $\cos\beta = 1$ where $\beta = 0$ and it can be obtained when $\theta = 0$

And central maximum is obtained when $\alpha = 0 = \pi/\lambda\; e\sin\theta = 0$

From equation (5), $I_{CM} = 4A^2$

(ii) Positions for secondary maxima:

From single slit theory we get $\alpha = \tan\alpha$ where we plot a graph for $y=\alpha$ and $y=\tan\alpha$. Now in case of double slit as it has two single slit, so secondary maxima position will lie on the intersections of $y=\alpha$ and $y=\tan\alpha$.

Here the position of secondary maxima,

$$\alpha = \pm \frac{3\pi}{2}, \pm \frac{5\pi}{2}, \pm \frac{7\pi}{2} \ldots$$

(iii) Position for minima:

From equation (5) for minimum intensity I should be zero.

If we consider $\alpha$, (diffraction)

For minimum intensity $\sin\alpha = 0$ $\{\alpha \neq 0\}$

$$\Rightarrow \sin\alpha = \sin \pm m\pi$$

$$\Rightarrow \alpha = \pm m\pi$$

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

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

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

where $m = 1, 2, 3 \ldots$

This is the equation of minima.

If we consider $\beta$,

The ~~equation of~~ minimami intensity, $\cos^2\beta = 0$

$$\Rightarrow \cos\beta = 0$$

$$\Rightarrow \cos\beta = \cos(2m+1)\pi/2$$

$$\Rightarrow \beta = (2m+1)\pi/2$$

where $m = 0, 1, 2, 3$

Again $\beta = \pi/\lambda\,(e+d)\sin\theta$

$$\therefore \quad \pi/\lambda\,(e+d)\sin\theta = (2m+1)\,\pi/2$$

$$\Rightarrow (e+d)\sin\theta = (2m+1)\,\lambda/2$$

This is also the equation of minima.

Due to diffraction

Due to interference

Resultant.

Polarization 01718578336

⊞ Define Nichol prism.

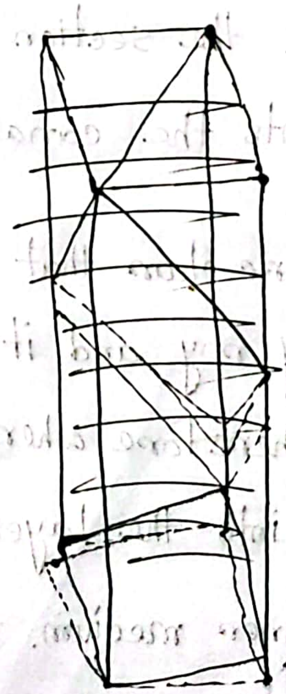
Nichol prism is an optical divice used for producing and analysing plane polarized light.

⊞ Describe the construction of Nichol prism.

The nicol prism is made in such a way that it eliminates one of the two rays by total internal reflection. It is generally found that the ordinary ray is eliminated and only the extraordinary ray is transmitted through the prism.

A calsite crystal whose length is three times its breadth is taken. Let A'BCDEFG'H represents such a crystal having A' and G' as its blunt corners and A'CG'E is one of the principal sections with $\angle A'CG' = 70°$

The faces A'BCD and EFG'H are ground in such a way that an angle ACG becomes = 68° insted of 71°. The crystal is then cut along the plane AKGL as shown in fig. 1. The two cut surfaces are grounded and polished optically flat and then cemented togather by Canada balsam



whose refractive index lies between the refractive indices for the ordinary and the extraordinary rays for calcite.

Refractive index for ordinary, $\mu_0 = 1.658$

Refractive index for canada balsam $\mu_B = 1.55$

Refractive index for the extraordinary $\mu_E = 1.486$

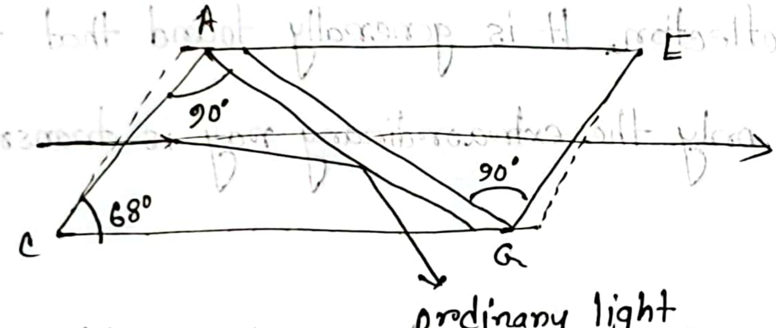
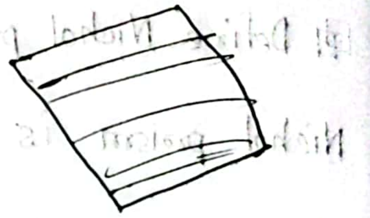



Fig. 2



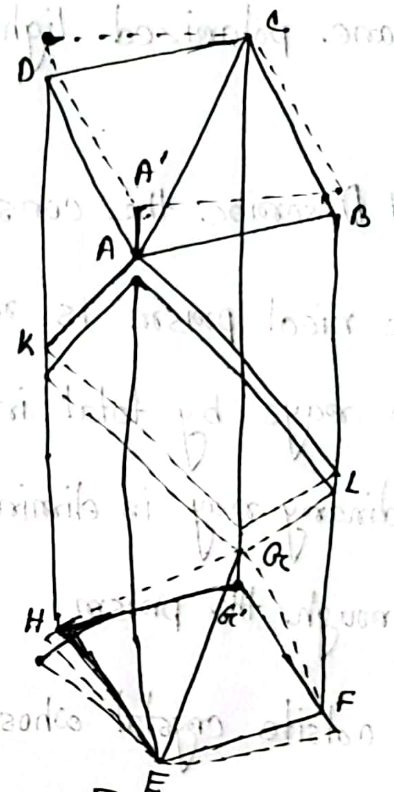



Fig. 1

In fig. 2 the section ACGE of the crystal is shown. The diagonal AC represents the canada balsam layer in the plane ALGK of Fig. ~~1~~

It is ~~cre~~ clear that canada balsam acts as a rarer medium for an ordinary ray and it acts as a denser medium for the extraordinary ray. Therefore when ordinary ray passes from a portion of the crystal into the layer of canada balsam it passes from a denser to a rarer medium. When the angle of incidence is greater than the critical angle, the ray is totally internally reflected and is not transmitted. The extraordinary ray is not affected and is therefore transmitted through the prism.

□ How nichol prism act as an analyzer and a polarizer?

⇒ Nichol prism can be used for the production and detection of plane polarized light.

⇒ When a beam of light transmitted through a calcite crystal, it breaks up into two rays, (1) the ordinary ray which has its vibration perpendicular to the principal section of the crystal (2) the extraordinary ray which has its vibration parallel to the principal section.

