I Year - II Semester **ENGINEERING PHYSICS** **L T P C**
4 0 0 3

OBJECTIVES: Physics curriculum which is re-oriented to the needs of Circuital branches
of graduate engineering courses offered by JNTUniv.Kkd. That serves as a transit to understand the branch specific advanced topics.

The courses are designed to:
- Impart concepts of Optical Interference, Diffraction and Polarization required to design instruments with higher resolution - Concepts of coherent sources, its realization and utility optical instrumentation.
- Study the Structure-property relationship exhibited by solid crystal materials for their utility.
- Tap the Simple harmonic motion and its adaptability for improved acoustic quality of concert halls.
- To explore the Nuclear Power as a reliable source required to run industries
- To impart the knowledge of materials with characteristic utility in appliances.

UNIT-I
INTERFERENCE: Principle of Superposition – Coherent Sources – Interference in thin
films (reflection geometry) – Newton's rings – construction and basic principle of Interferometers.

UNIT-II
DIFFRACTION: Fraunhofer diffraction at single slit cases of double slit, N-slits & Circular Aperture (Qualitative treatment only)-Grating equation - Resolving power of a grating, Telescope and Microscopes.

UNIT-III
POLARIZATION: Types of Polarization-production - Nicol Prism -Quarter wave plate
and Half Wave plate – Working principle of Polarimeter (Sacharimeter)

LASERS: Characteristics– Stimulated emission – Einstein's Transition Probabilities-Pumping schemes - Ruby laser – Helium Neon laser.

UNIT-IV
ACOUSTICS: Reverberation time - Sabine's formula – Acoustics of concert-hall.
ULTRASONICS: Production - Ultrasonic transducers- Non-Destructive Testing – Applications.

UNIT-V
CRYSTALLOGRAPHY & X-RAY DIFFRACTION: Basis and lattice – Bravais systems- Symmetry elements- Unit cell- packing fraction – coordination number- Miller
indices – Separation between successive (h k l) planes – Bragg's law.
NUCLEAR ENERGY – SOURCE OF POWER: Mass defect & Binding Energy – Fusion
and Fission as sources – Fast breeder Reactors.

UNIT-VI
MAGNETISM: Classification based on Field, Temperature and order/disorder – atomic
origin – Ferromagnetism- Hysteresis- applications of magnetic materials (Para &Ferro)..
DIELECTRICS: Electric Polarization – Dielectrics in DC and AC fields – Internal field –
Clausius Mossoti Equation - Loss, Breakdown and strength of dielectric materials – Ferroelectric Hysteresis and applications.
Outcome: Construction and working details of instruments, ie., Interferometer, Diffractometer and Polarimeter are learnt. Study Acoustics, crystallography magnetic and
dielectric materials enhances the utility aspects of materials.

Text Books:
1. A Text book of Engineering Physics – by Dr. M.N.Avadhanulu and Dr.P.G.Kshirasagar,
S.Chand & Company Ltd., (2014)
2. Physics for Engineers by M.R.Srinasan, New Age international publishers (2009)
3. Engineering Physics by D.K.Bhattacharya and Poonam Tandon , Oxford press (2015)

Refference books:
1. Applied Physics by P.K.Palanisamy , Scitech publications (2014)
2. Lasers and Non-Linear optics by B.B.Laud , Newage international publishers (2008)

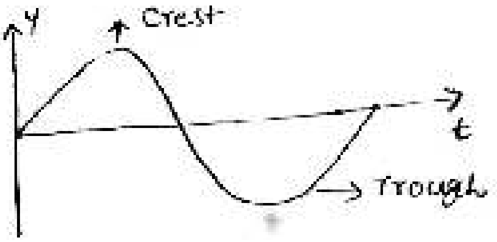
UNIT-I

The only Source of Knowledge is Experience
— Einstein

Interference

Introduction: Best phenomena that provides direct evidence for the wave nature of light is interference. Observations in our day to day life are multiple colours on soap bubble as well as on thin layer of floating oil when viewed under sun light.

Wave: Disturbance in the medium is known as wave. main Characteristic of the wave is Energy can take transition from one end to another end

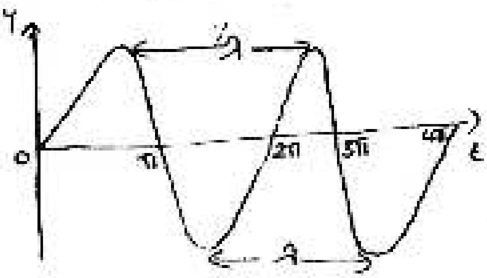


Crest:- The Section of the wave that rises above the undisturbed position is called the Crest.

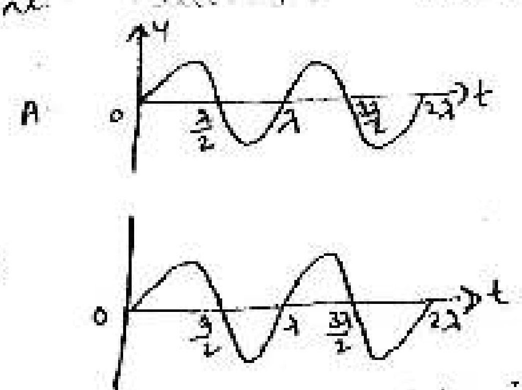
Trough:- The Section which lies below the undisturbed position.

Amplitude: It is the maximum positive displacement from the undisturbed position of the medium to the top of the Crest.

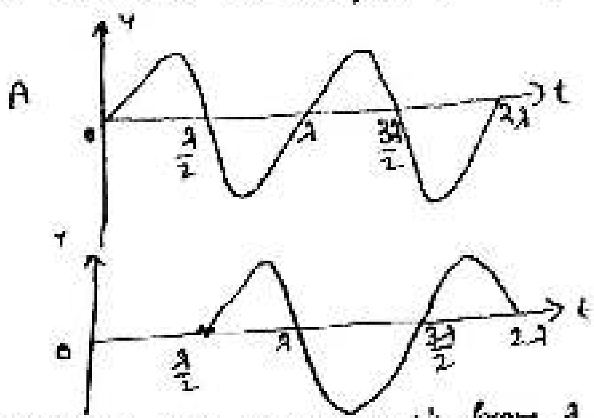
Wavelength: Distance between two adjacent Crests or troughs are nothing but wavelength (λ).



Path difference: The difference between the length of two paths.



A & B are Start at Same position 'O'.
There is no path difference



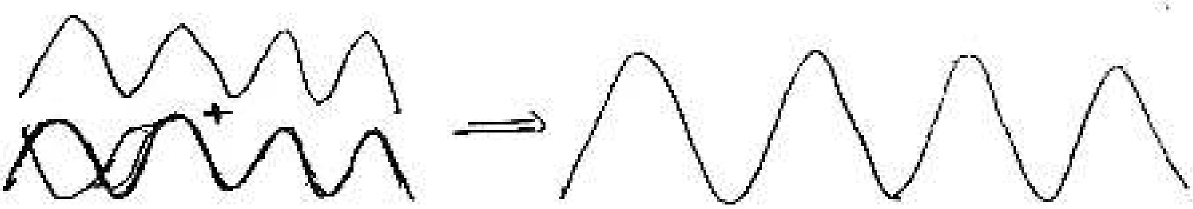
A start's from 'O' & B start's from λ/2.
Path difference λ/2.

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

Let us consider two waves travelling simultaneously in a medium. At any point let 'y_1' be the displacement due to one wave at any instant in the absence of the other and 'y_2' be the displacement of other wave at the same instant in the absence of the first wave.

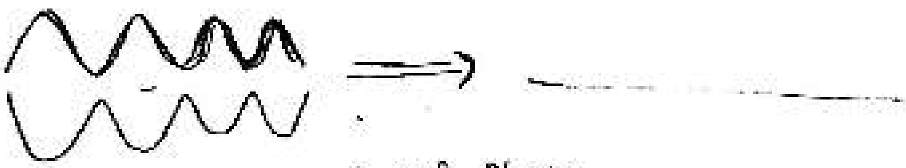
∴ The resultant displacement due to the presence of both waves is given by $y = y_1 \pm y_2$

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



(a) waves in phase.

-ve sign has to be taken when they are in the opposite direction



(b) waves out of phase.

Interference:- modification of intensity due to the superposition of waves is called Interference of light.

Interference can be classified into two types

(1) Constructive interference.

(2) Destructive interference.

Constructive interference:- If both the waves are in same phase (direction) the resultant displacement becomes maximum. i.e one wave of the crest coincide with the other wave of the crest or one wave of the trough coincide with the another wave of the trough

$\therefore y = a + a = 2a$

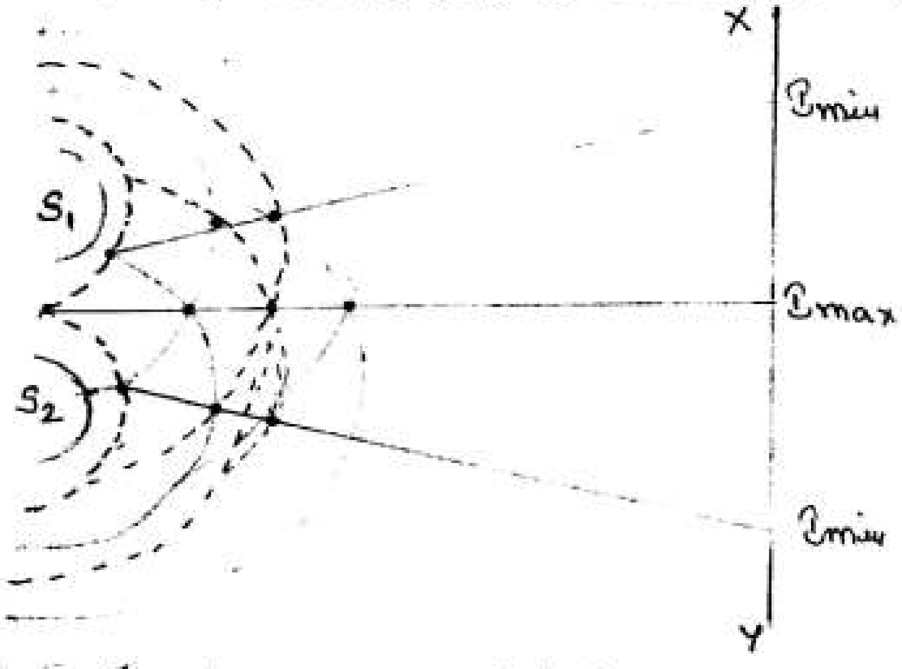
As the intensity is directly proportional to the square of the amplitude $\therefore I = R^2 = 4a^2$

The intensity at these points is four times the intensity due to one wave i.e intensity becomes maximum in constructive interference

Destructive interference:- If both the waves are in out of phase the resultant displacement becomes zero. i.e first wave of the crest coincide with the second wave of trough or first wave of trough coincide with the second wave of the crest.

$\therefore y = a - a = 0 \Rightarrow \therefore I = 0$

i.e intensity becomes zero in destructive interference.



Coherence:- Two waves are said to be coherent if their waves have
(i) Same wavelength (λ)
(ii) Same amplitude and
(iii) Constant (or zero) phase difference

NOTE: Two independent sources of light can never be coherent.

Conditions for the interference

1) The two interfering Sources should be coherent i.e the phase difference between them must remain constant with time
2) The two waves should have same frequency
3) If the interfering waves are polarized, they must be in the same state of polarization
4) The seperation between the light sources (d) should be as small as possible to get large fringe width.
(5) The displacement (D) of the Screen from the two sources should be quite large to obtain widely spaced fringes
6) The amplitudes of the interfering waves should be equal
(7) The Screen should be dark. If the screen is not dark, the minimum intensity will not appear to be zero, resulting a poor contrast between maxima and minima

Young's double slit experiment

Thomas Young demonstrated the concept of interference of light in 1802. Young in his experiment allowed sunlight to fall on a pinhole S. Spherical waves emerged out from S were made to fall on two pin holes A and B in an opaque screen. On the Screen (XY) kept at certain distance from the opaque screen, he observed few coloured bright and dark bands. Later the white light was replaced by monochromatic source of light and pinholes were replaced by narrow slits.

A single vertical slit S was illuminated by light of wavelength λ from a monochromatic source such as Sodium Vapour lamp. A and B were two narrow slits accurately parallel to each other and parallel to S. The width of each slit was about 0.03 mm and they were about 0.3 mm apart. Since A and B

The distance between two consecutive fringes

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

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

Condition for dark fringe :-

The point p will be dark if path difference is $(2n-1)\frac{\lambda}{2}$ where $n = 1,2,3 \ldots$ etc or $\frac{xd}{D} = (2n-1)\frac{\lambda}{2}$

$$\Rightarrow x_n = \frac{(2n-1)\lambda D}{2d}$$

The above equation gives the distances of the dark fringes from the Centre C. At distances $x_1, x_2, x_3 \ldots$ from C, dark fringes corresponding to $n = 1,2,3 \ldots$ etc. are formed

$\therefore$ for $n=1$ $x_1 = \frac{\lambda D}{2d}$; $n=2$, $x_2 = \frac{3\lambda D}{2d}$; $n=3$ $x_3 = \frac{5\lambda D}{2d}$

$$\ldots x_n = (2n-1)\frac{\lambda D}{2d}$$

$\therefore$ The distance between two consecutive dark fringes

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

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

$\therefore$ The distance between two consecutive bright or dark fringes is called band width. From above equations bright and dark fringes have equal widths.

$\therefore$ The width of the interference fringe (β) is

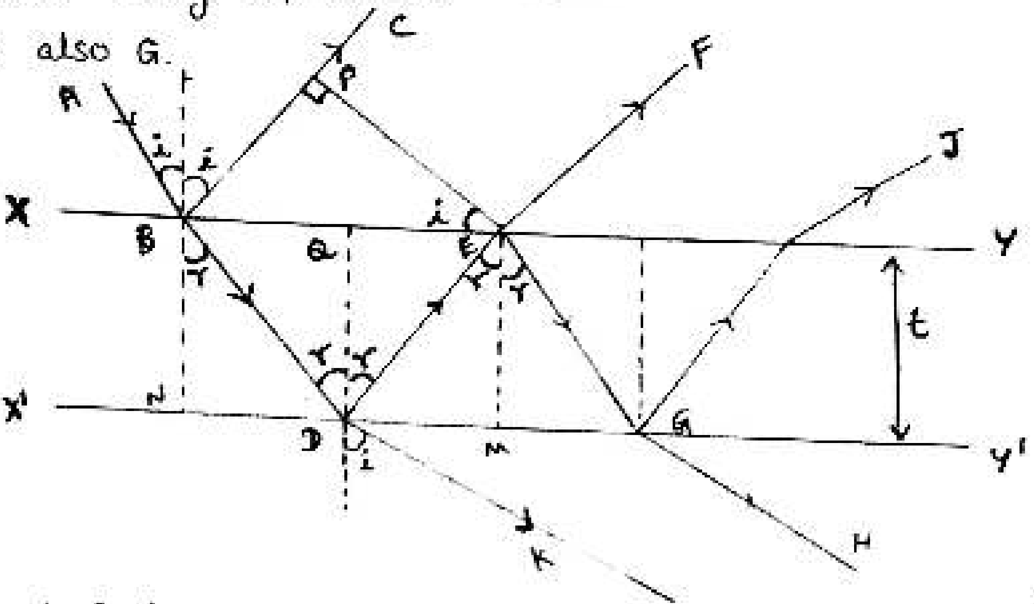
(i) directly proportional to the wavelength of light used (λ)

(ii) directly proportional to the distance of the Screen from the two Sources (D)

(iii) inversely proportional to the distance between the two coherent Sources (d)

Interference in thin film: ... film ... is due to superposition of light deflected from the top and bottom surfaces of the film.

