LASERS

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LASER → Light Amplification by Stimulated Emission of Radiation.

Characteristics

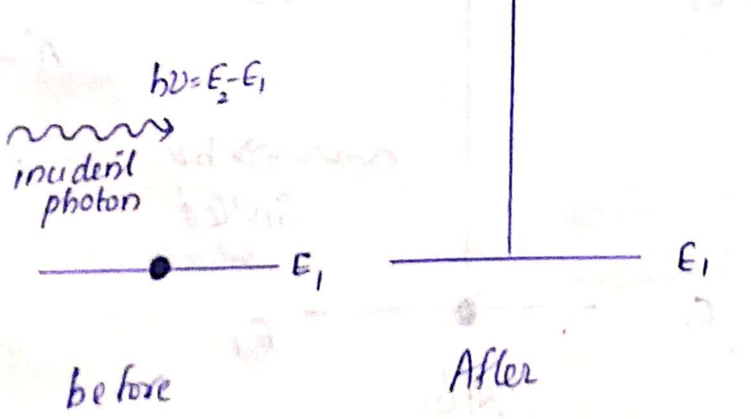
1) High directionality
2) Negligible divergence
3) High intensity
4) High degree of coherence
5) Highly monochromatic.

Interaction of light with matter

When photons travel through the medium, 3 different processes are likely to occur. They are absorption, spontaneous emission and stimulated emission.

a) Absorption

Suppose an atom is in the lower energy level E_1. If a photon of energy $h\nu = (E_2 - E_1)$ is incident on the atom, it imparts its energy to the atom and disappears. Then we say that the atom absorbed an incident photon. As a result of absorption of adequate energy, the atom jumps to the excited state E_2. This is called absorption or induced absorption.



$A + h\nu = A^*$

$A \rightarrow$ atom in lower state

$A^* \rightarrow$ atom in excited state

The probability that an absorption transition occurs is proportional to the photon density $\rho(\nu)$

$$P_{12} \propto \rho(\nu)$$

$$P_{12} = B_{12}\rho(\nu)$$

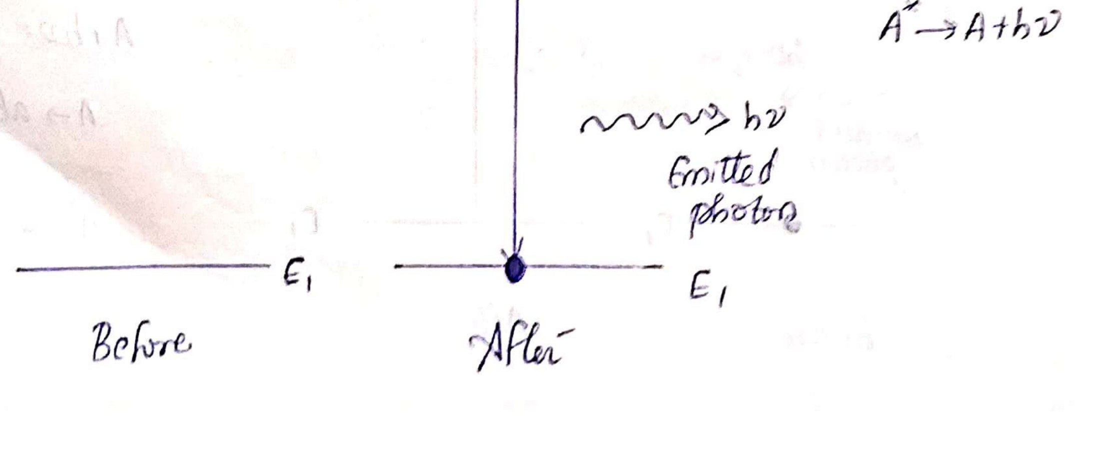
B_{12} = const = Einstein's coefficient for induced absorption

The no: of absorption transitions occuring in the material at any instant will be equal to the product of the no: of atoms at the energy level E_1 and the probability P_{12} for the absorption transition. When the atoms are more at the lower energy level, then more atoms can jump into the excited state. III'y when more photons are incident on the assembly of atoms, then more atoms can get excited to the higher energy level. Then the rate of absorption transition is given by

$$R_{abs} = B_{12}\rho(\nu)N_1 \qquad \text{—— (1)}$$

b) Spontaneous emission

When an atom at lower energy level is excited to a higher energy level, it cannot stay in the excited state for a relatively longer time. In a time of about $10^{-8}s$, the atom reverts to the lower energy state by releasing a photon of energy $h\nu$ ($h\nu = E_2 - E_1$). The emission of a photon occurs on its own and without any external impetus and this is called spontaneous emission.