When two nichol prisms $P_1$ and $P_2$ are placed adjacent to each other as shown in fig. 1. (i) one of them act as a polarizer and the other acts as an analyzer. Fig 1(i) shows the position of two parallel nichols and only the extraordinary ray passes through both the prisms.

If the second prism $P_2$ is gradually rotated, the intensity of the extraordinary ray decreases in accordance with Malus law and when two prisms are crossed. i.e; when they are at right angles to each other. Fig. 2 then no light comes out of the 2nd prism $P_2$. It means that light coming out of $P_1$ is plane polarized.

When the polarized extraordinary ray passes through the prism $P_2$

in this positions it act as an ordinary ray and is totally internally reflected by the canada balsam layer. so no light comes out of $P_2$. Therefore the prism $P_1$ produces plane polarized light and the prism $P_2$ detects it.

Hence $P_1$ and $P_2$ are called the polarizer and the analyzer respectively. The combination of $P_1$ and $P_2$ is called polariscope.

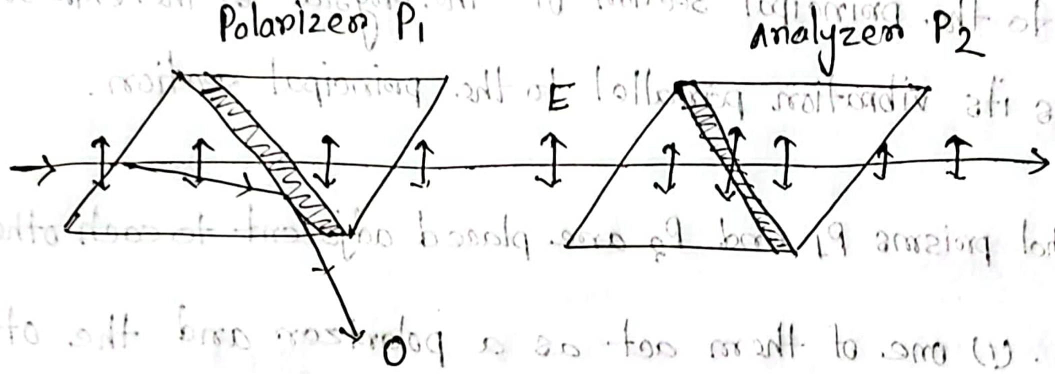



Fig. 1

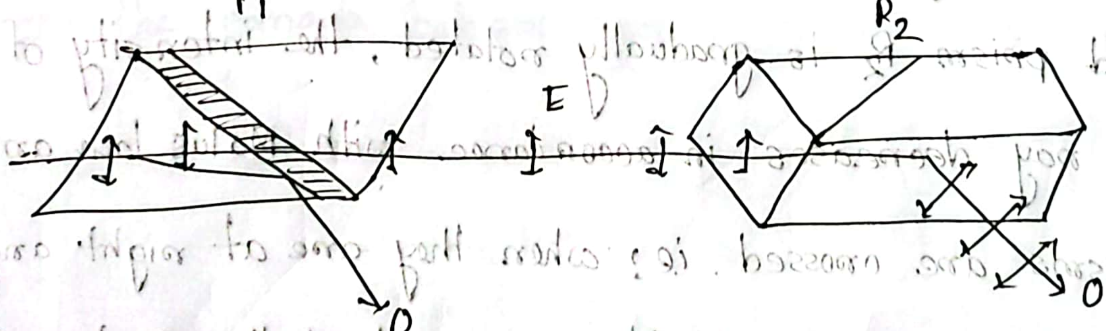



Fig. 2

## 田 Unpolarized light :

Light wave is a transverse electromagnetic wave made up of mutually perpendicular, fluctuating electric and magnetic fields. Traditionally, light wave is described by the electric field vector E. As the electric field is a vector, it points in a particular direction in space. The polarization of an electromagnetic wave refers to the orientation of its electric field vector E. If a light wave from an ordinary source is observed, it is seen that the direction of E is randomly varying with time on a very fast scale. The light from an incandescent bulb emits a mixture of light waves with electric field components that change randomly on a scale of $10^{-14}$s, almost as fast as the optical frequency itself. As a result the direction of oscillation of the electric field vector in an ordinary light beam occurs in all the possible planes perpendicular to the beam direction. A light wave, in which electric field vector oscillates in more than one plane, is called unpolarized light.

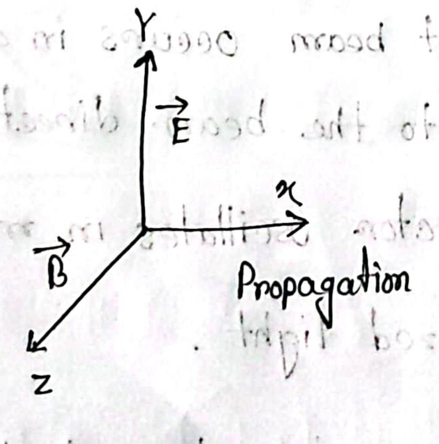
Light emitted by the sum, by an incandescent lamp, by a candle flame is unpolarized light.

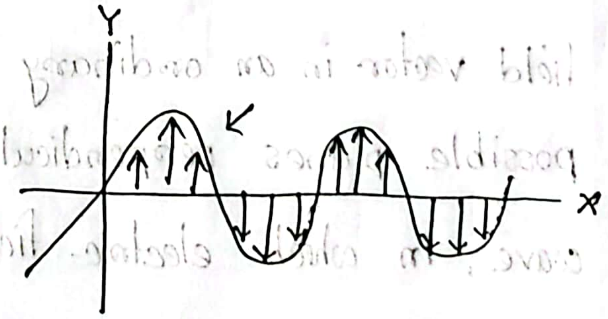
## Polarized light:

A polarized light wave is a light wave with a definite direction of oscillation of the electric field vector, which occurs in a single plane or in some specific way. Polarized light is the light that contains wave that only fluctuate in one specific plane.

## Polarization:

The process of transforming unpolarized light i.e; multidirection light or ordinary light into polarized light or one direction light is called polarization.



## Types of polarization :

There are three types of polarization :

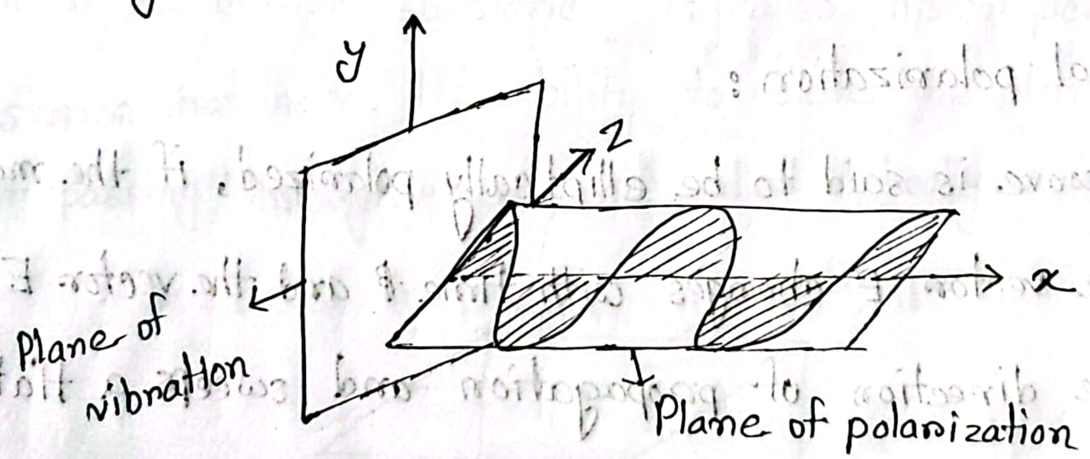
(I) Plane polarized light

(II) Circular polarization

(III) Elliptical polarization.