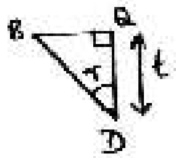
Let us consider a thin film of thickness t bound by two plane surfaces XY and X'Y' and let μ be the refractive index of material of the film. A ray of light AB incident on the surface XY at angle i is partly reflected along BC and partly refracted along BD. Let the angle of refraction be r. On the surface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



Reflected System:- The rays BC and EF constitute reflected system. To find the path difference between these reflected rays EP is drawn perpendicular to BC.

$$\text{Path difference} = (BD + DE)\mu - BP \longrightarrow (1)$$

In ΔBDQ

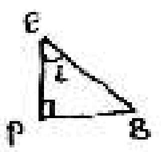


$$\cos r = \frac{DQ}{BD} = \frac{t}{BD}$$

$$\Rightarrow BD = \frac{t}{\cos r} = DE$$

$$\therefore \text{Path difference} = \frac{2\mu t}{\cos r} - BP \longrightarrow (1)$$

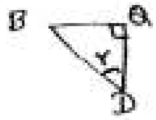
In ΔBPE



$$\sin i = \frac{BP}{BE} \Rightarrow BP = BE \sin i$$

$$= (BQ + QE)\sin i \rightarrow (2)$$

In Δ BDQ



$\tan r = \frac{BQ}{QD} = \frac{BQ}{t}$

$\Rightarrow BQ = t \tan r = QE$

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

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

$\therefore BP = \frac{2\mu t}{\cos r} \sin^2 r \longrightarrow (3)$

(3)rd equation substitute in (1) equation then we can get

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

$\therefore$ path difference $= 2\mu t \cos r \quad [\because 1-\sin^2 r = \cos^2 r]$

Since the ray BC is reflected at the air medium interface, it undergoes a phase change of π or path difference of $\frac{\lambda}{2}$.

$\therefore$ Path difference $= 2\mu t \cos r - \frac{\lambda}{2}$

(1) Condition for bright band

The film will appear bright if the path difference is $n\lambda$

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

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

(2) Condition for dark band

The film will appear dark if the path difference is $(2n+1)\frac{\lambda}{2}$.

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

(or) $2\mu t \cos r = (n+1)\lambda$ where $n = 0, 1, 2, 3 \ldots$ etc

$2\mu t \cos r = n\lambda$ where $n = 1, 2, 3 \ldots$ etc.

Colours of thin films:-

When a thin film is exposed to a white light such as sun light, beautiful colours appear in the reflected light.

Ex: Soap bubble and thin oil layer.

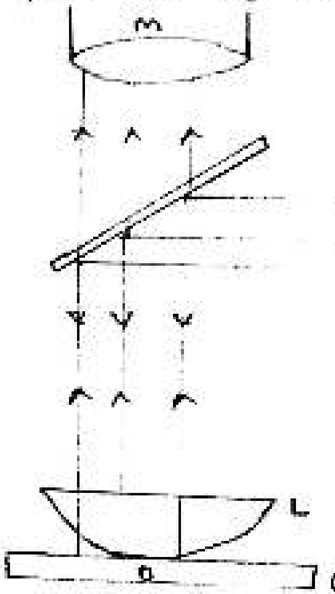
In the case of soap bubble let us assume that thickness of the film t is a constant. Then in the formula $2\mu t \cos r$, μ and r are the variables since white light has varying λ value, μ also varies with λ. Due to curved nature of bubble angle of incidence varies for different points on the bubble and hence accordingly angle of refraction r varies. Here in the formula $2\mu t \cos r = (2n+1)\frac{\lambda}{2}$, varies varying values of μ and r can satisfy the condition for constructive interference for a particular wavelength (λ) only. Accordingly that point will appear bright in that particular colour. In a similar way different points satisfy the conditions for constructive interference for different colours and hence appear multi coloured.

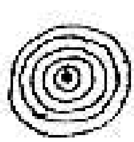
Let us now analyse the case of thin layer of oil film floating on water. In this case since the film is perfectly flat, when parallel rays such as sun light is incident, the angle of incidence i and hence angle of refraction r will remain constant. But for different λ values μ varies and also the thickness of the film t may not be constant throughout the film. Hence different points on the film satisfy the condition for constructive interference for different colours depending on the values of μ and t and hence appear multicoloured.

No dark band is seen because if a particular point satisfies condition for destructive interference for a particular wavelength, the same point may satisfy condition for constructive interference for different wavelength and hence throught the film we see multi colours.

Newton's rings:- A plano convex lens (L) having long focal length f is placed with its convex surface on a plane glass plate (G). A gradually increasing thickness of air film will be formed between plane glass plate and convex surface of plano convex lens. The thickness of air film will be zero at the point of contact and symmetrically increases as we go radially from the point of contact

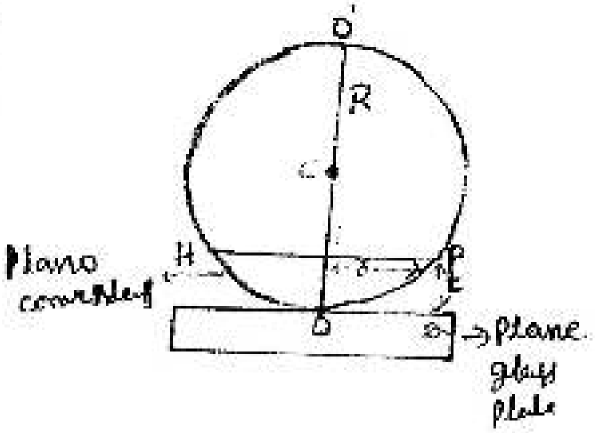
A monochromatic light of wavelength 'λ' is allowed to fall normally on the lens with the help of a glass plate 'G' kept at 45° to the incident monochromatic beam. A part of the incident light rays are reflected up at the convex surface of the lens and the remaining light is transmitted through the air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





Theory :-

Let R be the radius of the curvature of the lens L and let choose a point P at a distance r from O and let t be the thickness of air film at that point. Then the path difference between the light reflected at P and Q is 2t. When the additional path difference between the two reflected beams becomes $2t+\frac{\lambda}{2}$. When this path difference is $n\lambda$ constructive Interference occurs.



The condition for bright rings is $2t+\frac{\lambda}{2}=n\lambda$ →(1)

(or) $2t=(2n-1)\frac{\lambda}{2}$ where n=1,2,3...etc.

Similarly for dark rings the condition is

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

$$\boxed{2t = n\lambda} \longrightarrow (2)$$

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

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

$$\Rightarrow r^2 = t(OO' - EO) = t(2R-t)$$

$$= 2Rt - t^2$$

$$= 2Rt \text{ (approximately)}$$

$$\therefore \boxed{t = \frac{r^2}{2R}} \longrightarrow (3)$$

Substituting equation (3) in the (1) equation for bright rings

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

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

or $\boxed{r_n = \sqrt{\frac{(2n-1)\lambda R}{2}}}$ where $n = 1,2,3 \ldots$ etc. $\rightarrow (4)$

Substituting equation (3) in the (2) equation for dark rings

$$\frac{2r^2}{2R} = n\lambda \Rightarrow r^2 = nR\lambda \Rightarrow \boxed{r_n = \sqrt{nR\lambda}} \rightarrow (5)$$ where $n = 1, 2, \ldots$ etc.

For $n = 0$ the radius of the ring is zero which denotes the centre O. At the point of contact the thickness of air is zero, the ray reflected at the air-glass interface undergoes additional phase change π or path change of $\frac{\lambda}{2}$. Hence it appears dark.

From the equations (4) & (5) radius of rings are proportional to (i) $\sqrt{\lambda}$ and (ii) $\sqrt{R}$.

For the first dark ring $n=1$ $r_1 = \sqrt{R\lambda}$

Second dark ring $n=2$ $r_2 = \sqrt{2R\lambda}$

$\therefore$ Hence the spacing between the first and second dark rings

$\sqrt{2R\lambda} - \sqrt{R\lambda} = (\sqrt{2}-1)\sqrt{R\lambda} = (1.414-1)\sqrt{R\lambda}$

$\therefore r_2 - r_1 = 0.414\sqrt{R\lambda}$

For the third dark ring $n=3$ $\quad r_3 = \sqrt{3R\lambda}$

Fourth dark ring $n=4$ $\quad r_4 = \sqrt{4R\lambda}$

$\therefore$ The spacing between third and fourth dark rings

$r_4 - r_3 = \sqrt{4R\lambda} - \sqrt{3R\lambda} = (2-1.734)\sqrt{R\lambda}$

$\therefore r_4 - r_3 = 0.266\sqrt{R\lambda}$.

We find that with increase of order, the rings get closer.

Determination of wavelength of Sodium light using Newtons rings:-

Let R be the radius of curvature of the curved surface in contact with the glass plate and λ the wavelength of light used.

We know that the radius of n^{th} dark r is given by

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

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

$$D_n = 2r_n = 2\sqrt{nR\lambda} = \sqrt{4nR\lambda}$$

Hence $\quad D_n^2 = 4nR\lambda \longrightarrow (1)$

Similarly the diameter of the m^{th} dark ring is $D_m = \sqrt{4mR\lambda}$

$$D_m^2 = 4mR\lambda \longrightarrow (2)$$

Substracting equation's 2 to (1)

$$D_m^2 - D_n^2 = 4mR\lambda - 4nR\lambda$$

$\therefore$ or $\boxed{\lambda = \dfrac{D_m^2 - D_n^2}{4R(m-n)}}$

Hence by measuring the radius of rings of different orders and knowing the radius of curvature of the lens R, we can determine the wavelength λ of the given monochromatic source of light.

UNIT - 2

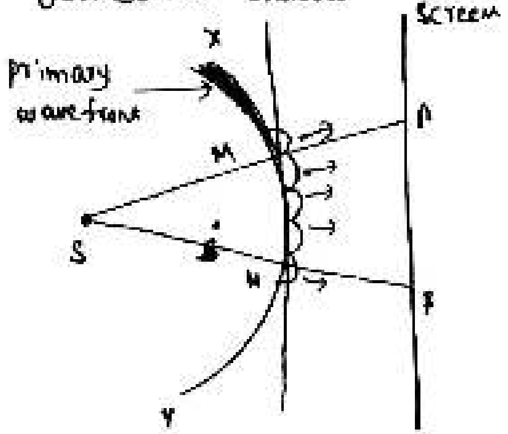
DIFFRACTION

Introduction:- The bending of light waves at an aperture or edge is known as diffraction.

When an object is placed in the path of light beam, the shadow of the object is formed, behind the object is due to diffraction.

Diffraction based on Huygen's wave theory:-

According to Huygen's wave theory every point on the primary wave front can act as second source of disturbance and secondary waves are generated from those points. The envelope of these secondary waves from secondary wavefront. Let primary wavefront XY from point source S of monochromatic light reach the aperture MN placed in its path. The light passing through the aperture has to cause brightness inside AB on the screen and regions beyond A and B have to be dark i.e., regions of geometrical shadow



Every point on the wave front reaching the aperture MN acts as secondary source of light and from those points light waves originate and thus secondary waves enter into the geometrical shadow region also. The waves from different parts of the primary wavefront travel different distances to reach any point on the geometrical shadow region and interfere to produce bright and dark fringes. Since the amplitude of secondary waves decrease while going away from A and B the intensity gradually falls to zero.

(12) Fresnel and Fraunhofer Diffraction. (3)

Fresnel Diffraction	Fraunhofer Diffraction
1. Either a point source or an illuminated narrow slit is used	1. Extended source at infinite distance is used
2. The wave front undergoing diffraction is either spherical or cylindrical.	2. the wave front undergoing diffraction is a plane wave front
3. The source and the screen are finite distances from the obstacle producing diffraction	3. the source and screen are at infinite distances from the obstacle producing diffraction.
4. No lens is used to focus the ~~rays~~ rays.	4. Converging lens is used to focus parallel rays.

Difference between interference and diffraction :-

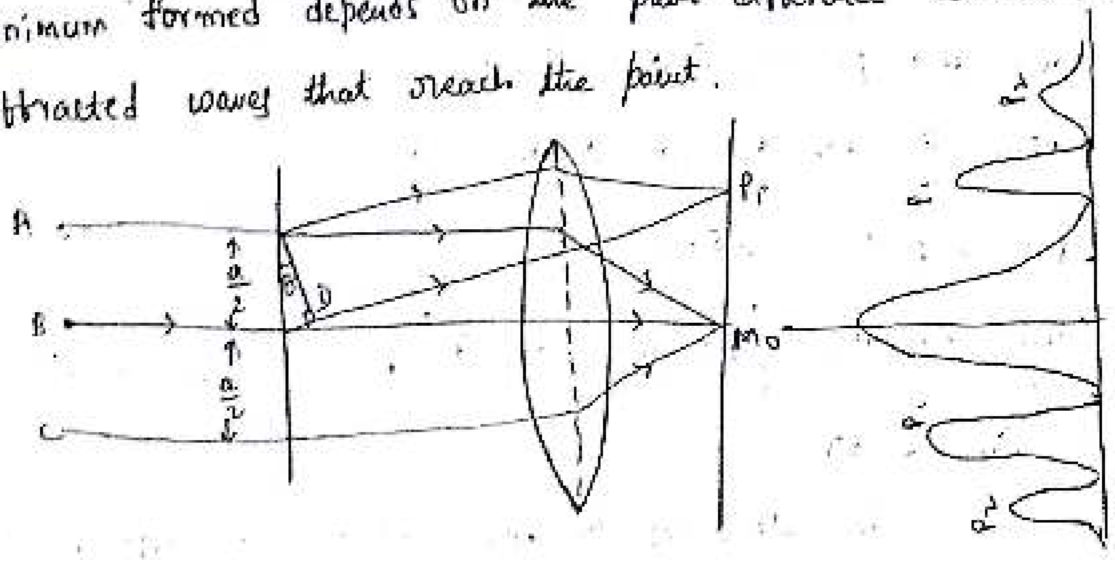
Interference	Diffraction
1. Superposition is due to two seperate wave fronts originating from two coherent sources	1. Superposition is due to secondary wavelets originating from different parts of the same wave front
2. The fringes normally have equal widths.	2. The width between fringes is never equal
3. All the bright fringes have the same intensity	3. The intensity of bright fringes usually decrease with increase of order.
4. All the dark fringes have zero intensity	4. The intensity of dark fringes is not zero

Fraunhoffer Diffraction at single slit

Let us consider a narrow slit of width 'a'. A monochromatic light of wavelength λ is collimated by a Lens. The collimated beam consists of plane wave fronts. When this beam is incident on the single slit, majority of the light beam passes through the slit without touching the slit edges, i.e. light transmits through the central portion of the slit. This undiffracted beam is converged at M_0 on the screen after passing through the lens. maximum intensity is observed at M_0, called the central maximum.

However, the light beam is diffracted at the two edges of the slit and produces a pattern of alternate maxima and minima with the central maxima at the centre of the pattern.

At a given point on the screen whether a maximum or minimum formed depends on the path difference between the diffracted waves that reach the point.



When slit is divided into two equal parts, $AB = a/2$; $BC = a/2$

AP_1 and BP_1 are two rays diffracted at an angle θ from the top of each half of the $BP_1 > AP_1$

∴ Path difference = $BP_1 - AP_1 = BD$

(4) To get minimum intensity at P_1, the path difference must be odd number multiple of $\lambda/2$

From Δ ADB $\sin\theta = \frac{BD}{AB} = \frac{BD}{a/2}$

i.e $BD = \frac{a}{2}\sin\theta$

but $BD = \frac{\lambda}{2}$ for minimum, then

$\frac{a}{2}\sin\theta = \frac{\lambda}{2}$ (or) $\boxed{a\sin\theta = \lambda}$

If the slit is divided into 4 equal parts, then

$\frac{a}{4}\sin\theta = \frac{\lambda}{2}$ (or) $a\sin\theta = 2\lambda$

For six equal parts $a\sin\theta = 3\lambda$

in general $\boxed{a\sin\theta = n\lambda}$ $n = 1, 2, 3, \ldots$ is condition for minima.

Suppose the slit is divided into 3 equal parts, such that the path difference between any two adjacent rays is $\lambda/2$. Then, two rays cancel each other and the 3rd reaches the screen and produces some intensity.

Then, $\frac{a}{3}\sin\theta = \frac{\lambda}{2} \Rightarrow a\sin\theta = \frac{3\lambda}{2}$

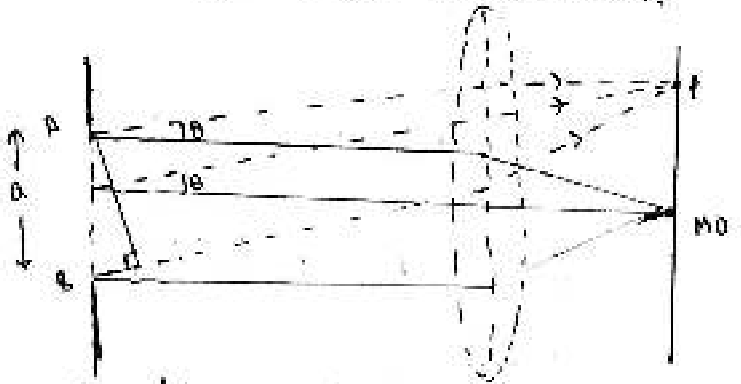
For 5 parts $a\sin\theta = \frac{5\lambda}{2}$

In general, $\boxed{a\sin\theta = (2n-1)\frac{\lambda}{2}}$ $n = 1, 2, 3 \ldots$ is condition for maxima.