The probability that a spontaneous transition occurs depends only on the properties of energy states E_2 & E_1 and is independent of the photon density.

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

A_{21} = const = Einstein's coefficient for spontaneous emission

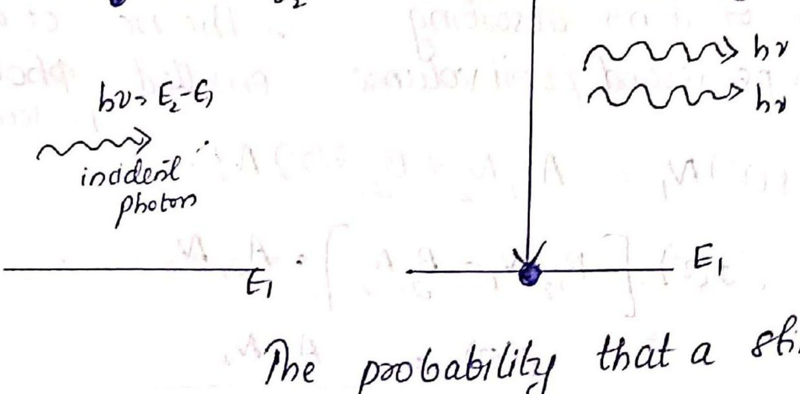
$1/A_{21}$ is a measure of the lifetime of the upper state against spontaneous transition to the lower state.

∴ The rate of spontaneous transition is

$$R_{spon} = A_{21} N_2 \qquad \text{——— (2)}$$

c) <u>Stimulated emission</u>

If a photon can stimulate an atom to move from a lower energy level E_1 to a higher energy level E_2 by means of absorption transition, then a photon should also be able to stimulate an atom from the same upper level E_2 to the lower level E_1. The phenomenon of forced photon emission by an excited atom due to the action of an external agency is called stimulated emission / induced emission.



$$A^* + h\nu \rightarrow A + 2h\nu$$

The probability that a stimulated transition occurs is given by,

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

$B_{21} \rightarrow$ Einstein coefficient for stimulated emission

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①

The rate of stimulated emission is

$$R_{st} = B_{21}\,\rho(\nu)\,N_2 \quad \text{—— (3)}$$

Characteristics of stimulated emission

1) The process is controllable
2) The induced photons has same frequency, phase, plane of polarisation.
3) Multiplication of photons.
4) Light amplification

The 3 processes namely absorption, spontaneous emission and stimulated emission occur simultaneously in a medium. Under steady state condition the absorption and emission processes balance each other.

$$R_{abs} = R_{sp} + R_{sti}$$

$$B_{12} N_1 \rho(\nu) = A_{21} N_2 + B_{21} N_2 \rho(\nu)$$

Einstein Relations

Under thermal equilibrium, the mean population N_1 and N_2 in the lower and upper energy levels resp must remain const. This condition requires that the no. of transitions from E_2 to E_1 must be equal to the no. of transitions from E_1 to E_2. Thus.

The no. of atoms absorbing photons persecond / unit volume = The no. of atoms emitted photons/unit per second volume

$$B_{12}\,\rho(\nu)\,N_1 = A_{21} N_2 + B_{21}\,\rho(\nu)\,N_2$$

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

$$\rho(\nu) = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2}$$

by dividing both the numerator and denominator on the right hand side of the above eqn with $B_{12} N_2$

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

but $$\frac{N_2}{N_1} = e^{-(E_2-E_1)/kT}$$

As $E_2 - E_1 = h\nu$

$$\frac{N_1}{N_2} = e^{h\nu/kT}$$

$$\therefore \rho(\nu) = \frac{A_{21}}{B_{12}}\left[\frac{1}{e^{h\nu/kT} - B_{21}/B_{12}}\right]$$

To maintain thermal equilibrium, the system must release energy in the form of electromagnetic radiation. It is required that the radiation be identical with blackbody radiation and be consistent with Planck's radiation law for any value of T. According to Planck's law.