### 1. Plane polarized light :

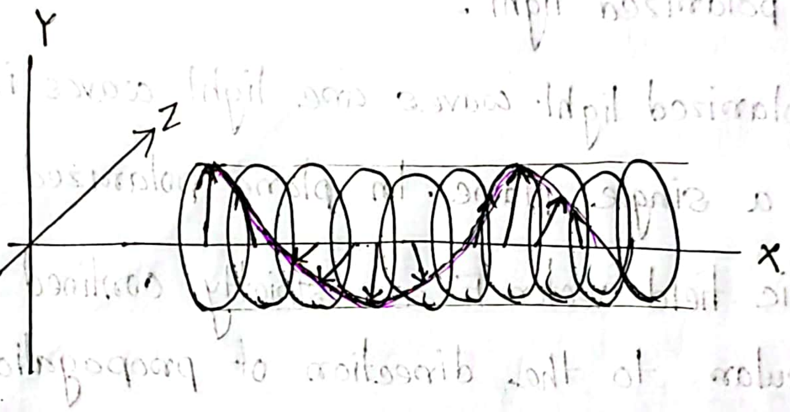
Plane polarized light waves are light waves in which the oscillations occur in a single plane. In plane polarized wave, the oscillations of electric field vector E are strictly confined to a single plane perpendicular to the direction of propagation. It is also known as linearly polarized wave.




Plane of vibration $\perp$ Plane of polarization

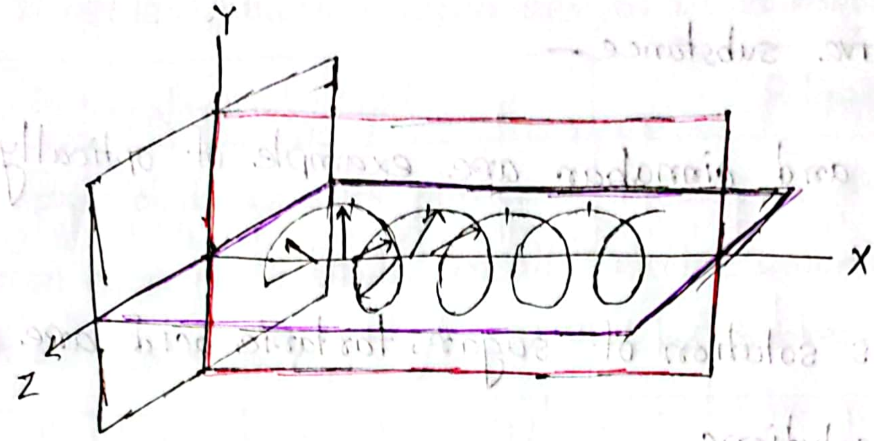
2. Circular polarization :

A light wave is said to be circularly polarized, if in the course of wave propagation, the ~~magnetic~~ magnitude of the electric vector E stays constant but it rotates at a constant rate about the direction of propagation and sweeps a circular helix in space.




3. Elliptical polarization :

A light wave is said to be elliptically polarized, if the magnitude of electric vector E changes with time and the vector E rotates about the direction of propagation and sweeps a flattened helix in space.




☐ What do you mean by optical activity? Explain.

☐ Write down the several optical active substance.

The ability to rotate the plane of polarization of plane polarized light by a certain substance is called optical activity.

Substance that have the ability to rotate the plane of the polarized light passing through them are called optically active substances.

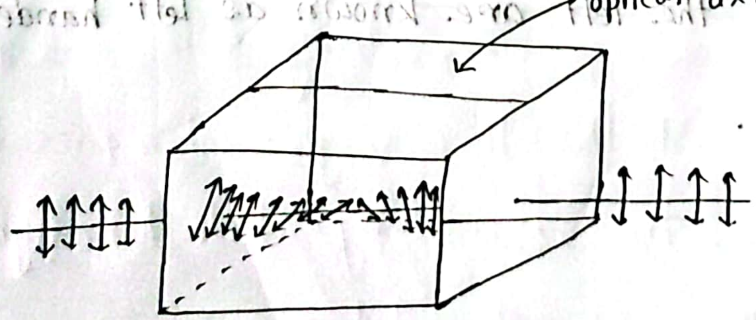



Fig. optically active crystal

Optically active substance—

(I) Quartz and cinnabar are example of optically active crystal.

(II) Aqueous solution of sugar, tartaric acid are optically active solutions.

Optically active substances are classified into two types:

1. Dextrorotatory substance:
Substance that rotate the plane of polarization of the light toward the right are known as right handed or dextrorotatory.

2. Laevorotatory substance:
Substance which rotate the plane of polarization of the light towards the left are known as left handed or Laevorotatory.

Distinguish between unpolarized and polarized light:

| Unpolarized light | Polarized light |
| --- | --- |
| 1. Consists of waves with planes of vibration equally distributed in all directions about the ray direction. | 1. Consists of waves having their electric vector vibrating in a single plane normal to ray direction. |
| 2. Symmetrical about the ray direction. | 2. Asymmetrical about the ray direction |
| 3. Produced by conventional light sources | 3. Is to be obtained from unpolarized light with the help of polarizers. |
| 4. May be regarded as the resultant of two incoherent waves of equal intensity but polarized in mutually perpendicular planes | 4. May be regarded as the resultant of two mutually perpendicular coherent waves having zero phase difference. |

## Specific rotation :

Specific rotation Is a property of a chiral chemical compound. It is defined as the change in orientation of monocromatic plane polarized light, per unit distance-concentration product, as light passes through a solution of an optically active substance.

## ~~Pori~~ Polarimeter :

A polarimeter is a scientific instrument used to measure the angle of rotation caused by passing plane polarized light through an optically active substance.

Some chemical substance are optically active and polarized light will rotate either to the left or right when passed through these substances, The amount by which the light is rotated is known as the angle of rotation.

Ⓓ Define ordinary and extraordinary light:

Ordinary light:

The ordinary light can be defined as the light/ray which has its vibrations perpendicular to the principal section of the crystal or light wave oscillate in different direction i.e; unpolarized light.