The intensities of these maxima are less than that of the central maximum decreases as we move away from the central maximum.

Diffraction due to single slit - Intensity calculation (15)

A monochromatic light beam of wavelength λ is incident on the single slit of width 'a'. The direct light is converged at P_0 on the screen by a lens. P_0 is the principle maximum. Light waves diffracted at an angle θ are focussed at P_1.



BC is the path difference between the top ray and the bottom ray.

From diagram $\sin\theta = \frac{BC}{AB}$

$\Rightarrow BC = AB\sin\theta = a\sin\theta$

Phase difference $= \frac{2\pi}{\lambda} \times a\sin\theta$

Suppose the slit is divided into 'n' equal parts and amplitude of light in each part is A'. Then phase difference between two successive parts is $\frac{1}{n}$ of total phase difference.

Say $\phi = \frac{1}{n}\left(\frac{2\pi}{\lambda} a\sin\theta\right)$

Using the method of vector addition of amplitude the resultant amplitude R is given by

$$R = \frac{A' \sin\left(\frac{n\phi}{2}\right)}{\sin\left(\frac{\phi}{2}\right)}$$

$$\Rightarrow R = \frac{A' \sin\left(\frac{n}{2} \frac{1}{n} \frac{2\pi}{\lambda} a\sin\theta\right)}{\sin\left(\frac{1}{n} \frac{2\pi}{\lambda} \frac{a\sin\theta}{2}\right)} = \frac{A' \sin\left(\frac{\pi a\sin\theta}{\lambda}\right)}{\sin\left(\frac{\pi a\sin\theta}{n\lambda}\right)}$$

[illegible] $\frac{\ldots \sin\theta}{\lambda}$

then $R = \frac{A' \sin\alpha}{\sin\left(\frac{\alpha}{n}\right)}$

As $\frac{\alpha}{n}$ is very small $\sin\left(\frac{\alpha}{n}\right) \approx \frac{\alpha}{n}$

$$\therefore R = A' \frac{\sin\alpha}{\frac{\alpha}{n}} = A'n \frac{\sin\alpha}{\alpha}$$

$$\therefore R = A \frac{\sin\alpha}{\alpha} \qquad [\because A'n = A]$$

$\therefore$ Intensity $I = R^2 = A^2 \left(\frac{\sin^2\alpha}{\alpha^2}\right)$

Condition for principal maxima:-

The expression for resultant amplitude R can be written in ascending powers of α as

$$R = \frac{A}{\alpha}\left[\alpha - \frac{\alpha^3}{3!} + \frac{\alpha^5}{5!} - \frac{\alpha^7}{7!} + \ldots\right]$$

$$\Rightarrow R = A\left[1 - \frac{\alpha^2}{3!} + \frac{\alpha^4}{5!} - \frac{\alpha^6}{7!} + \ldots\right]$$

If the negative terms vanish, the value R will be maximum

i.e $\alpha = 0$

$$\therefore \alpha = \frac{\pi a \sin\theta}{\lambda} = 0 \quad \text{or} \quad \sin\theta = 0 \quad \text{or} \quad \theta = 0$$

Now maximum value of R is A and intensity is proportional to A^2. The condition $\theta = 0$ means that this maximum is formed by those secondary wavelets which travel normally to the slit. The maximum is known as principal maximum.

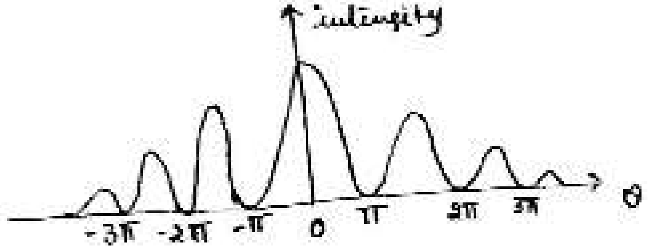
Minimum intensity positions:- the intensity will be minimum when $\sin\alpha = 0$. The values of α which satisfy the equation are

$\alpha = \pm\pi, \pm 2\pi, \pm 3\pi, \pm 4\pi \ldots$ etc $= \pm m\pi$

(7) or $\frac{\pi a \sin\theta}{\lambda} = \pm m\pi$ or $a\sin\theta = \pm m\lambda$ --- (1)

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

intensity distribution due to diffraction at a single slit



From equation (1) since θ is small $a\sin\theta = \pm m\lambda$ (m=1)

$\therefore \sin\theta = \theta = \frac{\lambda}{a}$ → (2)

If x is the half width of Central bright maxima and d is the distance between the slit and the Screen then

$\theta = \frac{x}{d} = \frac{\lambda}{a}$ (or) $x = \frac{d\lambda}{a}$

$\therefore$ width of the Central maxima $2x = \frac{2d\lambda}{a}$

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

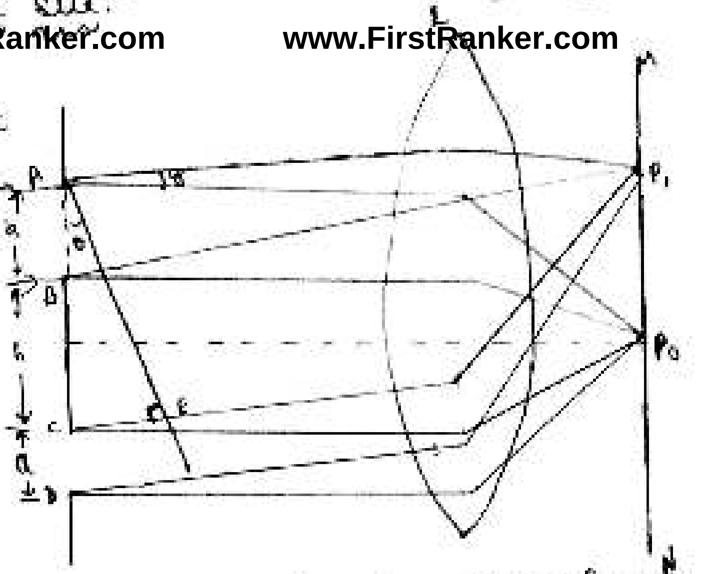
$\sin\theta = \frac{x}{f}$ [∵ f is the focal length of lens L_2]

$\therefore$ But from eqn (2) $\sin\theta = \frac{\lambda}{a}$

$\therefore \frac{x}{f} = \frac{\lambda}{a}$ (or) $a = \frac{f\lambda}{x}$

From above eqn with decrease of slit width, the fringe width increases. i.e when slit becomes narrower, the fringe becomes wider.

Fraunhofer Diffraction at Double slit:-



Let S be a point source of monochromatic light. L_1 is collimating lens of focal length f at a distance f from the source so that the lens renders parallel rays.

Let AB and CD be two rectangular slits of width 'a' and let 'b' be the seperation between the slits. Let a plane wavefront of wavelength λ fall normally on the slit. Let L be the collecting lens and MN be the screen.

When a plane wavefront falls normally on the slits, all the slits, all the secondary waves travelling in a direction parallel to OP_0 focus at P_0. Hence P_0 corresponds to the position of the central bright maximum.

(i) Interference due to diffracted secondary waves from corresponding points on the two slits.

(ii) Diffraction due to individual slits

Missing order in the double slit diffraction pattern

Certain directions the interference maxima may coincide with diffraction minima. Thus the combined effect of interference and diffraction result in missing of certain orders of interference maxima.

The condition for interference maxima is given by

$$(a+b)\sin\theta = n\lambda \longrightarrow (1)$$

The condition for diffraction minima is given by

$$a\sin\theta = p\lambda \longrightarrow (2)$$

where 'n' and 'p' are integers. If the values of a and b are such that both the conditions are satisfied simultaneously for the same value of θ, then in those directions certain interference maxima coincide with certain diffraction minima. Since this condition is satisfied for the same value of θ.

$$\therefore \quad \sin\theta = \frac{n\lambda}{a+b} = \frac{p\lambda}{a} \Rightarrow \frac{n}{a+b} = \frac{p}{a}$$

Case i) Let $a=b$ then $\frac{n}{2a} = \frac{p}{a}$ (or) $n = 2p$

Since $p = 1,2,3$ etc corresponding n values are 2,4,6 etc. This means that in the diffraction pattern $2^{nd}, 4^{th}, 6^{th}$ etc. orders of the interference maxima will be missing.

Case ii) Let $2a = b$ $\quad \frac{n}{3a} = \frac{p}{a}$

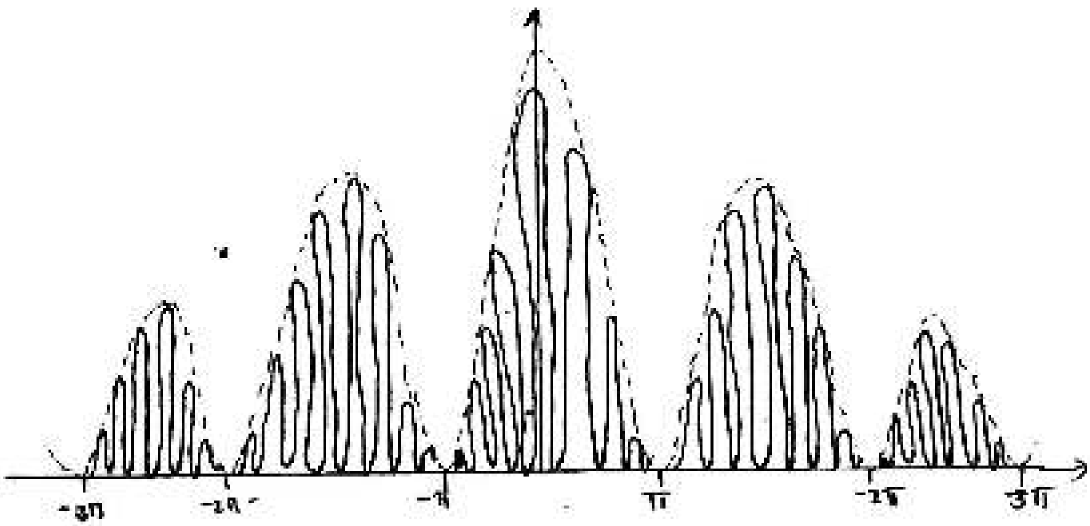
$$\Rightarrow n = 3p$$

Since $p = 1,2,3$ etc. corresponding 'n' values are 3,6,9 etc. This means that in the diffraction pattern $3^{rd}, 6^{th}, 9^{th}$ etc. orders of the interference maxima will be missing.

(iii) Let $a+b = a$ which means that $b=0$ then

$$\frac{m}{a} = \frac{p}{a} \quad \text{or} \quad n = p$$

Since $p = 1,2,3$ etc. Corresponding n values are also 1,2,3 etc. this means that all the orders of interference maxima will be missing in the ~~diffraction~~ diffraction pattern. i.e., we will be observing only diffraction pattern corresponding to single slit of width $2a$.

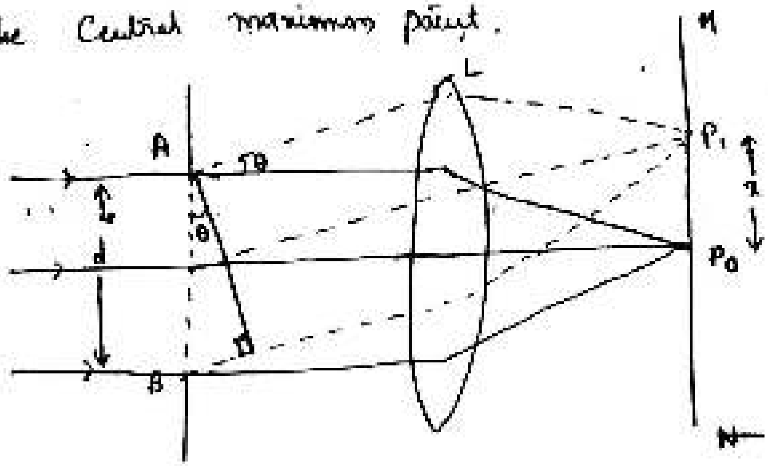


intensity distribution

The continuous curve represents the equally spaced interference maxima and minima while the dotted curve represents diffraction maxima and minima. The spacing of the interference maxima and minima depends on the values of 'a' and 'b' while the spacing between diffraction maxima depend on the value of 'a'.

(11) **Fraunhofer Diffraction at a Circular Aperture:-**

Let us consider a circular aperture of diameter 'd'. A plane wave front falls normally on this aperture AB. Every point on the wave front in the plane of the circular aperture is a source of secondary wavelets. They spreadout in all directions on passing through the aperture. Let the diffracted beam be focussed on the screen by a convex lens L. The waves travelling along the normal to the circular aperture are focussed at P_0. Since all these waves travelled the same distance to reach P_0, they all reinforce one another. Hence P_0 is the position of maximum intensity and this is the central maximum point.



Let us consider the waves travelling at angle θ with respect to the normal rays. They meet at the point P_1 on the screen. Let $P_0P_1 = x$. The path difference between the waves from A and B on reaching P_1 is given by AC.

In ΔABC $\quad \sin\theta = \frac{BC}{AB} = \frac{BC}{d}$

$\Rightarrow BC = d\sin\theta$

If this path difference is $\lambda, 2\lambda, 3\lambda$... etc, then P_1 will be a of maximum intensity i.e $d \sin\theta_n = \frac{(2n+1)\lambda}{2}$ is the condition for constructive interference.

If P_1 is a point of minimum intensity, with P_0P_1 as radius and P_0 as centre of a circle is drawn, all points on the circle will have the same path difference and hence satisfy the condition for minimum intensity. Thus, the diffraction due to a circular aperture consists of a bright central disc surrounded by alternate dark and bright concentric rings. The bright central disc is called Airy's disc and the concentric rings are called Airy's rings.

If a collecting lens L of focal length f is used either very near to the slit or when the screen is at larger distance from the lens.

$$\sin\theta = \theta = \frac{x}{f}$$

But from the condition for first secondary minimum

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

$$\therefore \quad \frac{x}{f} = \frac{\lambda}{d} \quad \text{or} \quad x = \frac{f\lambda}{d}$$

where x is the radius of the Airy's disc. Thus we find that with decrease of the diameter of the aperture, the radius of the Airy's disc increases.

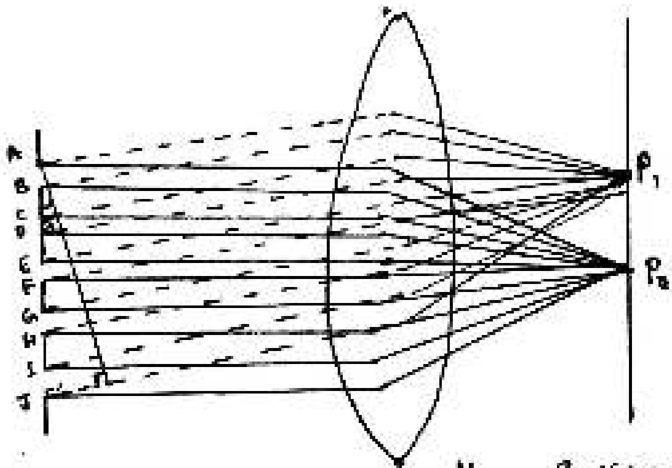
(13)

Plane Diffraction Grating:- A diffraction grating is an optical device consists of large number of narrow, uniform spaced parallel slits and each slit is seperated by an opaque region.

When a plane wavefront is incident normally on a grating surface, the incident light is transmitted through the slits and ~~ob~~ obstructucted by opaque portions. Such type of grating is called as plane transmission diffraction grating.

The ~~rulings are~~ combined width of a ruling and a slit is called "grating element". Points on successive ~~width of a ruling~~ slits seperated by a distance equal to the grating element are called "corresponding points".

THEORY:-



Let ABCDEFGHIJ represent the section of grating normal to the plane of the paper. AB, CD, EF... etc represent the slits of width 'a' each while BC, DE, FG.. etc represent opaque rulings of width b each. (a+b) which is the combined width of a ruling and a slit is called grating element. It is also the distance between two successive slits. Any two points on successive slits seperated by a distance (a+b) are called corresponding points.