$$\rho(\nu) = \frac{8\pi h\nu^3\mu^3}{c^3}\left(\frac{1}{e^{h\nu/kT}-1}\right)$$

$\mu \rightarrow$ refractive index of medium

$$\therefore \frac{A_{21}}{B_{12}} = \frac{8\pi h\nu^3\mu^3}{c^3}$$

and $$\frac{B_{21}}{B_{12}} = 1 \Rightarrow B_{12} = B_{21}$$

The above eqns are known as Einstein's relations.

$$\therefore B_{12} = B_{21} = \frac{c^3}{8\pi h\nu^3\mu^3} A_{21}$$

It shows the ratio of A_{21} to B_{12} is proportional to 3rd power of frequency of the radiation. This is why it is difficult to achieve laser action in higher frequency ranges such as X rays.

Metastable state

When suitable energy is given to an $\bar{e}$ in an atom, it 'jumps' from a lower energy state E_1 to a higher energy state E_2, where it can reside only for a time of about 10^{-8}s. In certain substance like ruby crystal there is an intermediate energy state 'E_m' for the atom which is b/w the energy levels E_1 & E_2. In such materials, the electron from the energy state E_2 does not jump directly back to the energy state E_1, but jumps to the energy state E_m. The $\bar{e}$ can remain in this energy level E_m for a time of about 10^{-3}s, much longer than that in E_2. This energy state is called metastable state.

Optical pumping and population inversion

At ordinary temp., the no: of electrons in the higher energy states in an atomic system is considerably smaller than that of the lowest energy state.

Consider a material whose atoms can reside in 3 different states E_1, E_2 & E_m. Since the life time of E_m is much longer than E_2, the atom reach the state E_m much faster than they leave the state E_m. Thus the state E_m contains more atoms than the state E_1. This is known as population inversion. The process by which it is obtained is called optical pumping.

Components of laser

1) Active medium :-

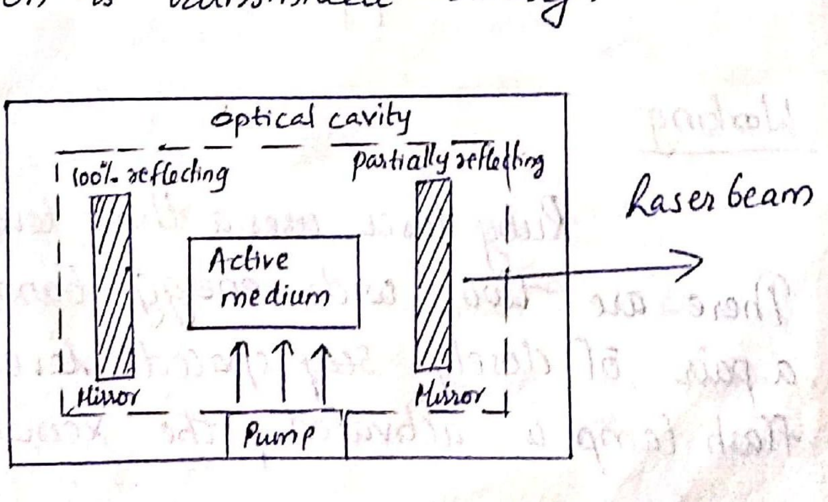
Some atoms have energy level system suitable for achieving and cause amplification of light. Those , atoms, which cause laser action, are called active centres. The medium hosting the active centres is called the active medium. Thus an active medium is a medium which when excited reaches the state of population inversion and promotes stimulated emissions leading to light amplification.

2) Pump :-

For achieving and maintaining the condition of population inversion, we have to raise continuously the atoms in the lower energy level to the upper energy level. It requires energy to be supplied to the system. Pumping is the process of supplying energy to the laser medium with a view to transfer it into the state of population inversion.