Extraordinary light:

The extraordinary light/ray can be define as the light/ray which has its vibrations parallel to the principal section of the crystal i.e; polarized light.

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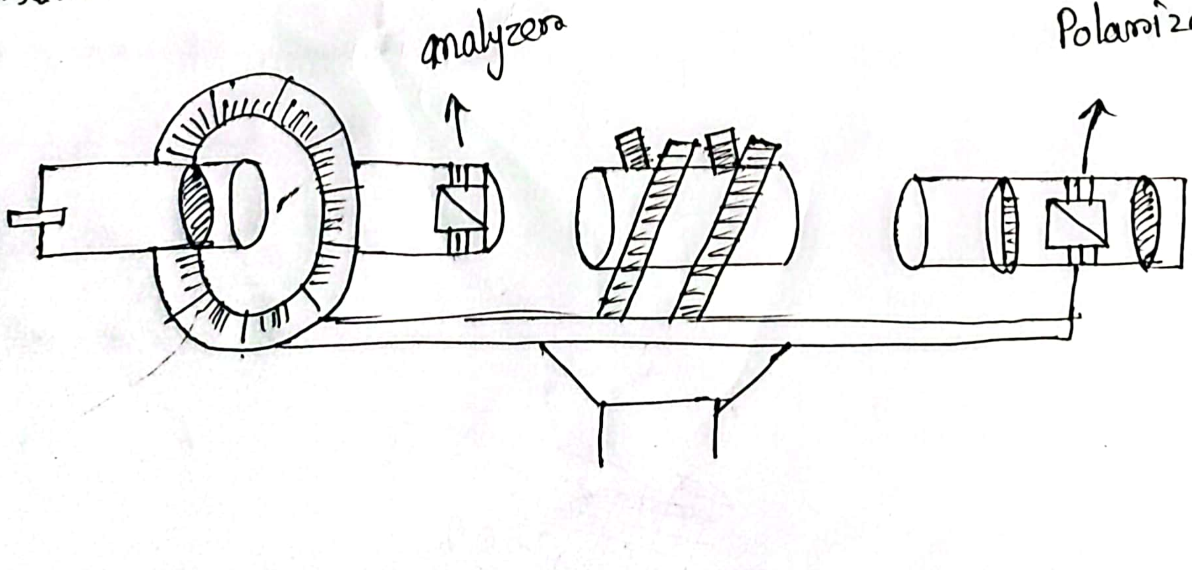
□ Determination of the specific rotation of a sugar solution using polarimeter.

Specific rotation is defined as the change in orientation of monocromatic plane polarized light per unit distance-concentration product, as light passes through a solution of an optical active substance.

In order to determine the specific rotation of sugar solution, the polarimeter tube is first filled with pure water and the analyzer is adjusted for equal darkness point. Polarimeter has two nicol prism inside its construction which are placed parallel to each other.

Nicol prism is an optical device used for producing and analyzing plane polarized light. It is made by cutting calcite crystal and bounded ~~to g~~ togather with an adhesive known as canada balsam.



After adjusting with pure water the tube is filled with sugar solution and placed inside the polorimeter in between two nicol prism. When monocromatic unpolarized light passes throug the 1st nicol prism the polarizer the light wave coming perpendicular to the plane of polarization of the nicol prism eliminated and only the parallel light wave passes through the prism and then through the solution. This is the polarized light and called the extraordinary light. ~~Light comes to our eye by telescope through analyzer. Analyzer can rotate. When Aanalyzer nicol prism is parallel to polarizer then light can come to our eye and we can see bright~~

The beam is then rotated as it passes through the sugar solution. After passing through the sample it go through the analyzer. When analyzer is rotated such that all the light or no light can pass through, then we can find rotation. ~~which~~ Now if the solution of length L cm or ($L/_{10}$ dec at $t°C$, contains m gm of ~~active~~ sugar per cc of the solution then it will ~~be~~ produce a rotation of the plane of polarization of plane polarized light of wavelength $\lambda$ and rotation $\theta$,

$$\theta = \frac{SLm}{10} \quad \text{———} (1)$$

$S$ is the specific rotation.

If $c$ be the percentage strength of the solution i.e; $c$ gm of active substance are present in 100 cc of solution.

Then, $m = \frac{c}{100}$

From (1),

$$\theta = \frac{SLc}{1000}$$

$$\Rightarrow S = \frac{1000\,\theta}{LC}$$

By this equation specific rotation of sugar solution can be obtained by using polarimeter.

# Holography

## Holography :

Holography is the method of reproducing a three dimensional image of an object by means of recording of interference pattern formed between two beams of coherent light coming ~~out~~ from the same source on photographic plate.

In this process, both amplitude and phase components of light wave are recorded on a light sensitive medium such as photographic plate. The recording is called hologram. Or, the plate or film with recorded wave patterns is called hologram.

## Photography :

Photography is the method of producing two dimensional image of an object.

4) What is the basic principle of holography?

⇒ In the holographic plate, both the beams combine and interference pattern will be formed. This interference pattern is recorded on the holographic plate. The three dimensional image of the object can be seen by exposing the recorded holographic plate i.e; hologram to coherent light. This is the principle of holography.

Holography is a two step process. First step is the recording of hologram where the object is transformed into a photographic record and the second step is the reconstruction in which the hologram is transformed into the image. A hologram is the result of interference occurring between two waves, an object beam which is the light scattered off the object and a coherent background, the reference beam, which is the light reaching the photographic plate directly. The reference beam and object beam are coaxial.

## ④ Distinguish between Holography and Photography.

| Holography | Photography |
|---|---|
| 1. Holography is a technique of producing 3D image. | 1. Photography is a technique of producing 2D image. |
| 2. Both intensity and phase of light waves are recorded. | 2. Only intensity of light waves are recorded. |
| 3. A laser is required to record a hologram. | 3. A photograph can be recorded using ordinary light. |
| 4. No lens is required to produce an image. | 4. Lens is required to produce an image. |
| 5. Image has very high resolution. | 5. Image has poor resolution. |
| 6. When a hologram is cut in half, the whole scene can still be seen in each piece. | 6. When a photograph is cut in half, each piece shows half of the scene. |
| 7. Reference beam is required | 7. Reference beam does not required |
| 8. Hologram can only be viewed with very specific forms of illumination. | 8. Photograph can be viewed in a wide range of lighting conditions. |

4. Describe the recording and reconstruction of Hologram.

The basic technique in holography divided into two parts-

1. Recording of the hologram
2. Reconstruction of the image.

Recording process:

To construct a hologram, a laser beam is divided into two beams, namely a reference beam and an object beam by a beam splitter. The reference beam goes directly to the photographic plate. The second beam of light is directed onto the object to be photographed. Each point of the object scatters the incident light and act as the source of spherical waves. Part of the light, scattered by the object, travels towards the photographic plate. At the photographic plate the innumerable spherical waves from the object combine with the plane light wave from the reference beam. The sets of light wave are coherent because they are from the same laser. They interfere and form interference fringes on the plane of the photographic plate. These interference fringes are a series of zone-plate like rings, but these rings are also superimposed, making a complex pattern of lines. The developed negative of these interference fringe-pattern is a hologram.