Let a plane wave-front be incident normally on the grating. The points in the Slits AB, CD, EF etc. act as Secondary Sources of light giving rise to Secondary waves. These waves Spread in all direction on the other side of the grating. The Secondary waves in the Same direction as that of the incident wave are focussed at P_0 on the Screen. Since all these Secondary waves have travelled equal distance to reach P_0, they reinforce Constructively and hence the point P_0 is the position of Central bright maximum.

Now let us Consider the Secondary diffracted waves proceeding in a direction which makes an angle θ with respect to the normal to the grating. AMM_1 is drawn normal to the diffracted light. Let us Consider the waves diffracted at the corresponding points A and C. The path difference the waves on reaching P_1 is CM. Since they travel equal path beyond AM.

In Δ ACM $\quad \sin\theta = \frac{CM}{AC}$

$\Rightarrow CM = (a+b)\sin\theta$

The Superposition of these waves at P_1 causes interference. P_1 will be bright when $\boxed{(a+b)\sin\theta = n\lambda}$

where $n = 0,1,2,3 \ldots$ and angles $\theta_1, \theta_2, \theta_3$ etc. Correspond to the directions of the principal maxima.

$\therefore \sin\theta = \frac{n\lambda}{a+b} = nN\lambda \Rightarrow \boxed{\lambda = \frac{\sin\theta}{Nn}}$

where $\frac{1}{(a+b)} = N$ is the number of grating elements or lines per unit width of the grating

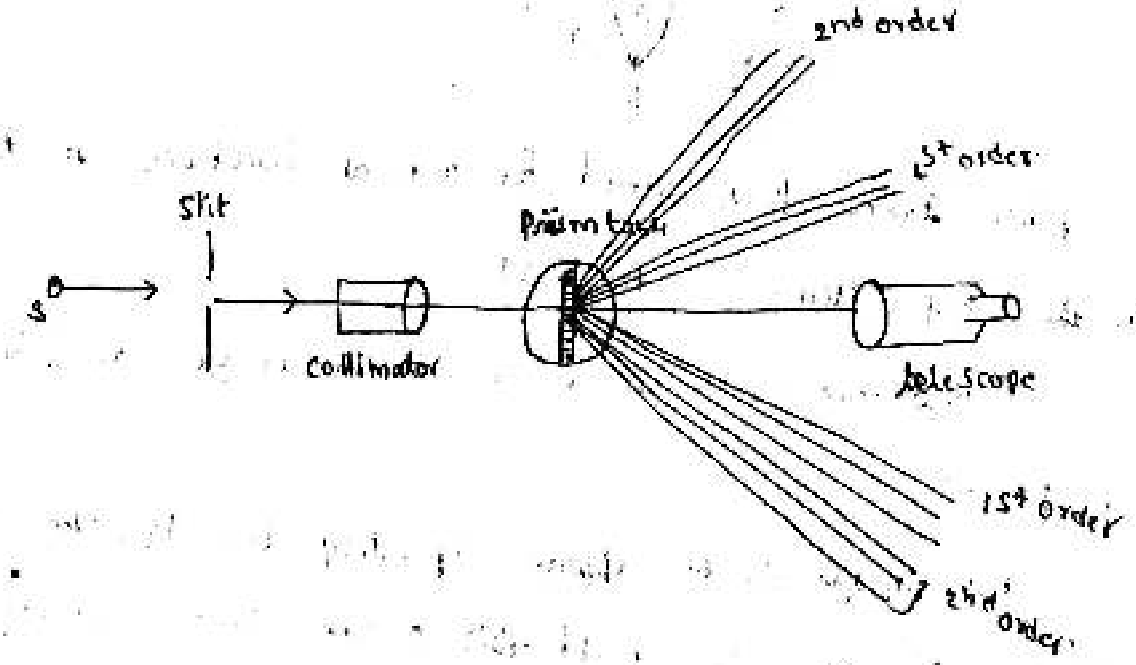
Maximum number of orders possible with a grating:

- The maximum value that θ can have is 90°. Hence the maximum possible value of sin θ is 1

$$\therefore\ nN\lambda \leq 1 \quad \text{or} \quad n \leq \frac{1}{N\lambda}$$

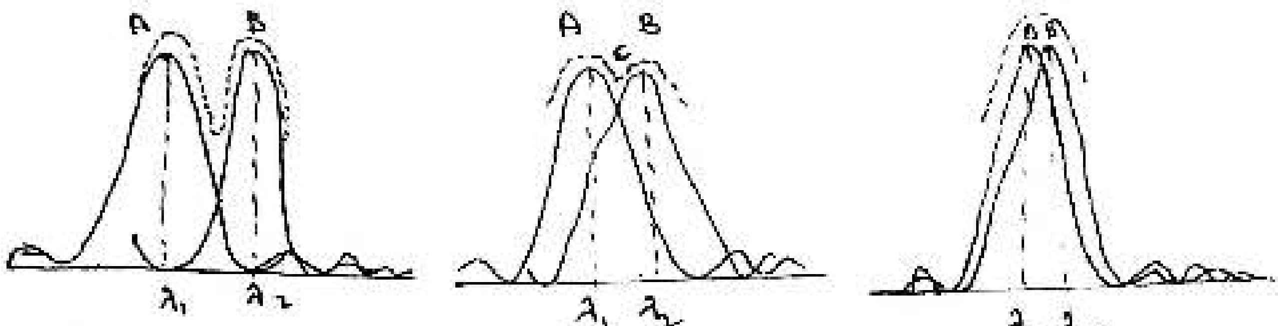
$$\text{or} \quad \boxed{nN\lambda \leq 1}$$

Grating Spectrum:- If we replace monochromatic source of light with white (mercury vapour) lamp which emits seven colours from violet to red. When the light from mercury vapour lamp falls normally on diffraction grating, diffraction spectra are produced by the grating and it consists of different orders of spectra on either of the central maximum. Each order of the spectrum consists of seven spectral lines.



Rayleigh's Criterion for Resolving power:-

According to him, two nearby images are said to be resolved if the position of the Central maximum of one coincide with the first Secondary minimum of the other and vice versa. A and B are the Central maxima of the diffraction pattern of two spectral lines of wavelength λ_1 and λ_2. the angle of diffraction of Central maximum of the image B is greater than the angle of diffraction of first minimum of A. Hence both the optical line appear well resolved.



well resolved. just resolved un resolved.

Case(i):- A and B are the Central maxima of the diffraction pattern of two spectral lines of wavelength λ_1 and λ_2. The angle of diffraction of Central maximum of the image B is greater than the angle of diffraction of minimum of A. Hence both the optical lines appear well resolved.

Case(ii) The position of Central maximum of wavelength λ_1 coincide with the position of the first minimum of wavelength λ_2. Similarly the position of Central maximum of wavelength λ_2 coincide with the position of the first minimum of wavelength λ_1 In the resultant intensity Curve, in the middle of the Central maxima of A and B, a dip is Seen at C. When we turn the Spectrograph from A to B, a noticeble decrease in intensity is observed at C. Thus the Spectral lines λ_1 and λ_2 can be distinguished from one another According to Rayleigh, they are said to be just resolved.

Resolving power of Grating:-

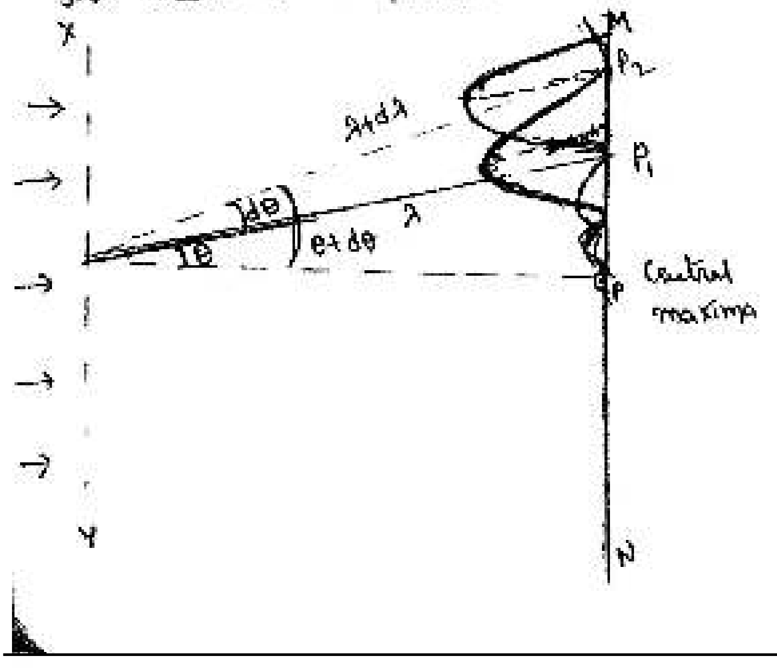
The method of seeing two close objects as seperate using some optical instrument is called resolution. The capacity of the instrument to produce two seperate images of very close objects is called resolving power.

" The resolving power of a grating is its ability to show two neighbouring lines in a spectrum as seperate."

If we consider two very close spectral lines of wave-length λ and $\lambda+d\lambda$ its resolution is given by

$$\text{spectral resolving power} = \frac{\lambda}{d\lambda}$$

∴ " The resolving power of a diffraction grating may also be defined as the ratio of the wavelength of any spectral line to its difference of wavelengths between this line and a neighbouring line such that the two spectral lines can be just seen as seperate.



XY is the grating surface. MN is the field of view of the telescope. Position P_1 corresponds to the n^{th} primary maximum of spectral line λ at angle of diffraction θ. Position P_2 corresponds to the n^{th} primary maximum of spectral line $(\lambda+d\lambda)$ at an angle of diffraction $\theta+d\theta$.

The direction of n^{th} primary maximum of spectral line λ is given by $(e+d)\sin\theta = n\lambda \rightarrow (1)$

For N no. of slits $N(e+d)\sin\theta = Nn\lambda \rightarrow (2)$

The direction of $(n+1)^{th}$ primary maximum of spectral line $\lambda + d\lambda$. [angle $(\theta + d\theta)$]

$$N(e+d)\sin(\theta + d\theta) = Nn(\lambda + d\lambda) \rightarrow (3)$$

The direction of n^{th} minima is the direction of $(\theta + d\theta)$ having wavelength 'λ'

$$N(e+d)\sin(\theta + d\theta) = (Nn+1)\lambda$$

$$N(e+d)\sin(\theta + d\theta) = Nn\lambda + \lambda \rightarrow (4)$$

from eqn's (3) & (4)

$$Nn\lambda + \lambda = Nn\lambda + Nn\,d\lambda$$

$$\therefore \lambda = Nn\,d\lambda$$

$$\therefore \boxed{\frac{\lambda}{d\lambda} = Nn}$$

From above equation resolving power is directly proportional to

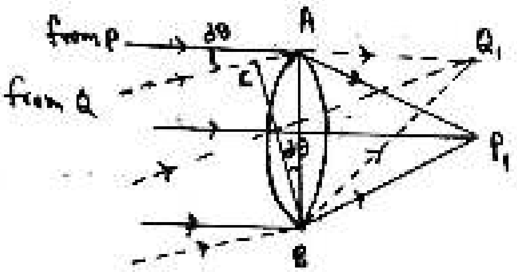
(1) Order of the spectrum

(2) The total no. of lines per unit width of grating.

Resolving power of a telescope

The minimum distance by which two points on the object are seperated from each other so that their images as produced by the telescope are just seen as seperate is called the "limit of resolution" of telescope. The reciprocal of limit of resolution is known as the resolving power.

Let us consider a telescope having an objective of aperture AB = d. Let P & Q be two point objects lying on the object plane and having an angular seperation dθ. Parallel rays from these 2 point object P and Q gives rise to two point-images formed in the focal plane of the objective of the telescope P_1 and Q_1 lying in the



Point image P_1 is formed for normal incidence of the light on the lens. Hence $AP_1 = BP_1$

Thus the first maximum of the image of P is formed at P_1.

For image Q_1 to appear seperately from P_1, the first maximum of image Q_1 should fall on the first secondary minimum of the image P_1. This condition is achieved if the path difference between the extreme rays from P and Q must be λ. To calculate this path difference BC is drawn normal to the rays coming from Q.

Now the path difference is AC. Let $AC = \lambda$

Now let us divide the lens into two halves AO and OB. If the path difference between the rays reaching Q, from A and B is λ, then the path difference between the rays reaching Q, from A and O, as well as from O and B will be $\frac{\lambda}{2}$. Hence the rays from all such corresponding points on the upper half of the lens AO and lower half of the lens OB interfere distructively forming first secondary minimum at Q.

From fig $AC = AB \cdot d\theta$ ($\because \angle CBA = d\theta$)

or $d\theta = \frac{AC}{AB} = \frac{\lambda}{d}$

where AB the aperture of the lens is equal to d.

$d\theta$ is called the limit of resolution of the telescope objective.

By more rigorous treatment Airy showed that λ should be replaced by 1.22λ.

Thus $d\theta = \frac{1.22\lambda}{d}$

$\therefore$ Resolving power $= \frac{1}{d\theta} = \frac{d}{1.22\lambda}$

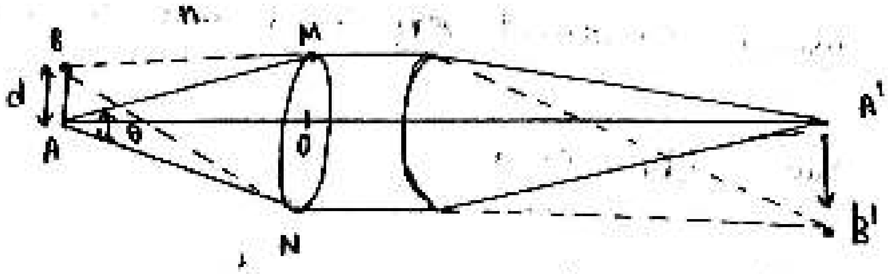
$\therefore$ Resolving power of telescope depends upon

1. The diameter of the objective and
2. The wavelength of light used. Larger the diameter of the objective and smaller the wavelength of light used, higher the resolving power of the telescope.

Resolving power of a microscope :- the resolving power of a microscope is defined as the reciprocal of the linear distance between two microscopic objects that can be just resolved when seen through the microscope.

$$\therefore \text{Resolving power} = \frac{1}{d} = \frac{2n\sin\theta}{\lambda}$$

where, d is the distance between two point objects, θ be semi-vertical angle of the cone formed by object at objective lens, λ is the wavelength of light, n the refractive index of the medium between the object and objective lens. To achieve high resolution, n sinθ must be large which is called as numerical aperture of the optical system. The resolving power of a microscope increases with increase in the numerical aperture.

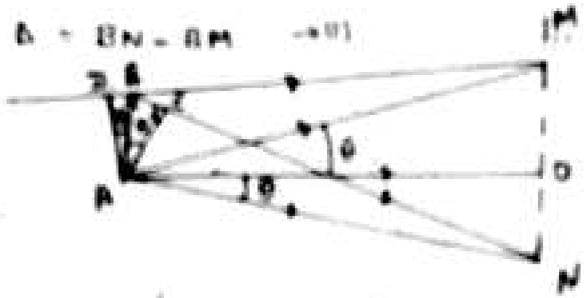


Microscope is an optical instrument used to magnify the microscopic objects. MN is the aperture of the objective lens of the microscope. Let A and B be the two minute objects at a distance d. A' and B' be the corresponding Fraunhofer diffraction pattern of the two images of two objects. Assume that A' is the position of central maximum of A and B' is the position of of the Central maximum of B. According to Rayleigh Criterion, if the position of the central maximum B' coincides with the first minimum of the image A or vice versa, the two images are said to be just resolved.

The path difference Δ between the light rays travelling from B to A' is given by $\Delta = (BN + NA') - (BM + MA')$

but we have $NA' = MA'$

$\Delta = BN - BM$ → (1)



From fig AD is perpendicular to BM and AC is perpendicular to BN, then we have

$BN - BM = (BC + CN) - (DM - DB)$ → (2)

But $CN = AN = AM = DM$

eqn (2) becomes $BN - BM = BC + DB$ → (3)

From the Δ ACB and Δ ADB

$BC = AB \sin\theta = d\sin\theta$ → (4)

and $DB = AB \sin\theta = d\sin\theta$ → (5)

From eqn's (4) & (5) $\Delta = 2d\sin\theta$ → (6)

If the eqn (6) is equal to $2d\sin\theta = 1.22\lambda$, then A' is the first minimum of the image B', the two images are said to be just resolved

$$2d\sin\theta = 1.22\lambda$$

$$d = \frac{1.22\lambda}{2\sin\theta}$$

Here we have considered the object is self-luminous.