3) Optical resonant cavity :-

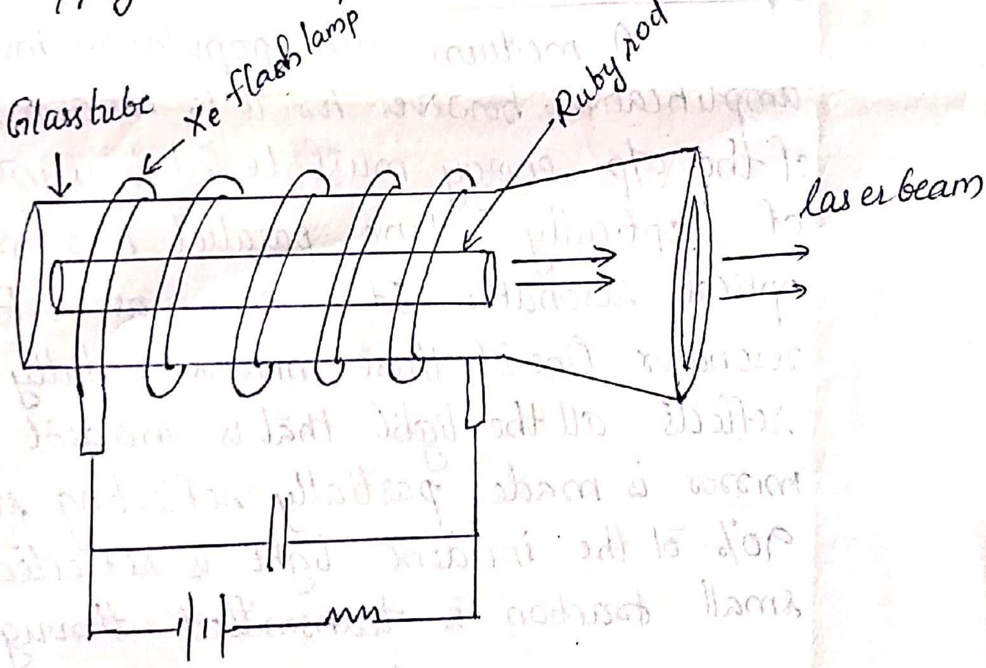
A medium with population inversion is capable of amplification; however for it to act as an oscillator, a part of the o/p energy must be fed back into the system. A pair of optically plane parallel mirrors constitute an optical resonator. It is known as a Fabry-Perot resonator. One of these mirrors is fully reflecting and reflects all the light that is incident on it. The other mirror is made partially reflecting such that more than 90% of the incident light is reflected from it and a small fraction is transmitted through it as the laser beam.



Ruby laser

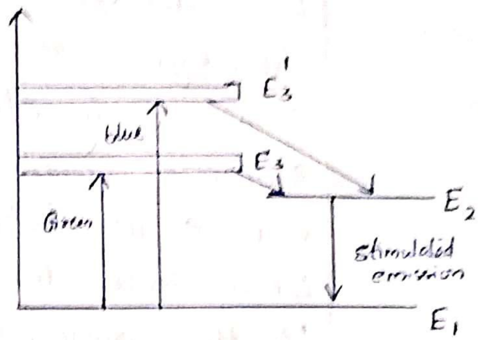
Ruby laser is an example for solid state laser. A solid state laser is one in which the active centres are fixed in a crystal or glassy material. The ruby laser was invented by Maimann in 1960.

The ruby rod consists of Al_2O_3 with some of the aluminium atoms replaced by chromium. Cr^{3+} ions are the actual active centers. Ruby rod is taken in the form of a cylindrical rod. Its ends are grounded and polished such that the end faces are exactly parallel and are also $\perp^r$ the axis of the rod. One face is silvered to achieve 100% reflection while the other is silvered to give 10% transmission and 90% reflection. The laser rod is surrounded by a helical flash lamp filled with Xenon. Whenever activated by the power supply the lamp produces flashes of white light.



Working

Ruby laser uses a three level pumping scheme. There are two wide energy bands E_3 and E_3' and a pair of closely ~~seat~~ spaced levels at E_2. When the flash lamp is activated, the xenon discharge generate an intense burst of white light lasting for a few milli seconds. The Cr^{3+} ions are excited to the energy bands E_3 and E_3' by the green and blue components of white light. The energy levels in these bands have a very small lifetime. Hence the excited Cr^{3+} ions rapidly lose some of the energy to the crystal lattice and undergo non-radiative transition. They quickly drop to the level E_2