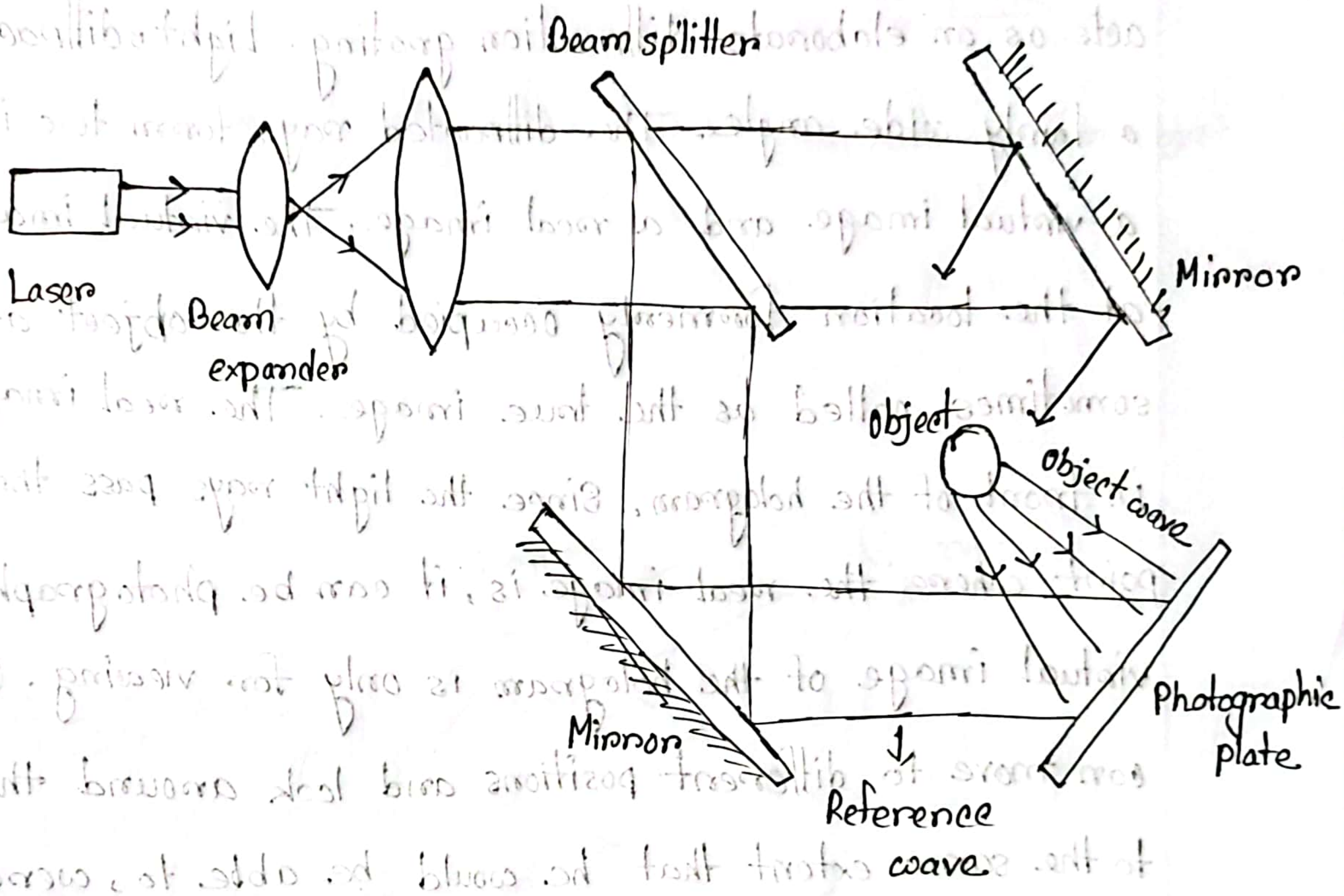
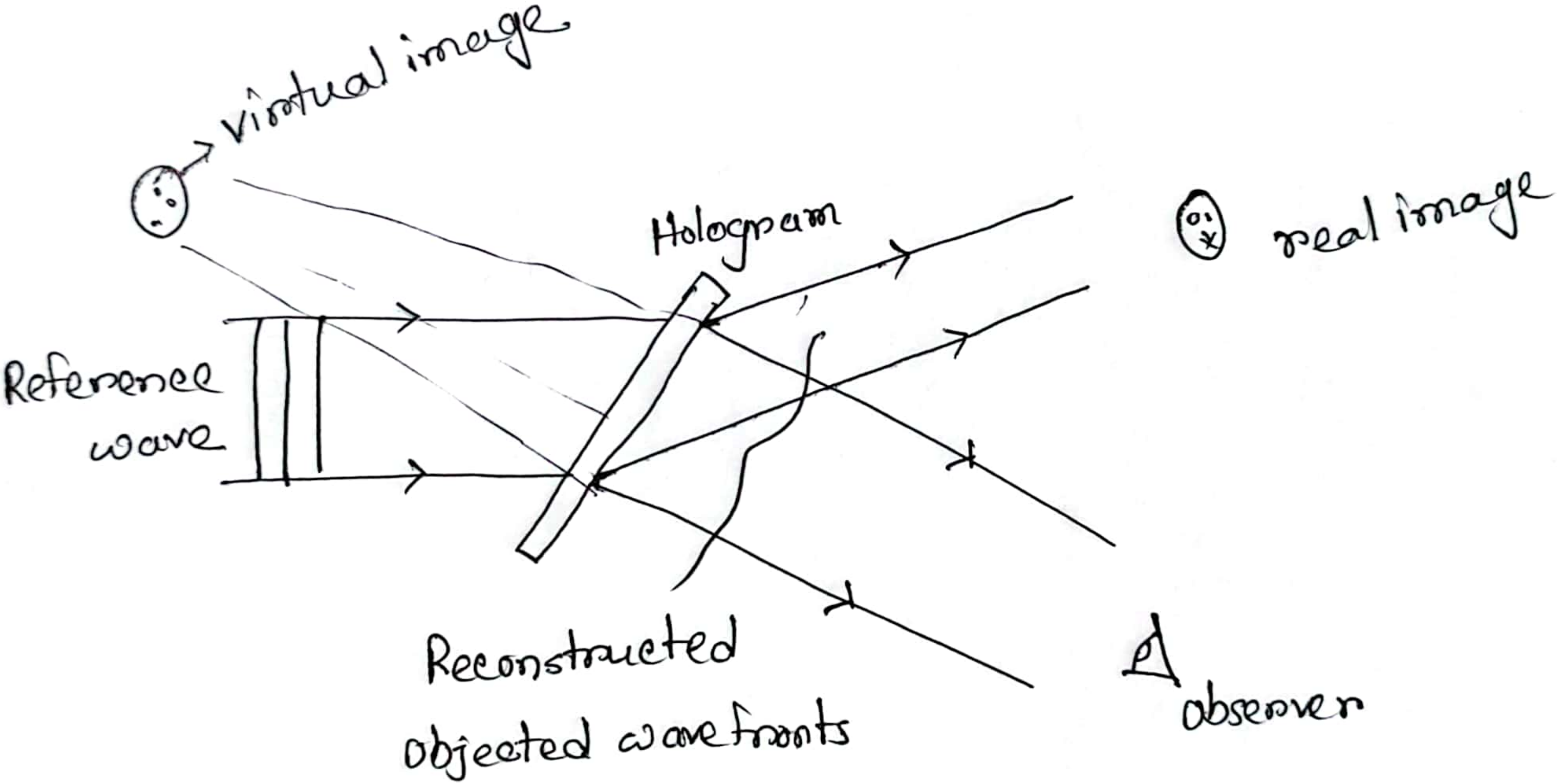