In the microscope, the objects are not self-luminous. According to Abbe, the least distance between two just resolvable object points A and B is given by:

$$d = \frac{\lambda}{2n\sin\theta} \rightarrow (5)$$

where λ is the wavelength of light, n is the refractive index of the medium between the object and the objective of the microscope.

∴ The reciprocal of equation (6) is

$$\frac{1}{d} = \frac{2n\sin\theta}{\lambda}$$

∴ In above equation $n\sin\theta$ is called the numerical aperture of the objective of the microscope. From above relation, it is clear that, to get the maximum resolution between two objects:

1. n, the refractive index must be large
2. The objective lens diameter should be large
3. Shorter wavelength of the light should be used.

they can be adjusted exactly perpendicular to each other. The mirror M_1 is mounted on a carriage and can be moved exactly parallel to itself with a micrometer screw fitted with a graduated drum which can read a displacement $\sim 10^{-5}$ cm. The interference bands are observed with the help of telescope T.

Working: Light from the source S is made parallel with a a collimating lens L and then it is made to fall on the glass plate G_1. It is partly reflected at the back surface of G_1 along AC and partly transmitted along AB. The ray AC travels normally towards plane mirror M_1 and so it it is reflected along the same path and comes out along AT. The refracted or transmitted light is received by the mirror M_2 normally, reflected along the same path and then moves along AT after reflection from the back surface of G_1. So the two beams received along AT are produced from a single source by the division of amplitude and we may get interference patterns depending upon the distances travelled by them.

It is clear from diagram that a ray starting from source S and suffering reflection at the mirror M_1 travels the glass plate G_1 twice where as the ray reflected from mirror M_2 travels through the glass plate G_1 only once. To compensate it a second glass plate G_2 is introduced in the path AB and is made exactly parallel to G_1.

diffraction. The resolving power of the grating is 1000

32. If the Resolving power of a grating in its first order is 1000, its resolving power in second order is **2000**
33. The concept of Resolving Power is invented by **Rayleigh**
34. Our eye can see two close objects as separated only if the angle subtended by them at the eye is greater than **5 minutes**
35. The method of seeing two close objects as separate using some optical instrument is called **Resolution**
35. Spectral resolving power is **λ/dλ**
36. The expression for resolving power of a grating is **λ/dλ = Nn**
37. For Telescope resolving power is **d/1.22 λ**
38. For microscope Resolving power is **2(NA) / λ (NA = Numerical Aperture)**
39. Maximum number of orders possible with the grating is always an **Integer**
40. Polarization of light is evidence for **Transverse wave nature of light**
41. The phenomenon causing polarization of light is **Double refraction**
42. Polarization of light conclusively proves that **Light waves are transverse**
43. When the angle of incidence for O-ray on the Canada balsam is greater than the critical angle, then the phenomenon takes place is **Total internal reflection**
44. In elliptically polarized light **Amplitude of vibrations changes in magnitude and direction**
45. Nicol prism is based on the action of **Double refraction**
46. The phenomenon of double refraction is also called as **Birefringence**
47. Canada balsam acts as a rarer medium for **O-Ray**
48. Example for uniaxial crystal is **Topaz**
49. The line which is passing through the blunt corners of the crystal is called **Optic axis**
50. If an electron excites from lower state to higher state then the process is known as **absorption**
51. Which process does not require the inducement of energy **spontaneous emission**
52. Coherent light is emitted by **stimulated emission**
53. The life time of ground state is **infinite**
54. If N_1 & N_2 are populations of energy states E_1 & E_2 respectively in a system and $E_2 > E_1$ then condition for population inversion will be $N_1 < N_2$
55. Spontaneous emission is postulated by **Bohr**
56. Stimulated emission is postulated by **Einstein**
57. The population of the various energy levels of a system in thermal equilibrium is given by **Boltzmanns distribution law**
58. The lasing action is possible only if there is **population inversion**
59. Emission of photon when an electron jumps from higher energy state to lower energy state due to interaction of external energy is called **stimulated emission**
60. Among the following laser sources which source will give visible light radiation **He-Ne laser**
61. In He-Ne lasers, the ratio of He Ne mixture is **10:1**
62. Which of the following emits pulsed mode laser? **Ruby laser**
63. The doping percentage of chromium in Ruby is **0.05%**
64. In ruby laser the flash tube contains **Xenon gas**
65. In He-Ne laser, the emission takes place from which atoms? **Ne atoms**
66. The wavelength of radiation emitted by Ruby laser is **6943** Å
67. The pumping process used in He-Ne gas laser is **Electric discharge**
68. The pumping process used in Ruby laser is
a) **Optical Pumping**
69. The colour of laser radiation that comes out of He-Ne laser is
c) **Red**
70. The light is guided through transparent glass fibers by
c) **total internal reflection**
71. Total internal reflection takes place only when the light travels from
b) **denser to rarer medium**

UNIT - 3 (A)

Polarization

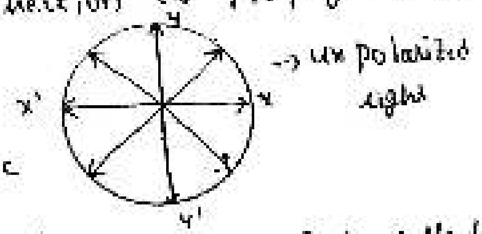
Introduction:- Interference and diffraction are the phenomenon which confirmed the wave nature of light beyond any doubt but it could not establish whether light waves are longitudinal or transverse.

"The transverse nature of light has been established by polarization phenomenon". In transverse motion the particles of the medium execute periodic oscillations in a direction perpendicular to the direction of propagation of the wave.

Light is nothing but an electromagnetic wave. The light emitting atoms are oscillating independently emitting individual wave trains. As a result the oscillations are at random. Hence in nature most light as it occurs is unpolarized.

"If the oscillations are confined to only one direction then it is called plane polarized light.

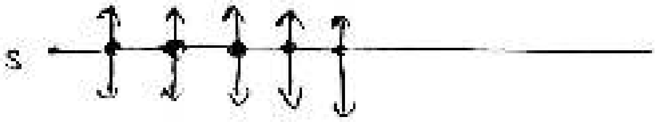
* In unpolarized light the electric field oscillates in all directions perpendicular to the direction of propagation of light.



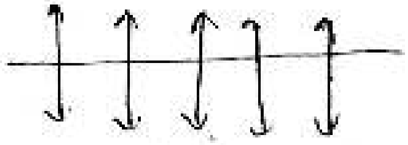
* If the oscillations of the electric field are confined to a only one direction, then it is called plane polarized light.

Representation of polarized and unpolarized light:-

Light waves are transverse and so have vibrations at right angles to the direction of propagation. Light emitting atoms are oscillating independently. The waves emitted have their own planes of vibration. Hence the waves vibrate in all possible planes with equal probabilities. If the direction of propagation of light is considered ~~to be consists of~~ along the plane of paper then unpolarized light the vibrations are indicated by dots and arrows



un polarized light

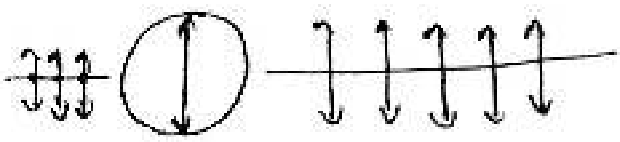


vertical vibrations

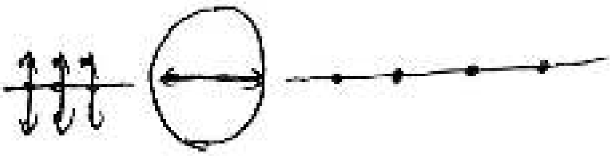
(Horizontal vibrations)

Types of polarized light:-

(1) plane polarized light:- If the vibrations are confined to a single plane then it is called plane polarized light (or) linearly polarized light.



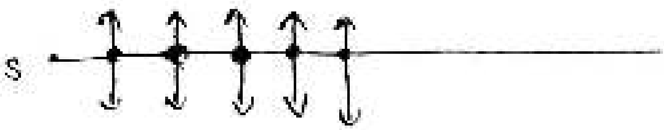
(vertical vibrations)



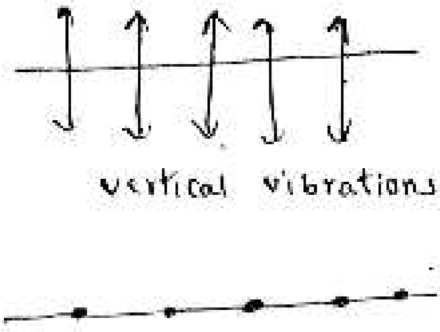
(Horizontal vibrations)

Note:- The vibrations along the paper are represented by arrows. The vibrations ~~along~~ perpendicular to the plane of the papers are represented by dots.

Partially plane polarized light:- If the linearly polized light contains small additional component of unpolarized light, it becomes partially plane polarized light. Then it is represented by either more planes with equal probabilities. If the direction of propagation of light is considered to be ~~consists of~~ along the plane of paper then unpolarized light the vibrations are indicated by dots and arrows



un polarized light



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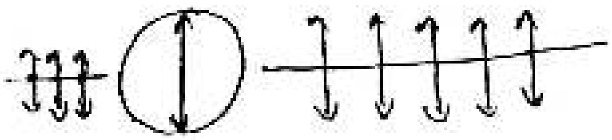
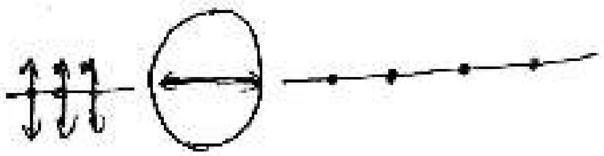


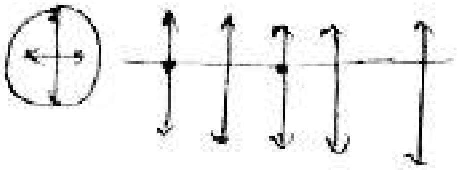
(vertical vibrations)



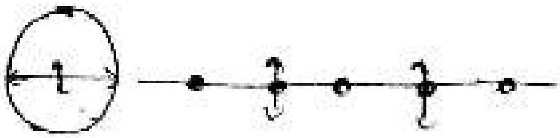
(Horizontal vibrations)

Note:- The vibrations along the paper are represented by arrows. The vibrations ~~along~~ perpendicular to the plane of the papers are represented by dots.

Partially plane polarized light:- If the linearly polized light contains small additional component of unpolarized light, it becomes partially plane polarized light. Then it is represented by either more arrows and less dots (or) less arrows more dots



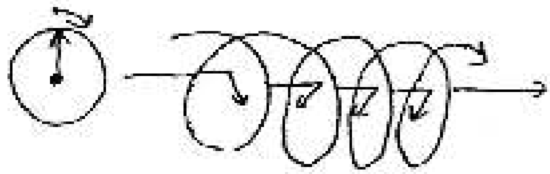
(more vertical and less horizontal vibrations)



(more horizontal and less vertical vibrations)

Circular polarized light:- In circular polarization, the electric vector of constant amplitude no longer oscillations but rotates while proceeding in the form of a helix the projection of a wave on a plane intercepting the axis of propagation gives a circle with the amplitude of the vector remaining constant.

If the vector rotates in the clockwise direction with respect to the direction of propagation, it results in right circularly polarized light while the rotation in the anti-clockwise direction results in left circularly polarized light



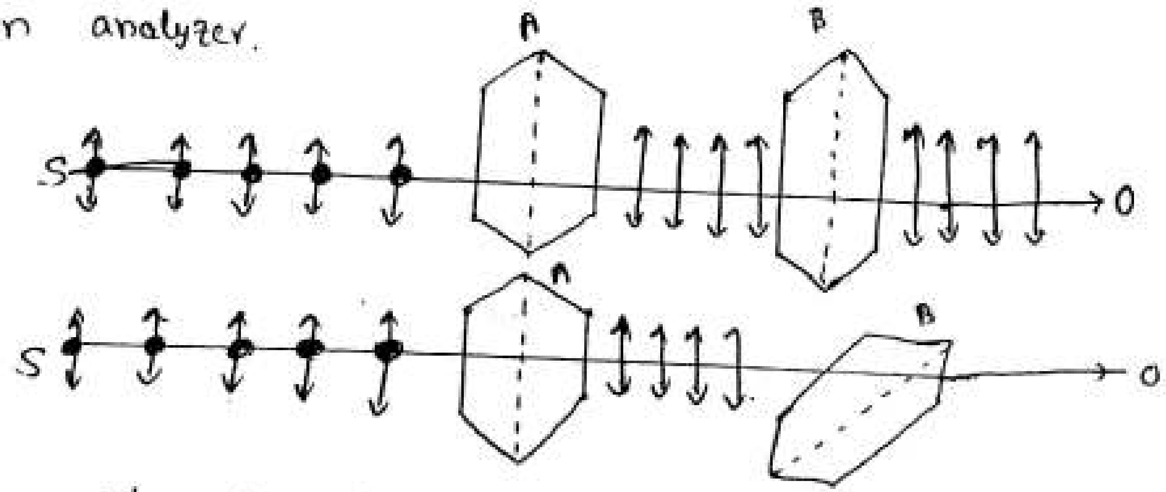
Elliptically polarized light:- In circular polarization the electric vector of constant amplitude rotates while proceeding. If the amplitude of the electric vector is not a constant but varies periodically then it results in elliptically polarized light. For Example, If the electric vector has minimum amplitude while oscillating vertically and rotates while propagating & have maximum amplitude when oscillating horizontally.

Production of polarized light:

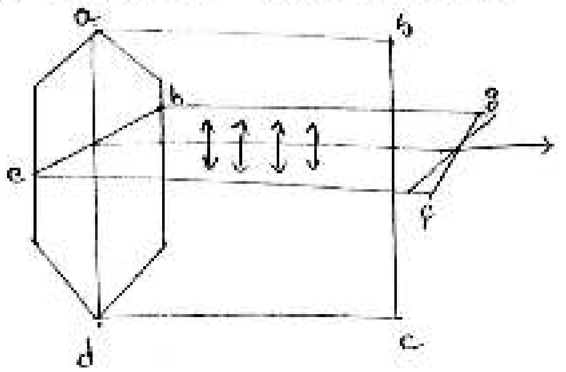
Tourmaline crystals are used for produce the plane polarized light. [These crystals have the same behaviour with respect to light waves as slits S_1 and S_2 have with respect to transverse waves in stretched string]

Let us consider a tourmaline crystal A cut parallel to its crystallographic axis. Let unpolarized light from source S enter the crystal. The light emerging out of the crystal is plane polarized. When the crystal is rotated with emergent path of light as axis, the intensity of emergent beam does not vary. Now another crystal B is introduced. When the crystallographic axis of both A and B are parallel, light passes through B also without any fall of intensity.

When crystal B is rotated, gradually intensity of light emerging out of B decreases and when the crystallographic axis of B and A are perpendicular, no light passes through B. Hence crystal A is a polarizer and crystal B which is used to analyse whether the light emergent from A is polarized or not is an analyzer.

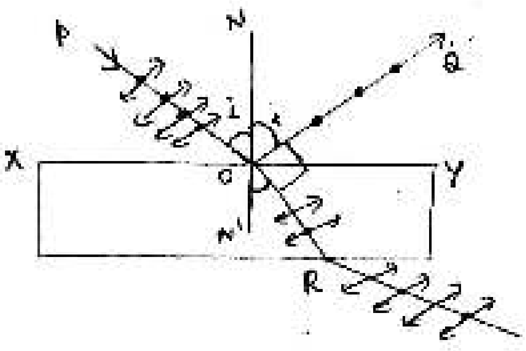


The property of plane polarized light differ with respect to two planes, one containing vibrations and another at right angles to it. The abcd contains oscillations of light and this plane is called plane of oscillations and the plane efgh perpendicular to the plane of oscillation is called plane of polarization



Polarization by reflection:-

In 1808, a French Scientist Malus found that when unpolarized light was reflected at the surface of some transparent medium such as glass, water etc. the reflected light was found to be partially plane polarized. The degree of polarization changed with the angle of incidence. For a particular angle of incidence the reflected light was found to be completely plane polarized.



The angle of incidence for which the reflected beam is completely plane polarized is known as polarizing angle (or) angle of polarization. This angle is also known as "Brewster's angle".