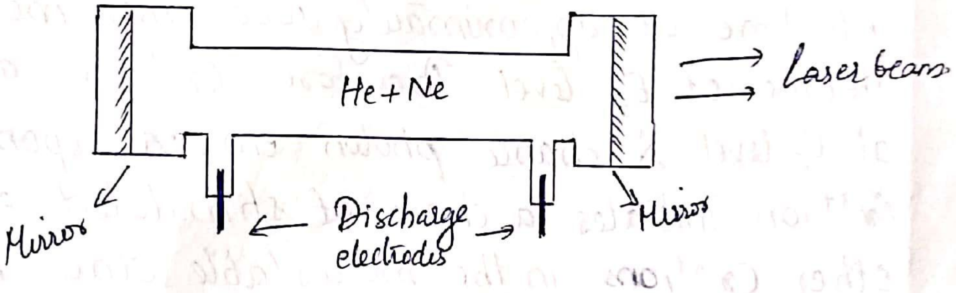


The pair of levels at E_2 are metastable state having a lifetime of approximately 1000 times more than the lifetime of E_3 level. Therefore Cr^{3+} ions accumulate at E_2 level. A chance photon emitted spontaneously by a Cr^{3+} ion initiates a chain of stimulated emission by other Cr^{3+} ions in the metastable state. Red photons of wavelength 6943 A° travelling along the axis of the ruby rod are repeatedly reflected at the end mirrors and light amplification takes place. A strong intense beam of red light emerges out of the front-end mirror.

He-Ne Laser

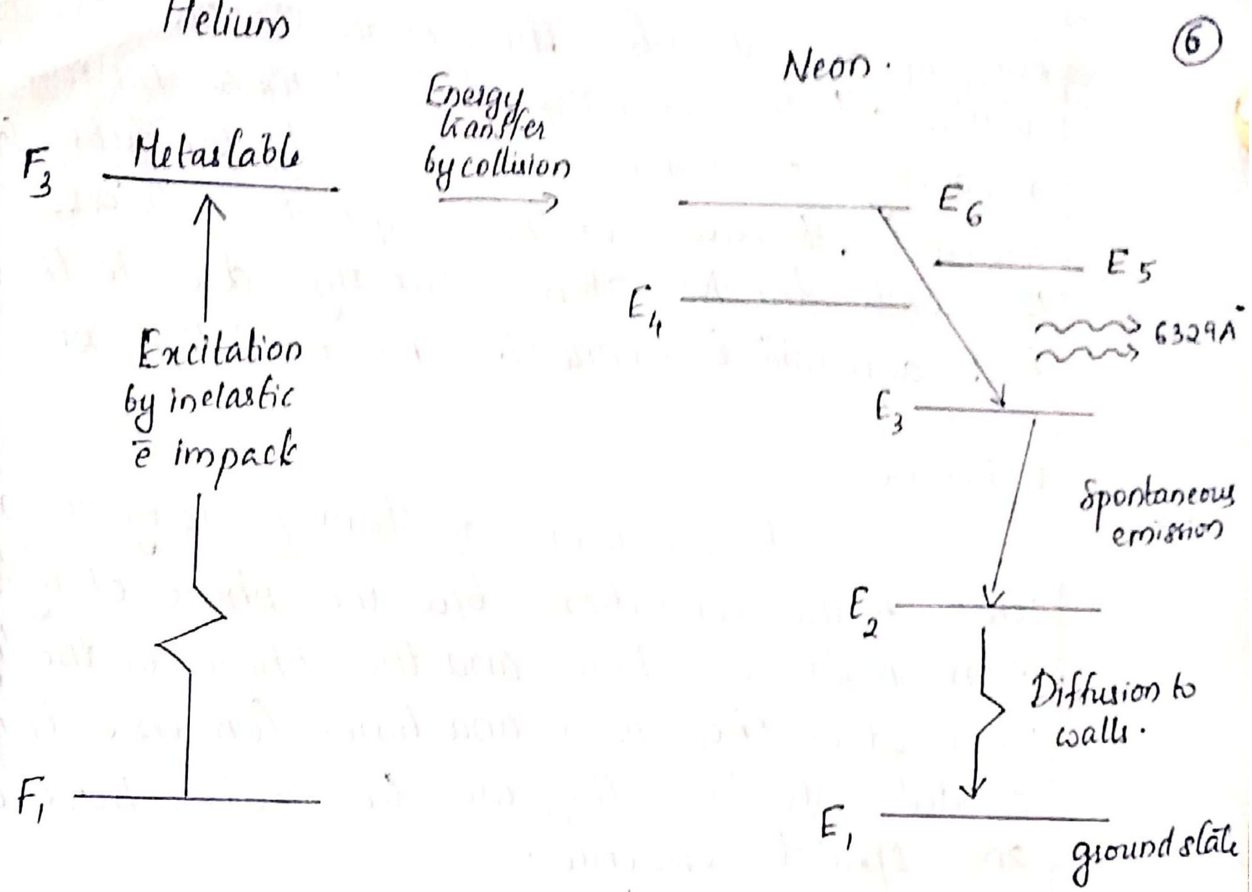
He-Ne laser is the 1st gas laser. In gases, the energy levels of atoms involved in the lasing process are narrow and as such required sources with sharp wavelength to excite atoms. Therefore optical pumping is not used in gas lasers. The most common method of exciting gas laser medium is by passing an electric discharge through the gas. Electrons present in the discharge transfer energy to atoms in the laser gas by collision