Fig: Recording of a holograph

Thus the holograph does not contain a distinct image of the object but carries a record of both the intensity and the relative phase of the light waves at each point.

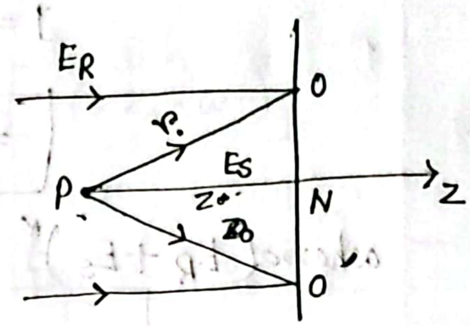
2. Reconstruction of the image :

For reconstruction of the image, the hologram is illuminated by a parallel beam of light called reconstruction wave. Most of the light passes straight through, but the complex of fine fringes acts as an elaborate diffraction grating. Light is diffracted at a fairly wide angle. The diffracted rays form two images : a virtual image and a real image. The virtual image appears at the location formerly occupied by the object and is sometimes called as the true image. The real image formed in front of the hologram. Since the light rays pass through the point where the real image is, it can be photographed. The virtual image of the hologram is only for viewing. Observer can move to different positions and look around the image to the same extent that he would be able to, were he looking directly at the real object. This type of hologram is known as a transmission hologram since the image is seen by looking through it. The three dimensional image is seen suspended in midair at a point which corresponds to the position of the real object which was photographed.


virtual image
Hologram
real image
Reference wave
Reconstructed objected wavefronts
observer

## [E] Theory of Holography :

Let the light beam from a coherent source illuminate a point object P. The beam consists of plane waves. Most of the plane waves reach the photographic plate directly. Part of the light is scattered by the point object and spherical waves are produced. They also reach the photographic plate.




Hologram of a point object

The resultant field at O,

$$E = E_R + E_S$$

where, $E_R$ = Field due to reference beam

$E_S$ = Field scattered from the object.

The field of the scattered wavefront,

$$E_S = \frac{E_0}{r_0} e\left[ i(kr_0 - \omega t)\right] \quad \text{where } [\because r = PO] \quad \text{——— (1)}$$

The field of reference beam by the plane wave is,

$$E_R = E_{R1}\, e\left[ i(kz_0 - \omega t)\right] \quad \text{where, } [\because z_0 = PN] \quad \text{——— (2)}$$

The intensity at O is,

$$I = |E_R \pm E_S|^2$$

$$\boxed{= (E_R + E_S)(E_R + E_S)^*}$$

where $(E_R + E_S)^*$ is the complex component value of $(E_R + E_S)$

$$\boxed{= E_R E_R^* + E_R E_S^* + E_S E_R^* + E_S E_S^*}$$

$$= |E_R|^2 + \frac{|E_S|^2}{r_0^2} + \frac{E_S E_R^*}{r_0} e\left[ik(r_0 - z_0)\right] +$$

$$\frac{E_S^* E_R}{r_0} e\left[ik(z_0 - r_0)\right] \quad \text{——(3)}$$

By combining the last two term,

$$I = |E_R|^2 + \frac{|E_S|^2}{r_0^2} + \frac{K}{r_0} \cos\left[k(r_0 - z_0) + \phi\right] \quad \text{——(4)}$$

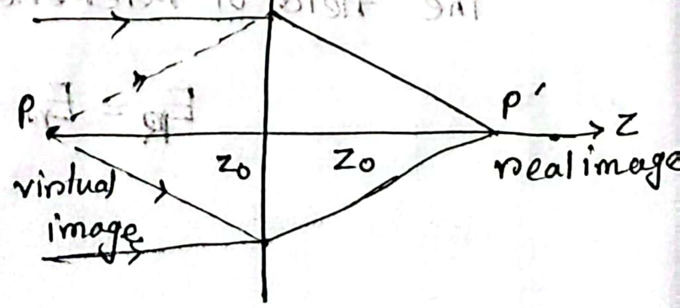
where $K$ and $\phi$ is constant.

The total intensity $I$ is a function of cosine term and shows a series of maxima and minima. The power transmission of the plate $T^2$ is given by,

$$T^2 = 1 - \alpha I$$

Since $\alpha I << I$ then,

$$T = 1 - \frac{1}{2}\alpha I$$



When the hologram is illuminated by the reference beam, the field of the transmitted wave may be written as;

$$E = TE_R = \left[1 - \frac{1}{2}\alpha I\right] E_R \, e\left[i(kz_0 - \omega t)\right]$$

$$= \left[1 - \frac{\alpha}{2}|E_R|^2 - \frac{\alpha}{2}\frac{|E_S|^2}{r_0^2}\right] E_R \, e\left[i(kz_0 - \omega t)\right] -$$

$$\frac{\alpha}{2}\frac{E_S E_R^*}{r_0} e\left[ik(r_0 - z_0)\right] E_R \, e\left[i(kz_0 - \omega t)\right] -$$

$$\frac{\alpha}{2}\frac{E_S^* E_R}{r_0} e\left[ik(z_0 - r_0)\right] E_R \, e\left[i(kz_0 - \omega t)\right]$$

$$= \left[1 - \frac{\alpha}{2}|E_R|^2 - \frac{\alpha}{2}\frac{|E_S|^2}{r_0^2}\right] E_R \, e\left[i(kz_0 - \omega t)\right] -$$

$$\frac{\alpha E_S |E_R|^2}{2 r_0} e\left[i(kz_0 - \omega t)\right] - \frac{\alpha E_S^* E_R^2}{2} e\left[i(2kz_0 - kr_0 - \omega t)\right] \qquad (5)$$

This 1st term represents the incident plane wave with some attenuation.

The second term represents a spherical wave identical with that emitted by the object except for a constant factor.

The third term represents also a spherical wave, which is identical to the original wave but converges at a point P'.