At this angle, the reflected and transmitted lights are at right angle to each other.

Brewster's law:- The refractive index of the material medium μ is equal to the tangent of the angle of polarization i_p.

$$\mu = \tan i_p$$

This is called Brewster's law. Applying this law to prove reflected and refracted rays are at right angles

Proof XY represents the surface of transparent medium. PO is the incident unpolarized light while OQ and OR are the reflected and refracted light rays

$\angle PON = i$ (angle of incidence)

$\angle N'OR = r$ (angle of refraction)

From Snell's law $\mu = \frac{\sin i}{\sin r}$ → (1)

From Brewster's law $\mu = \tan i = \frac{\sin i}{\cos i}$ → (2)

from (1) & (2) we get $\frac{\sin i}{\sin r} = \frac{\sin i}{\cos i}$

$\cos i = \sin r \Rightarrow \sin(90-i) = \sin r$

$\therefore 90 - i = r \Rightarrow \boxed{i + r = 90}$ → (3)

From Fig $\angle NOQ + \angle QOR + \angle N'OR = 180°$

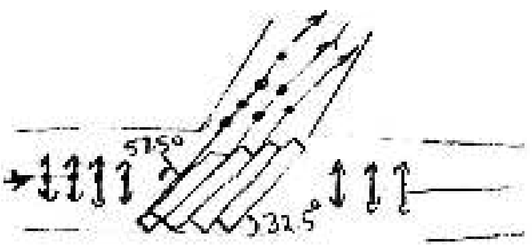
$i + \angle QOR + r = 180°$

$\angle QOR = 180 - (i+r)$

$= 180 - 90 = 90°$

∴ The reflected and refracted rays are at right angles.

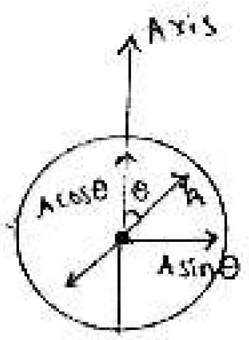
Polarization by transmission:- When unpolarized light is incident at polarizing angle the reflected light is completely plane polarized and transmitted light is partially plane polarized. The transmitted light contains a greater proportion of light vibrating parallel to the plane of incidence. If the process of reflection at polarized angle is repeated using number of



plates all inclined at polarizing angle, finally the transmitted light becomes purely plane polarized. Such an arrangement is known as pile of plates.

The polarizing angle for glass is 57.5°. The pile of plates consists of number of glass plates fixed in a tube of suitable size inclined at angle of 32.5° to the axis of the tube so that the angle of incidence is 57.5°. A beam of mono chromatic light entering the tube falls on the pile of plates at the polarizing angle. Each plate filters the vibrations at right angles to the plane of incidence by reflection. Hence after the beam has traversed about 15 plates, the transmitted light has vibrations only in the plane of incidence. Thus pile of plates acts as a polarizer.

Malus law:- when unpolarized light passes through a polarizer, the transmitted light is plane polarized. When the polarized light is passed through an analyser, the intensity of transmitted light varies with the angle between the planes of polarizer and analyser.



Malus stated that "The intensity of the polarized light transmitted through the analyser varies as the square of cosine of the angle between the plane of transmission of the analyser and the plane of polarizer."

Proof: Polarized light can be resolved into two components

(i) parallel to the plane of transmission of the analyser

(ii) perpendicular to the plane of the analyser.

Let A be the amplitude of the incident plane polarized light with its plane of vibration at an angle θ with the axis of the analyser. The resolved component of amplitude A along optic axis is $A\cos\theta$. This component is transmitted through the analyser. The intensity of the transmitted light is given by

$$I_1 = (A\cos\theta)^2 = A^2\cos^2\theta$$

When $\theta = 0$ i.e the plane of vibration is along the optic axis of the analyser.

$$I_1 = A^2$$

Let this maximum value be $I_0 = A^2$

$$I_1 = I_0\cos^2\theta$$

When $\theta = 90°$, i.e the plane of vibration is normal to the optic axis of the analyser

$$I_1 = I_0\cos^2\theta = 0.$$

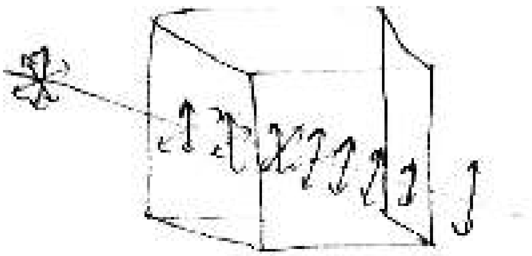
$\therefore$ The intensity of polarized light transmitted through the analyser varies as the square of $\cos\theta$, where θ is the angle between the plane of vibration of incident plane polarized light and optic axis of the transmitter.

Polarization by Scattering:-

When light beam passes through a medium consisting of very small particles, light is scattered. If the dimensions of the particles are smaller than wavelength of light, then the intensity of scattered light is found to be inversely proportional to the fourth power of wavelength. $I \propto \frac{1}{\lambda^4}$. If light is passed through such a medium and scattered light is analysed in a direction perpendicular to the direction of propagation of light, the scattered light

is found to be plane polarized.
Ex blue colour of the sky.

Polarization by selective absorption:-

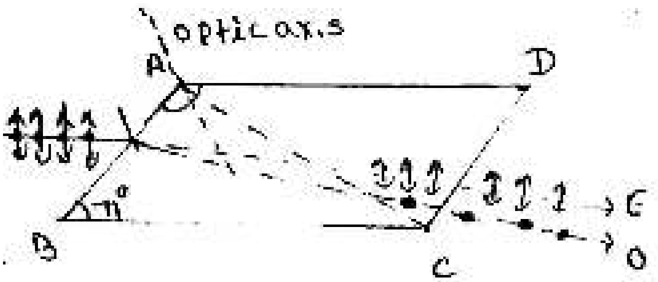


Light passing through the crystal is split into two components, the horizontal and vertical. The horizontal component is being completely absorbed by the crystal and hence vertical component alone comes out. The light emerging from crystal, therefore is linearly polarized.

Double refraction: (birefringence):-

Unpolarized light has two components one vertical and another horizontal. When unpolarized light passes through certain anisotropic crystals like calcite or quartz, velocity of propagation of these two components vary. This means that the material exhibits two different refractive indices. Both the components have the same angle of incidence, they have different angle of refraction.

When unpolarized light passes through such crystals, we get two refracted beams and this phenomenon is called double refraction.



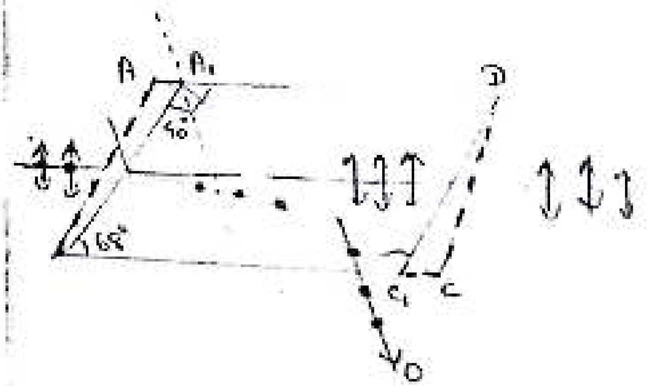
Calcite is a good example of a system of anisotropic crystals. It is rhombic in shape and the line AC joining the blunt corner A and C is called the crystal axis.

A line through A which makes equal angles with the three edges gives the direction of "optic axis". Any line parallel to this line is also optic axis. Since optic axis is not a line but direction.

"When unpolarized light passes through the crystal, in a direction different from optic axis, it is split into ordinary ray (O-ray) and extra ordinary ray (E-ray). The O-ray travels with the same velocity in all directions. The corresponding refractive index is called ordinary refractive index (μ_o). The extra ordinary ray travels with same velocity as that of ordinary ray along optic axis direction. In other directions the velocity gradually changes and in a perpendicular direction to optic axis the change is maximum. The refractive index of extraordinary corresponding to this direction is called extra ordinary refractive index (μ_e).

Nicol's Prism:- Nicol prism is one of the most important device used to produce plane polarized light. This was invented by William Nicol in 1828. Calcite crystal is modified such that it eliminates one of the two refracted rays by "total internal reflection".

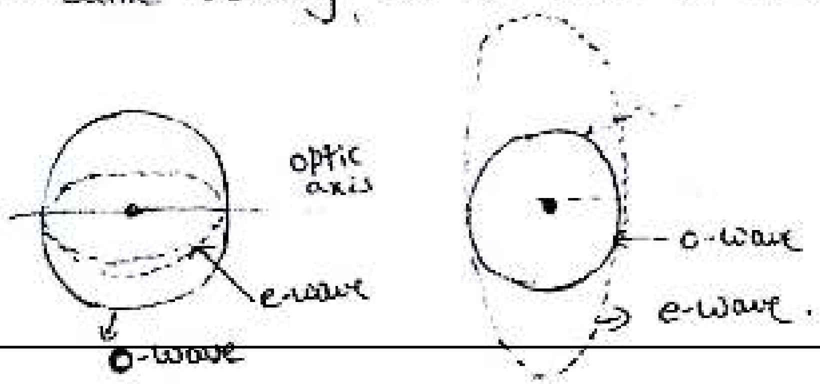
A calcite crystal whose length is three times its breadth is taken. The two ends AB and CD of the crystal are cut, so that the angle ABC reduces from 71° to 68°. Then the crys is cut into two halves along the plane A_1C_1 which passes throu the blunt corners and perpendicular to both the principal sectio and end faces. A_1C_1 makes an angle of 90° with C_1D and A_1B the two cut faces are well polished and cemented together usin a thin layer of Canada balsam, a clear transparent material. It has refractive index 1.55 for λ = 5893 Å. When unpolarized Sodium light enters the Nicol prism it splits into o-ray and e-ray. O-ray has the refractive index 1.6584 while the same for e-ray varies between 1.4864 to 1.6584. Inside the crystal when o-ray meets the thin layer of Canada balsam cement, it has to travel from denser medium to rarer medium. Be



Because of shaping of the crystal face, the o-ray is refracted more so that the angle of incidence at the Canada balsam interface is greater than the critical angle. Hence it undergoes total internal reflection and leaves the crystal through its side as shown. Hence e-ray alone emerges out of the other face of the prism.

Nicol prisms are good polarizers and analyzers and can be used to produce and analyse plane polarized light.

Wave plates.- Let us assume a point source inside the crystal at its centre to understanding of variation of velocity of e-ray with direction. The wave corresponding to o-ray travels with same velocity in all directions resulting in sphere. The wave corresponding to e-ray travels with different velocities in different directions and the wave front advances



ellips… [illegible] axis … o-ray and e-ray travel with same velocity and the difference is maximum along the direction perpendicular to optic axis.

* In some crystals velocity of e-ray is less than that of o-ray. the ellipsoidal wavefront of e-ray lies within the spherical wavefront of o-ray; the ellipsoidal wavefront of e-ray lies within the spherical wave front o-ray. Such crystals are called positive uniaxial crystals

Ex. Quartz Crystal

* In other crystals the ellipsoidal wavefront of e-ray lies away from the of o-ray. Such crystals are called negative uniaxial crystals.

Ex. Calcite.

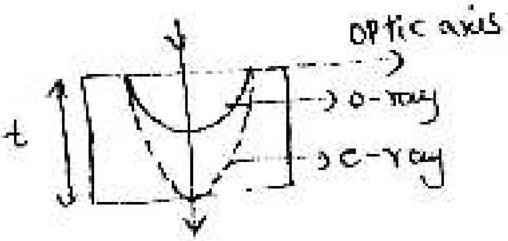
Quarter and half plates :- Let us consider a doubly refracting crystal. [illegible] in which its optic axis lies along its surface. Suppose an unpolarized light of wave length 'λ' incident normally on the crystal surface, the o-ray and e-ray travel with increasing path difference along their direction of propagation.

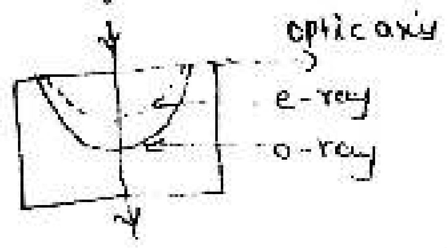
If 't' is thickness of the wave plate then

optical path for o-ray = $\mu_o t$

optical path for e-ray = $\mu_e t$

∴ Optical path difference $\Delta = (\mu_o \sim \mu_e)t$, where μ_o and μ_e are refractive indices of o-ray and e-ray respectively.





Hence optical path difference = $(\mu_0 \sim \mu_e)t$

If the thickness of the plate is such that this path difference is $\lambda/4$, then the plate is called quarter wave plate

$$(\mu_0 \sim \mu_e)t = \frac{\lambda}{4}$$

$$\therefore \boxed{t = \frac{\lambda}{4(\mu_0 \sim \mu_e)}}$$

If the thickness of the plate is such that the path difference is $\lambda/2$, then the plate is called half wave plate.

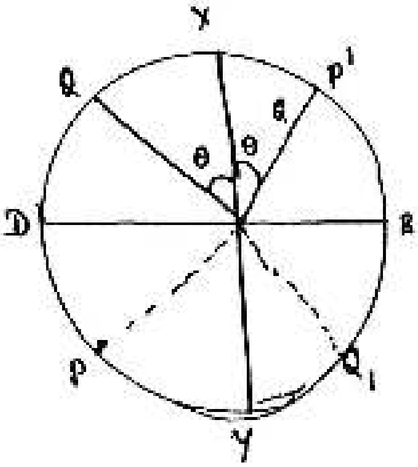
$$(\mu_0 \sim \mu_e)t = \frac{\lambda}{2}$$

$$\boxed{\therefore t = \frac{\lambda}{2(\mu_0 \sim \mu_e)}}$$

viewed through a telescope. The telescope is focussed on the half shade.

Action of Laurentz Half Shade plate:-

The Laurentz system consists of a half shade plate in two halves, one of the quartz cut parallel to its optic axis and the other, a matching plate of glass so choosen as to absorb and reflect the same amount light as the quartz plate. The quartz plate is a half wave plate. It introduces a path difference of $\lambda/2$ between the ordinary and extraordinary rays in the transmission normal through it. Let the plane of vibration of the plane polarised light from the polariser P falls normally on half shade plate along CP. The light passing through the glass plate remains unaffected, while that falling on the quartz plate is broken up into two components e-ray (CX parallel to optic axis XY) and O-ray (perpendicular to the optic axis, that is along CB).



As in quartz O-ray travels faster. Hence on emergence, O-ray has vibrations along CD and e-ray has vibrations still along CX. Therefore, the emergent wave CQ is the resultant of vibrations along CD and CX. ~~Hence~~ Here $\angle P'CX = \angle QCX = \theta$. Thus the angle b/w the vibration planes of light emerging from quartz, CQ and that of light emerging from glass, CP is 2θ

Thus there are two plane polarised lights one emerging from the glass with vibrations in the plane CP while other emerging from quartz with vibrations in the plane CQ. If the principal plane of the analyzing Nicol A is parallel to QCQ', the light from the quartz plate will passed unobstructed. Thus, the quartz plate half will be brighter than the glass plate half. If the principle plane of the analyzing Nicol A is parallel to PCP', then the light from glass plate will pass unobstructed while the light from the quartz plate will be partially obstructed. Thus the right half will appear brighter as compared to the left half. But when the principle plane of the analyzing Nicol A is parallel to the optic axis XCY, the two halves appear equally illuminated.

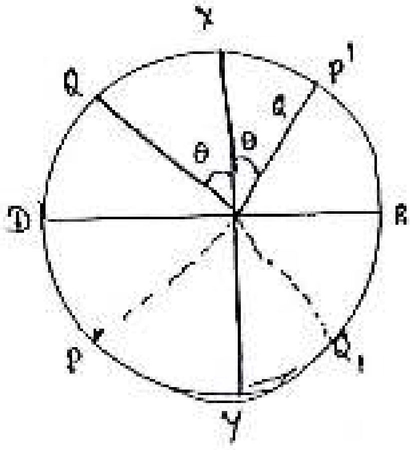
Determination of the specific Rotation of Sugar Solution :-

To find the specific rotation of cane sugar or of an optically active substance, the glass tube T is first filled with clear water and the analyzer A is set in the position of equal brightness of the two halves of the field of view. The reading of the verniers is noted.