## ⊞ Applications of Holography :

1. Three dimentional photography
2. Optical computers
3. Bio medical application
4. Compact disk
5. Holographic scanners
6. Holographic Interferometry
7. In security system
8. Credit cards
9. Arts
10. Microscopy
11. Data storage
12. Determine the young's modules of materials.
13. Grocery store.
14. Scanner or bioscanner.
15. X-ray holography.

# LASER

Laser:

Laser stands for Light Amplification through Stimulated Emission of Radiation.

A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electro-magnetic radiation.

## Types of Laser:

1. Rubby Laser
2. Helium-Neon LASER
3. Carbon dioxide LASER
4. Semiconductor LASER
5. PN-Junction LASER
6. Nd: YAG LASER

## Characteristics of Laser beam:

The important characteristics of laser beam are-

1. Directionality: The conventional light sources emit light uniformly in all directions but laser emits lights only in one direction.

2. High monocromacity: It means that all the laser rays have same wavelength and frequency when they are emitted from the same source.

3. High intensity: The laser beam intensity would be constant with distance as its energy concentrated in a small region of space.

4. Negligible divergence: The conventional light sources emit light in the form of spherical wavefronts and highly divergence but laser light propagates in the form of plane wave and the divergence of a ~~laq~~ laser is very small.

5. High degree of coherence :- It means that all the laser rays have the constant phase relation among themselves so that laser light is a high degree of coherence.

Q. Explain the basic principle of LASER action.

A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electro-magnetic radiation. The term LASER means Light Amplification through Stimulated Emission of Radiation. The first Laser was invented in 1960 by Theodore H. Maiman.

Principle :

Due to stimulated emission the Photons multiply in each step- giving rise to an intense beam of photons that are coherent and moving in the same direction. Hence the light is amplified (by stimulated emission) of the radiation. Termed (LASER).

stimuated emission এর কারণে প্রতিটি ধাপে ফোটন বহুগুণ বৃদ্ধি পায় এবং একটি ফোটন beam এর জন্ম দেয় যা coherent ও same direction এ চলে। আর light stimulated emission of radiation দ্বারা amplified হয়। তাই Laser

The essential component of a laser are –

(i) Active Medium –

A medium in which population inversion can be achieved is known as active medium.

(ii) Active center –

The material in which the atoms are raised to the exited state to achieve population inversion is called active center.

(iii) Pumping action :–

The process to achieve the population inversion in the medium is called pumping action.

It is essential requirement for producing a laser beam.

Method of pumping action –

The methods commonly used for pumping action are –

(1) Optical pumping (Excitation by photons)

(2) Electrical dischange method (Excitation by electrons)

(3) Direct conversion.

(4) In elastic atom - atom collision between atoms.

[4] Explain spontoneous and stimulated emission.

Emission:

A two level atomic system has two energy levels $E_1$ and $E_2$. $E_2$ is greater than $E_1$ (i.e; $E_2 > E_1$) when the atom makes a transition from the uper level $E_2$ to lower level $E_1$ then a radiation of energy $\Delta E = E_2 - E_1$ is emitted.

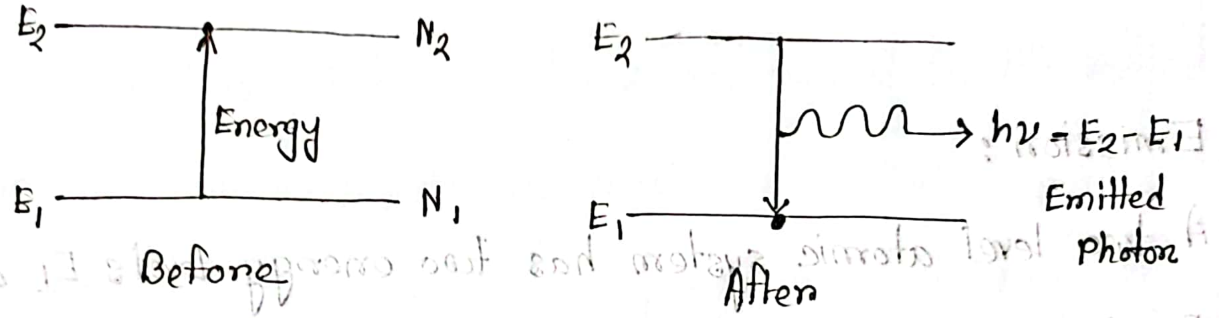
whose frequency is,

$$v = \frac{E_2 - E_1}{h}$$

$$\therefore \; E_2 - E_1 = hv$$

(1) Spontaneous emission :

Spontaneous emission is an energy conservation process by which electrons in the exited state return to the ground state by emitting Photons.




When an atom at lower energy level is exited to a higher energy level, it can not stay in the exited state for a relatively longer time. In a time of about $10^{-8}$ s the atom reverts to the lower energy state by releasing a photon of energy $h\nu$.

$$h\nu = E_2 - E_1$$

Since the lower energy level is much stable than higher energy level. The number of spontaneous transitions depends only on the number of atom $N_2$ at the excited state.

∴ The rate of spontaneous transition is given by,

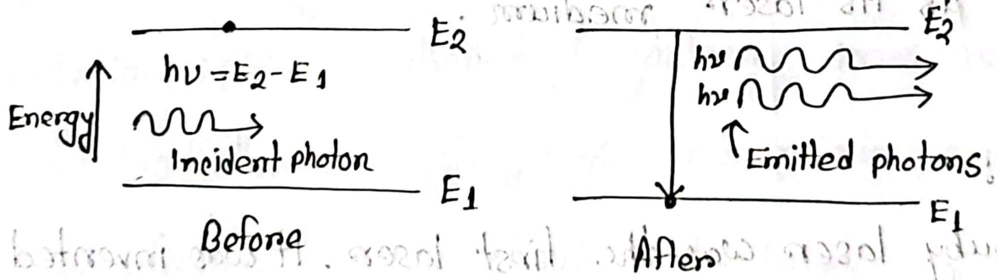
$$R_{sp} = A_{21} N_2$$

The process of spontaneous emission is independent of the incident light energy.

Where $A_{21}$ is a constant and known as Einstein coefficient for spontaneous emission. $A_{21}$ represents the probablity of spontaneous transition from level $E_2$ to $E_1$. ~~is zero~~. As spontaneous emission is not possible from $E_1$ to $E_2$. ~~$A_{12} = 0$~~ So $A_{12} = 0$ .

(II) Stimulated emission :

Stimulated emission is the process by which incident photon interacts with the excited electron and force it to return to the ground state.




When an atom is stimulated/induced to jump from higher energy level $E_2$ to lower energy Level $E_1$ by the present of electromagnetic radiation and emit a photon of energy $h\nu = E_2 - E_1$ which is known as stimulated emission or induced emission.

The rate of stimulated emission of photons is given by

$$R_{st} = B_{21}\, P(\nu)\, N_2$$

where $B_{21}$ is the constant of Einostein co-efficient for stimulated emission. $B_{21}$ represents the probablity for induced transition from level $E_2$ to $E_1$.