Now, the sugar solutions of known concentration are filled in the tube and the tube is placed again in the same place. Due to optical activity of the solution, the vibrations on passing from the quartz half and the glass half is rotated. Therefore, on the introduction of the tube containing viewed through a telescope T. The telescope is focussed on the half-shade.

Action of Laurentz Half Shade plate:-

The Laurentz system consists of a half shade plate in two halves. one of the quartz cut parallel to its optic axis and the other, a matching plate of glass so choosen as to absorb and reflect the same amount light as the quartz plate. The quartz plate is a half wave plate. It introduces a path difference of $\lambda/2$ between the ordinary and extra ordinary rays in the transmission normal through it. Let the plane of vibration of the plane polarised light from the polariser P falls normally on half shade plate along CP. The light passing through the glass plate remains unaffected, while that falling on the quartz plate is broken up into two components e-ray (CX parallel to optic axis XY) and o-ray (perpendicular to the optic axis, that is along CB).



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the Sugar Solution, the field of view is not equally bright. The analyzer is rotated in the clockwise direction and is brought to a position so that the whole field of view again appears equally bright. The new position of the verniers on the circular scale is noted. The difference in the two readings of the analyzer gives the angle of rotation θ produced by the solution. In the actual experiment, the angles of rotation for the solutions various concentrations are measured. A

∴ The specific rotation of the cane sugar is determined by using the formula given.

$$S = \frac{\theta}{LC}.$$

where L is the length of the tube in cm, C is the concentration of the solution in gm/cc and θ is the angle of rotation in degrees.

Biquartz polarimeter:-

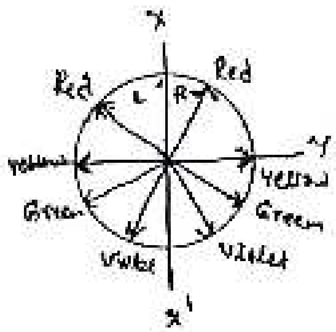
Biquartz polarimeter is an accurate instrument which is more sensitive than a half shade polarimeter used for finding the angle of rotation produced by an optically active substance. The experimental parts of biquartz polarimeter are the same as that of half shade polarimeter except that the half shade device is replaced by biquartz plate and monochromatic light is replaced by white light.

One piece of quartz produces right handed rotation and the other left handed.

When plane polarised white light is passed through each half of this plate, its different components will be rotated through different angle by each half but in the opposite directions. Each rotates the plane of polarisation of yellow light through 90°. Thus, the rotatory dispersion occurs in each plate. The left half plate rotates the plane of vibrations in anti-clockwise direction and right half in the clock wise direction.

The red rays are rotated least, while the violet rays are rotated most. The intermediate rays are rotated through the angle lying between least of red and maximum of violet. For yellow the rotation is 90°.

If the principal plane of the analysing nicol be parallel to XX', the yellow light will be completely quenched and the other colours will be present in the same proportion in each half. In this position, the field of view appears grey (blue + red). This is called the tint of passage or transition tint. A slight rotation of the analysing nicol to one side from this position will change the colour of one half blue, while that of the other half to red. If the analysing Nicol is rotated to other side, the colours of the two halves are interchanged.



LASER

Light Amplification by Stimulated Emission of Radiation

Introduction:- The word "LASER" is an acronym for Light Amplification by Stimulated Emission of Radiation. In 1960 Maiman first achieved laser action at optical frequency in ruby. The power of the laser is several mw and size of the advanced laser system is one tenth of the diameter of a human hair.

Characterstics of the LASER:-

Directionality:- During the propagation of a laser its angular spreading will be less and occupies less area where it incidents. Hence it possesses high degree of directionality.

Ex- Laser beam of 10cm diameter is operated on to the moon then it doesn't spread over not more than 5 km.

Monocromaticity:- The property of exhibiting a single wavelength by a light is called monocromaticity i.e, when it is sent through a prism then a single line will be appeared in the optical spectrum.

Brightness (Intensity):- The laser beam is highly bright as compared to the conventional light sources because more light energy is concentrated in a small region. Laser light is coherent, so at a time many photons are in phase and they superimpose to produce a wave of larger amplitude. The intensity is proportional to the square of amplitude. Hence, the intensity of the resultant laser beam is very high.

Coherence:- The property of existing either zero or constant phase angle difference between two or more wave is known as coherence.

Coherence is of two types

Spatial coherence:- If a wave maintains a constant phase difference or in phase at two different points on the wave over a time 't', then the wave is said to have spatial coherence.

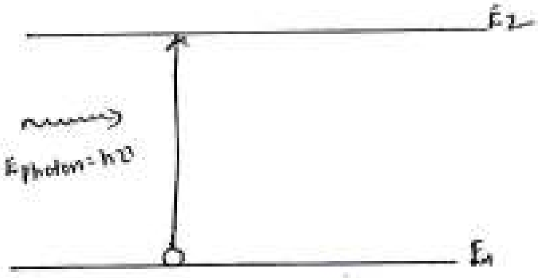
Temporal coherence:- If there exists either zero or constant phase angle difference between two light fields measured at two instants at the same point then wave is said to have temporal coherence.

Definitions:-

In lasers the interaction between matter and light is of three different types. They are absorption, spontaneous emission and stimulated emission. In these processes, two energy levels of atoms are involved. Let E_1 and E_2 be ground and excited states of an atom. Transition between these states involves absorption or emission of photon of energy $E_2 - E_1 = h\nu_{12}$ where 'h' is planck's constant.

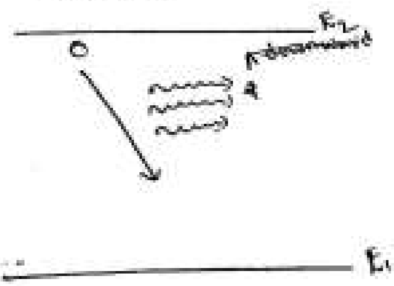
Absorption:-

Let us consider a system in which two energy levels are present whose energies are E_1 and E_2 where E_1 is ground state and E_2 is excited state.



Usually atoms are in the ground state as long as external forces are not applied. When a photon of energy $h\nu = E_2 - E_1$ is incident on the atom lying in ground state then it excites to higher state E_2. This phenomenon is known as absorption.

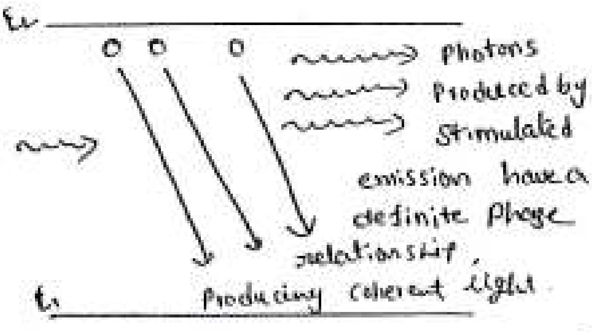
Spontaneous Emission:- Let us assume that the atom is in the excited state E_2. After the life time the atom deexcites to its ground state spontaneously emitting a photon of energy $h\nu = E_2 - E_1$. This phenomenon is known as spontaneous emission.



$E_{photon} = h\nu = E_2 - E_1$

Stimulated Emission:-

Let us assume that the atom is in the excited state E_2, if a photon of energy $h\nu = E_2 - E_1$ is incident on it before the life time



is stimulates the atom from E_2 to E_1, then a photon of energy $h\nu$ releases along with incident photon. These two photons will have same energy and phase. This phenomenon is known as stimulated emission. The emitted photons in this case have the single wave-length and they are in phase. Thus the photons are coherent.

Distinction between Spontaneous & Stimulated Emission :-

Spontaneous Emission	Stimulated Emission
1. Emission takes place without any stimulus energy	1. Emission takes place with the help of stimulus energy
2. Incoherent radiation	2. coherent radiation
3. Low intense and less directional	3. High intense and more directional
4. polychromatic radiation	4. monochromatic radiation
5. This emission is postulated by bohr	5. This emission is postulated by Einstein
6) Ex: Light from Sodium or mercury Lamp	6) Ex: Light from Ruby (or) He-Ne laser.

Life time :- The absorption of time spent by an atom in the excited state is known as lifetime of that energy state

Ex. For Hydrogen atom life time is 10^{-8} sec.

metastable State :- The excited state, which has long life time is known as metastable state. According to Heisenberg's uncertainity principle metastable state is an excited state of an atomic system whose energy level width is very small so that the life time of the electrons is very large.

∴ Heisenberg's uncertainity principle

$$\Delta E \, \Delta t \geq \frac{h}{2\pi}$$

where ΔE is the width of the energy level and Δt is the

Life time of the electrons in that energy level.

Then $\Delta E \propto \frac{1}{\Delta t}$

Thus the lt life time of the electron in the metastable state will be very large due to its narrow size and hence it is easy to achieve population inversion at this level to start lasing action.

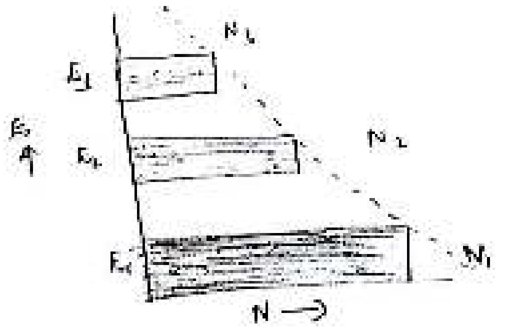
Population:- The number of atoms per unit volume in an energy level is known as population of that energy level.

If N is no. of atoms per unit volume in an energy state E then expression for population (according to Boltzman's distribution law)

$$N = N_0 \exp\left(\frac{-E}{K_B T}\right)$$

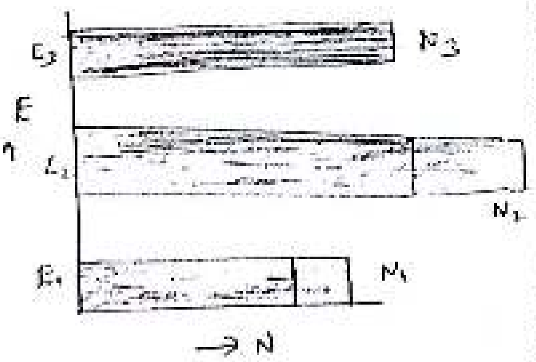
where N_0 is the population in the ground state.
K_B is the Boltzmann's Constant and
T - Temperature

From the equation of population. It is maximum in the ground state and decreases exponentially as energy of energy level increases.



Population inversion:-

Usually in a system the number of atoms (N_1) present in the ground state (E_1) is larger than the number of atoms (N_2) present in the higher energy state. The process of making $N_2 > N_1$ is called population inversion.



Let E_1, E_2 and E_3 be ground state, metastable state and excited state of energies of the system respectively such that $E_1 < E_2 < E_3$. N_1, N_2, N_3 are the no. of populations of energy levels E_1, E_2 and E_3 respectively.

E_1 lifetime is unlimited and it is most stable state. E_3 lifetime is very less and it is the most unstable state where as E_2 has more life time than

When suitable form of energy is supplied to the system in a suitable way, then the atoms excite from ground state (E_1) to excited states (E_2 and E_3). Due to unstability, excited atoms will come back to ground state after the lifetime of the respective energy states E_2 and E_3. If this process is continued then atoms will excite continuously to E_2 & E_3.

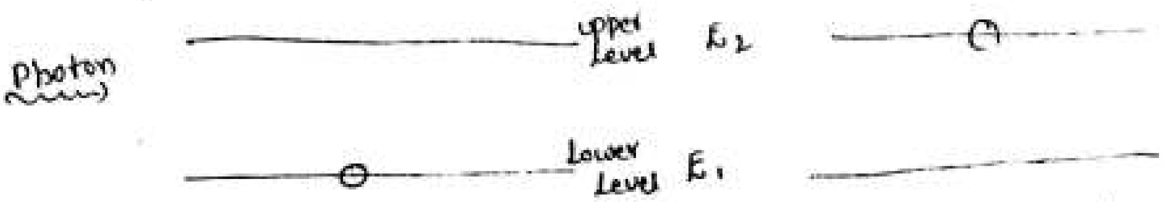
E_3 is the most unstable state. atoms will fall into E_2 immediately. At a stage the population in E_2 will become more than the population in ground state. This situation is called population inversion and

Pumping:- The process of supplying suitable form of energy to a system to achieve population inversion is called pumping

Types (1) optical pumping (2) Electric discharge method
(3) Direct conversion (4) Chemical reactions.

Einstein's Coefficients:-

Stimulated Absorption:- In this a photon stimulates an electron to move from a lower energy state E_1 to higher state E_2 by means of absorption



The no of stimulated upward transitions per unit volume per unit time per unit frequency is directly proportional to the incident energy density $u(\nu)$ and properties of energy level E_1 and E_2.

$\therefore P_{12} \propto u(\nu) \Rightarrow P_{12} = B_{12}\, u(\nu)$

where B_{12} is proportionality constant, represents properties of energy levels known as Einstein's coefficient of absorption.

(i) Spontaneous emission:- The rate of probability to occur spontaneous emission process from energy level E_2 to energy level E_1 depends only on properties of energy levels E_1 & E_2. This process is independent of energy density $U(\nu)$.

$$\therefore (P_{21})_{spon} = A_{21}$$

where A_{21} is proportional constant, represents properties of energy levels known as Einstein's coefficient of spontaneous emission.

(ii) Stimulated emission:- The rate of probability to occur stimulated emission process from energy level E_2 to E_1 depends on properties of energy levels 1 and 2 as well as proportional to stimulated energy density $U(\nu)$ of frequency ν incident on the atom.

$$(P_{21})_{stimulated} \propto U(\nu)$$

$$\therefore (P_{21})_{stim} = B_{21}\, U(\nu)$$

where B_{21} is proportionality constant, represents properties of energy levels known as Einstein's coefficient of stimulated emission.

The total transition probability of atoms from energy level E_2 to energy level E_1 can be written as

$$P_{21} = (P_{21})_{spontaneous} + (P_{21})_{stimulated}$$

$$\boxed{P_{21} = A_{21} + B_{21}\, U(\nu)}$$

Relation Between Einstein's Coefficients:-

Let us consider N_1 and N_2 be populations in the energy levels E_1 and E_2 respectively in a system of atoms, which is at thermal equilibrium at a temperature T.

The number of atoms that take transitions per unit volume from energy level E_1 to energy level E_2 in unit time can be written as

$$N_1 P_{12} = N_1 B_{12}\, U(\nu) \longrightarrow (1)$$

The number of atoms that take transitions per unit volume from energy level E_2 to Energy level E_1 in unit time can be written as

$$N_2 P_{21} = N_2 \left[A_{21} + B_{21} u(\nu)\right] \rightarrow (2)$$

At equilibrium, the number of transitions from energy level E_1 to energy level E_2 will be equal to the number of transitions from energy level E_2 to Energy level E_1

$$N_1 P_{12} = N_1 P_{21}$$

$$\Rightarrow N_1 B_{12} u(\nu) = N_2 \left[A_{21} + B_{21} u(\nu)\right] \quad [\text{from eqn's } (1) \& (2)]$$

$$\Rightarrow N_1 B_{12} u(\nu) - N_2 B_{21} u(\nu) = N_2 A_{21}$$

$$\left[N_1 B_{12} - N_2 B_{21}\right] u(\nu) = N_2 A_{21}$$

$$\Rightarrow u(\nu) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}} = \frac{N_2 A_{21}}{N_2 B_{21}\left[\frac{N_1}{N_2}\left(\frac{B_{12}}{B_{21}}\right) - 1\right]}$$

$$\Rightarrow u(\nu) = \frac{A_{21}}{B_{21}} \frac{1}{\left[\frac{N_1}{N_2}\left(\frac{B_{12}}{B_{21}}\right) - 1\right]} \rightarrow (3)$$

According to Boltzmann's distribution law

$$N_1 = N_0 \exp\left(\frac{-E_1}{k_B T}\right) \qquad N_2 = N_0 \exp\left(\frac{-E_2}{k_B T}\right)$$

$$\therefore \frac{N_1}{N_2} = \exp\left[\frac{+(E_2 - E_1)}{k_B T}\right] = \exp\left(\frac{+h\nu}{k_B T}\right) \rightarrow (4) \quad [\because E_2 - E_1 = h\nu]$$

Substituting equation (4) in equation (3) we get

$$u(\nu) = \frac{A_{21}}{B_{21}} \frac{1}{\left[\exp\left(\frac{h\nu}{kT}\right)\frac{B_{12}}{B_{21}} - 1\right]} \rightarrow (5)$$

According to planck's radiation law

$$u(\nu) = \frac{8\pi h \nu^3}{c^3} \frac{1}{\left(\exp\left(\frac{h\nu}{kT}\right) - 1\right)} \rightarrow (6)$$

Comparing equations (5) & (6)

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{c^3} \quad \text{and} \quad \frac{B_{12}}{B_{21}} = 1$$

$$\Rightarrow \frac{A_{21}}{B_{21}} \propto \nu^3 \quad \text{and} \quad B_{12} = B_{21}$$

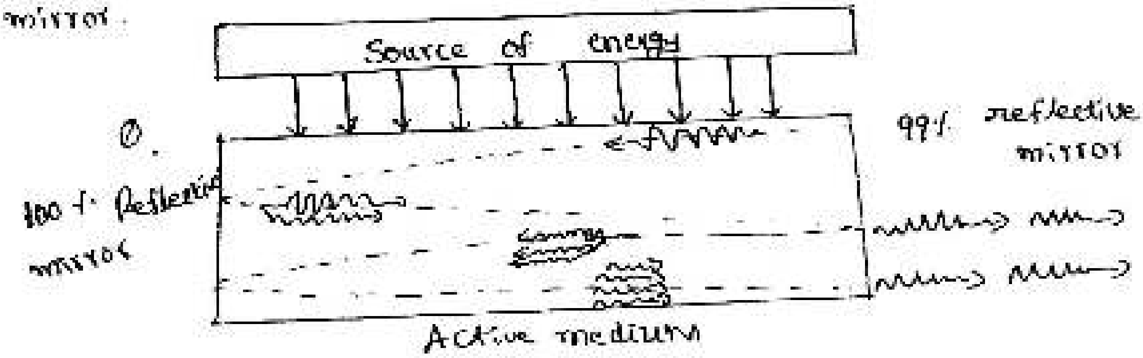
The first relation shows that the ratio of Einstein's coefficients of A_{21} and B_{21} is proportional to cube of the frequency of incident photon. The second relation shows the rate of probability of induced emission and absorption are equal, when the system is in equilibrium.