## Construction and working of Ruby Laser:

Ruby Laser:

A ruby laser is a solid-state laser that uses the synthetic ruby crystal as its laser medium.

Construction:

Historically ruby laser was the first laser. It was invented in 1960 by theodore Maiman. The ruby laser rod is in fact a synthetic ruby crystal, $Al_2O_3$, doped with chromium ions at a concentration ~~laser rod is in fact~~ of about 0.05% by weight. $Cr^{3+}$ ions are the actual active centers and have a set of three energy levels suitable for realizing lasing action whereas aluminium and oxygen atoms are inert.

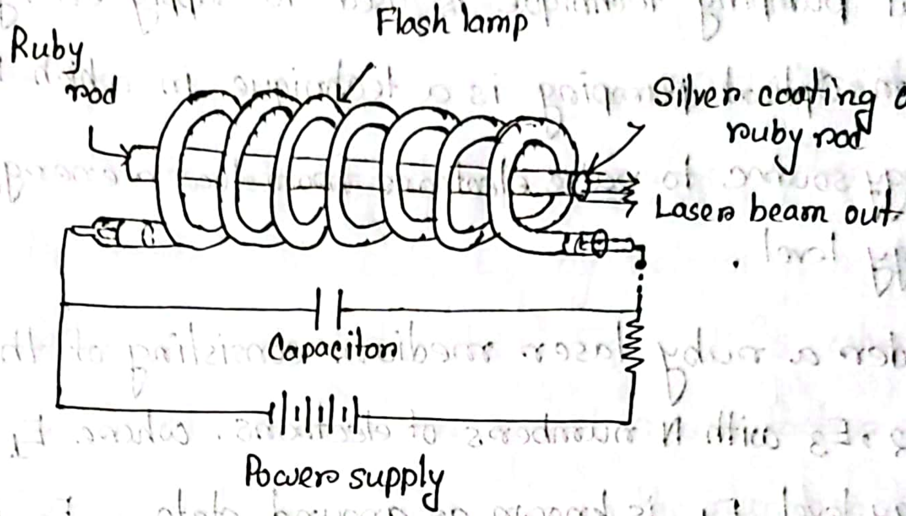



Fig. 1

The schematic of a ruby laser is shown in the fig. 1. Ruby rod is taken in the form of a cylindrical rod of about 4 cm in length and 0.5 cm in diameter. Its ends are grounded and polished such that the end faces are exactly parallel and are also perpendicular the axis of the rod. One face is silvered to achieve 100% reflection while the other is silvered to give 10% transmission and 90% reflection. The silvered faces constitute the Fabry - Perot resonator. The laser rod is surrounded by a helical photographic flash lamp filled with ~~zero~~ xenon. Whenever activated by the power supply the lamp produces flashes of white light.

**Working:**

The ruby laser is a three level solid-state laser. In a ruby laser optical pumping technique is used to supply energy to the laser medium. Optical pumping is a technique in which light is used as energy source to raise electrons from lower energy level to the higher energy level.

Consider a ruby laser medium consisting of three energy levels $E_1, E_2, E_3$ with N numbers of electrons. where $E_1 < E_2 < E_3$. The energy level $E_1$ is known as ground state, $E_2$ is metastable state and $E_3$ is pump state.

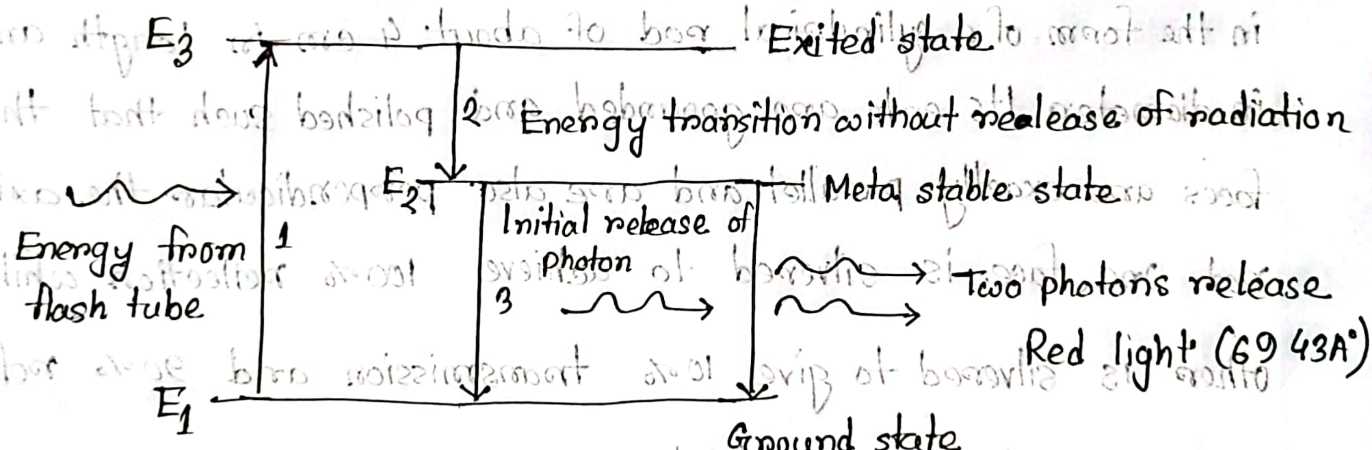



Fig. 1 Energy level diagram of ruby laser.

Let assume that initially most of the electrons are in the lower energy state ($E_1$) and only a tiny number of electrons are in the exited states ($E_2$ and $E_3$)

When light energy is supplied to the laser medium of ruby laser, the electrons in the lower energy state or ground state ($E_1$) gains enough energy and jumps into the pump state ($E_3$).

The lifetime of pump state $E_3$ is very small ($10^{-8}s$) so the electrons in the pump state do not stay for long period. After a short period they fall into the metastable state $E_2$ by releasing radiationless energy. The lifetime of metastable state $E_2$ is $10^{-3}s$ which is much greater that $E_3$. Therefore electron reach much faster in $E_2$ than they leave $E_2$. This result in an increase in the number of electron in metastable state $E_2$.

After some period, the electrons in the metastale state $E_2$ falls into the lower energy state $E_1$ by releasing energy in the form of photons. This is called spontaneous emission of radiation.

When this emitted photon interacts with the electron in the metastable state, it forcefully makes that electron fall into the ground state $E_1$. As a result, two photons are emitted. This is called stimulated emition of radiation. This is a continuous process. Due to this continuous interaction with the electrons million of photons are produced. Thus the light gain is achieved from Ruby laser.

## Application of laser:

(1) Welding and cutting

(2) Communication

(3) Bar code scanners

(4) Laser printing

(5) CD's and optical discs

(6) Laser ~~cot~~ cooling

(7) Laser spectroscopy

(8) Holography