LASER SYSTEM :- It consists three parts

(i) Source of energy:- It supplies suitable form of energy to the active medium to achieve population inversion. i.e. it performs pumping process.

(ii) Active medium:- It is a medium in which metastable state is present. In metastable state only the population inversion takes place. & It can be a solid, liquid, gas or semiconductor diode junction.

(iii) Optical Cavity:- It is an enclosure of active medium and essentially consists of two mirrors. one mirror is fully reflective and other one is partially transparent. Due to mirrors arrangement emitted laser takes back and forth reflections until it gains sufficient energy to come out. The output laser is emitted from partially transparent mirror.



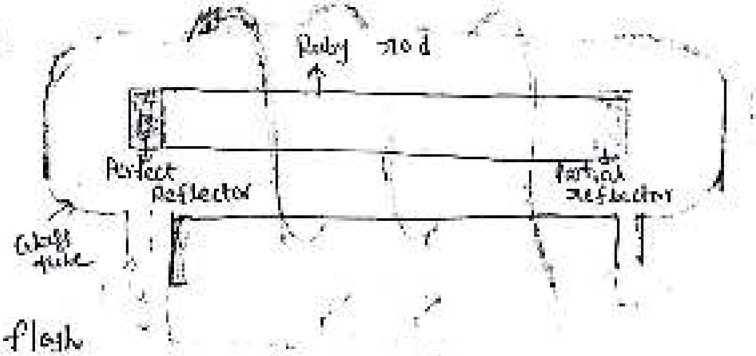
Ruby LASER :- Ruby laser is a solid state three level laser system demonstrated by maiman in 1960. It produces pulsed laser which is useful for various industrial applications like surface hardening, hard facing, cladding of various industrial products. It is a high power laser, which has hundreds of mw. Each pulse will come out in duration of 10 nano seconds.

Source of energy - Xenon flash light

Active medium - Ruby Crystal rod

Optical Cavity - Arrangement of silver polished Surface on either sides of the Ruby rod

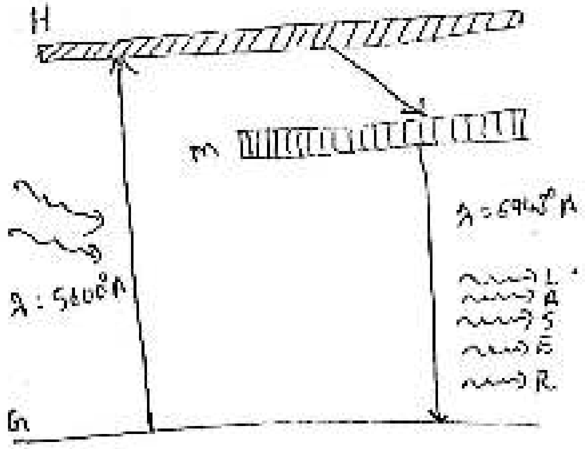
Construction:- Ruby laser is made up of cylindrical ruby Crystal rod of composition Al_2O_3 and 0.05 % of Cr_2O_3, which length is few Centimeters and diameter is 0.5 cm. It has partially silver polished Surfaces on either sides through which laser is emitted. A Xenon flash tube is arranged around the ruby rod which



Supplies green colour flash light of wavelength 5600 Å to the active medium to achieve. Only a part of flash light is used for the pumping the Cr^{+3} ions, while the rest heats up the apparatus. A cooling arrangement is provided to keep the experimental setup at normal temperature.

Working Principle:

The Chromium atoms have three active energy levels they are name ground state (G), meta-stable state (M) and Higher state (H). Due to the supply of Xenon flash light to the ruby rod, the Chromium atoms begin to excite from G state to excited states M & H.



Once Chromium atoms are excited to upper energy level H, they require two steps to return back to their ground state G. First step is from higher state H to metastable state M, which is shorter jump and energy emitted in this transition process to the Crystal lattice as heat. This transition is called radiation less transition.

The Chromium atoms returned to M level can remain in this State for several milli seconds. The accumulation of excited atoms at M level increases the population at M level and then transition occur, from M to G level emitting out the photons randomly. Due to continuous working of flash lamp, the Chromium atoms are raised continuously to higher energy state H and then to M level.

At a particular stage population of excited Chromium atoms will be reversed and more Chromium atoms at M than at G. At this position photons begin to interact with Chromium atoms at level M to a significant extent. This results in stimulated emission of other identical photons and a cascade begins.

The photons travelling parallel to the access of the ruby rod are used for stimulation while the photons travelling in any direction other than this will pass out from the ruby rod. In the meantime photons moving back and forth inside the ruby rod continue to build up until the intensity of radiation is great enough to come out it bursts through the partial silver polished surfaces and it serves as output laser.

The output beam of wavelength is 6943°A and frequency 4.32×10^{14} Hz. This wavelength is in the red region of the visible spectrum.

Pumping Source: In optical pumping, a light source such as a flash discharge tube is used. This method is adopted in solid state laser. In electric discharge method, the electric field causes ionization of the medium and raises it to the excited state. This technique is used in gas lasers. In semiconductor diode lasers, a direct conversion of electrical energy into light energy takes place.

ENGINEERING PHYSICS MODEL BITS

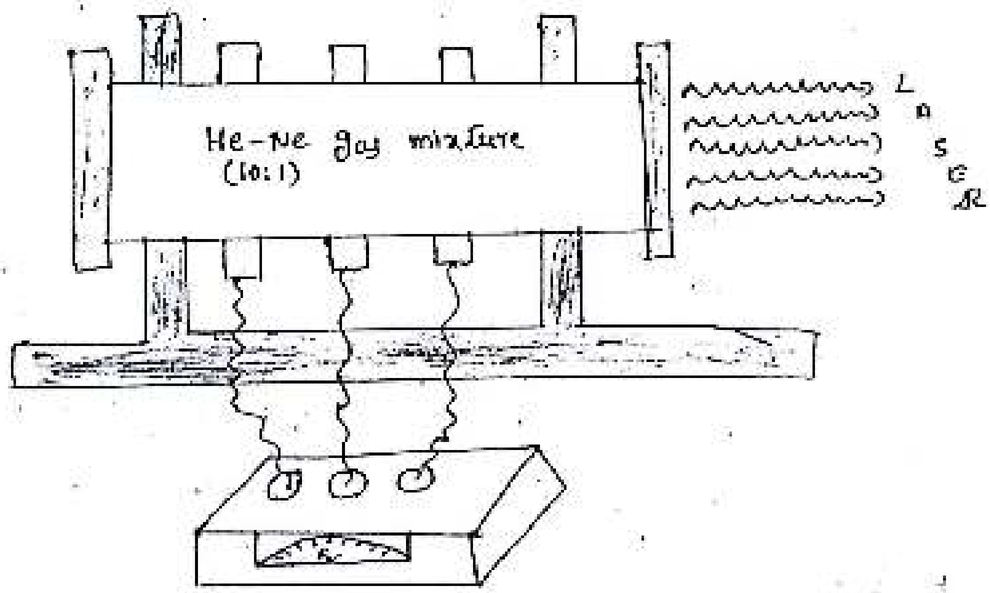
1. If a light ray travels a distance of s in a medium of refractive index μ , the equivalent distance in air medium is **μs**
2. The soap bubble appears multicoloured when exposed to white light
3. In order that a thin film of oil floating on the surface of water should show colours due to interference, the thickness f the oil film should be of the order 10000 Å
4. Reflected light interference is **complimentary** to transmitted light interference
5. The path difference in case of a thin film of thickness t and refractive index when exposed to monochromatic light of wavelength λ is 2μtcosr-(λ/2)
6. The condition for constructive interference in case of a thin plane parallel film in reflected system is **2μtcosr = (2n+1)λ/2**
7. The condition destructive interference in case of a thin plane parallel film in reflected system is **2μtcosr = nλ**
8. When a thin film of oil or soap bubble is illuminated with white light, multiple colours appear. This is due to interference
9. If the film thickness is extremely small when compared to wavelength λ of light used to expose it, then the film appears bright
10. A parallel beam of light λ = 5890 Å is incident on a glass plate (μ = 1.5) such that angle of refraction into plate is 60°. The smallest thickness of the plate which will make it appear dark by reflection would be 3927 Å
11. In Newtons rings experiment the locus of points having constant thickness of air film forms circle
12. When the Newtons rings are viewed through a microscope, the central ring is seen dark because **phase difference of π due to phase change on reflection**
13. The air film in the Newtons rings apparatus is replaced by an oil film. The radius of the rings decreases
14. The convex lens in Newtons rings apparatus is replaced by an ordinary glass plate, then **shape the fringes is irregular**
15. In the Newtons rings apparatus the convex lens used should have large radius of curvature
16. If white light is used in the Newtons rings experiment, then the central spot will be
 a) multi coloured
 b) dark

17. If the glass plate of the Newtons rings apparatus is replaced by a plane mirror, then the fringes will **disappear**
18. In Newtons rings experiment the condition for bright fringes in case of reflected light is
 a) $D_n \propto \sqrt{2n-1}$
19. In Newtons rings experiment the condition for dark fringes in case of reflected light is
 d) $D_n \propto \sqrt{n}$
20. In Newtons rings experiment the diameter of 40^{th} ring is 0.1 m with air film. When an oil film is formed the diameter of the same ring becomes 0.089 m. The refractive index of oil is **1.26**
21. The condition for maxima in the two slit diffraction is **(a+b) sinθ =n λ**
22. In a double slit diffraction, if the width of the slit is equal to the spacing between the slits, then **Even order interference maxima will be missing**
23. In a double slit diffraction, the fringe spacing on a screen 50cm away from the slits would be----if they are illuminated with blue light λ =480nm, slit separation b =0.1nm and slit width a =0.020nm 2mm
24. When white light is incident on a diffraction grating, the light diffracted more will be **Red**
25. Monochromatic light falling normally on a grating give rise to a diffracted second order beam at an angle of 30°. If the grating has 5000 lines/cm, the wavelength of light is
 c) 500nm
16. Maximum number of orders possible with the grating is **Directly proportional to the grating element**
27. Points on a successive slits separated by a distance equal to the grating element are called **Corresponding points**
28. The combined width of a ruling and a slit is called **Grating element**
29. Number of orders visible would be ---- if the wavelength of light is 5000 Å and the number of lines per cm on the grating is 6655 Å
30. The condition for Diffraction minima is given by **a sinθ =p λ**
31. A grating is able to resolve two very close spectral lines of wavelength 5860 Å and 5896 Å in its first order

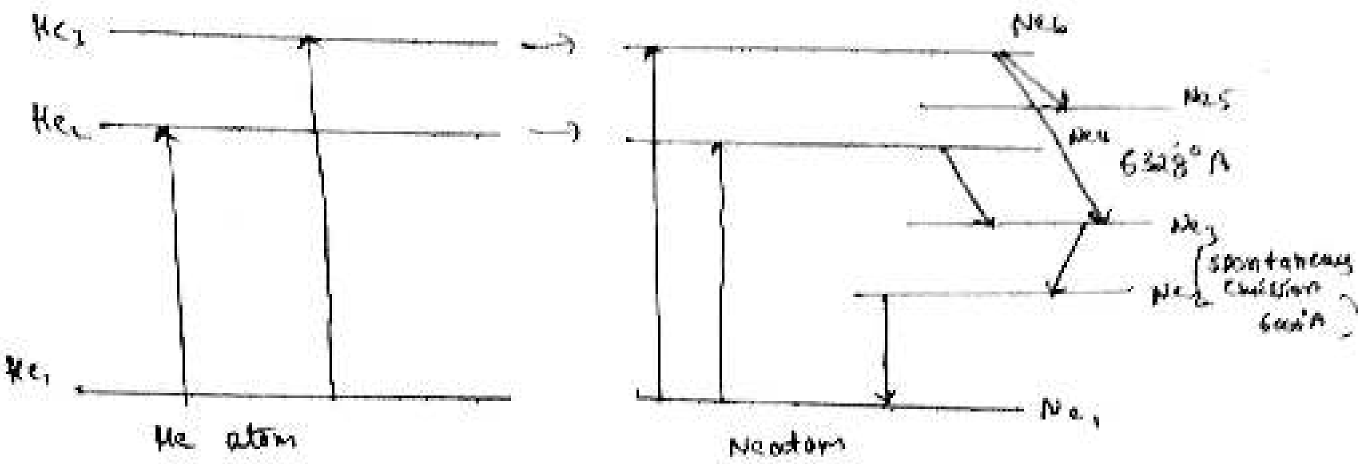
He-Ne LASER :- It is a gaseous laser system and is used to produce a continuous laser. This laser is highly directional, monochromatic, coherent and stable.

Source of energy : R.F oscillator
Active medium : He & Neon gas mixture
Optical cavity : Arrangement of reflector

Construction :- The He-Ne laser consists of quartz tube with a diameter of about 1.5 cm and 80 cm length which has three electrodes to connect R.F oscillator. This tube is filled with a mixture of Neon under a pressure of 0.1 mm of Hg and Helium under a pressure of 1mm of Hg. At one end of the tube a perfect reflector is arranged while on the other end a partial reflector. The active material is excited due to energy discharge through the gas mixture by means of radio frequency oscillator with a frequency of several MHz.



Working Principle :- In Helium (He) atoms three energy levels are present, they are named as He_1, He_2 & He_3 whereas in Neon (Ne) atom six active energy levels, they are named as Ne_1, Ne_2, Ne_3, Ne_4, Ne_5 & Ne_6. Ne_4 and He_2 have same energy and life time and similarly Ne_6 and He_3. When the electric discharge is passed through the He-Ne gas mixture, then the electrons are accelerated towards the positive electrode. During their passage they collide with Helium and Neon atoms, but only He atoms are suitable to excite to the upper states labeled He_2 and He_3. These are metastable states in Helium atoms. Thus the atoms remain in these levels for a sufficiently long time. Now these atoms interact with Neon atoms, which are in the ground state. The interaction excites the Neon atoms to the metastables labelled Ne_4 and Ne_6 while the He atoms return to their ground state.



As the energy exchange continue between He and Ne atoms, the population of Neon atoms in the excited state Ne_4 and Ne_6 increase more and more. At a stage population inversion will be achieved in the metastable state Ne_4 and Ne_6.

(i) Neon atoms de exite from Ne_6 to Ne_5. During this transition electromagnetic radiation of wavelength of 3390°A will be emitted.

- Many other Neon atoms de exite from Ne_6 to Ne_3. During this transition electromagnetic radiation of wavelength 6328° A will be emitted. ~~this is the~~ :