Construction :- He-Ne laser consists of a long discharge tube filled with a mixture of helium and neon gases in the ratio 10:1. Neon atoms are the active centre and have energy levels suitable for laser transitions while helium atoms help in exciting Neon atoms. Electrodes are provided in the discharge tube to produce discharge in the gas. They are connected to a high voltage power supply. The tube is hermetically sealed by inclined windows arranged at its two ends. On the axis of the tube, two mirrors are arranged externally which form the Fabry-Perot resonator. The distance b/w the mirrors is adjusted to be $m\lambda/2$ such that the resonator supports standing wave pattern.



Working

He-Ne Laser employs a 4-level pumping scheme. When the power is switched on, a high voltage of about 10kV is applied across the gas. It is sufficient to ionize the gas. The ēs and ions produced in the process of discharge are accelerated towards the anode and cathode resp. The energetic ēs excite helium atoms through collisions. The excited He reaches the metastable state E_3. They cannot return to the ground level through spontaneous emission. However, it can return to ground level by transferring its excess energy to a neon atom through collision. Such an energy transfer can take place when the two colliding atoms have identical energy levels. Such an energy transfer is known as resonant energy transfer.



Thus such a transfer takes placed b/w excited He atom and ground level neon atom. Heluim atom drop to the ground level after exciting neon atom. This is the pumping mechanism in He-Ne laser. The upper state of neon atom E_6 is a metastable state. Therefore neon atoms accumulate in this upper state. The E_3 is sparsely populated at ordinary temp, and a state of population inversion is readily established b/w E_6 & E_3 levels. Random photons emitted spontaneously prompt stimulated emission and lasing occurs. The transition $E_6 \rightarrow E_3$ generates a laser beam of red colour of wavelength 6329 A°.

From the level E_3 the neon atoms drop to E_2 level spontaneously. E_2 level is however a metastable state. Consequently, neon atoms tends to accumulate at E_2 level. It is necessary that these atoms are brought to the ground state E_1 quickly; otherwise the no. of atoms at the ground state will go on diminishing and the laser ceases to function. The only way of bringing the atoms to the ground state is through collision. If the discharge tube is made narrow, the probability of atomic collisions with the tube walls increases. Because of the frequent collisions with the walls, the Ne atoms rapidly drop to the ground level and will be available for excitation once again.

Coherence

Coherence is an important property of light. It refers to the connection b/w the phase of light waves at one point and time and the phase of the light wave at another point and time. Coherence can be divided into two. They are temporal coherence and spatial coherence.

Coherence length :-

The light emitted by an ordinary light source is not an infinitely long, simple harmonic wave but is composed of a jumble of finite wave trains. ∴ we call it as quasi-monochromatic source. The length of the wave train over which it may be assumed to have a fairly sinusoidal character and predictable phase is known as coherence length.

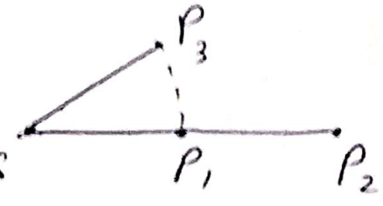
Coherence time :-

The time interval during which the phase of the wave train can be predicted reliably is called coherence time.

a) Temporal coherence

It is also known as longitudinal coherence. Let a point source of quasi-monochromatic light s emit light in all directions. Let us consider light travelling along the line SP_1P_2. The phase relationship b/w the points P_1 and P_2 depends on the distance P_1P_2 and the coherence length of the light beam.

The electric fields at P_1 and P_2 will be correlated in phase when a single wave train extends over greater length than the distance P_1P_2 ie, if the distance P_1P_2 is less than the coherence length. Then the waves are correlated in their rising and falling and they will preserve a const phase difference.



Spatial coherence

If the phase difference for any two fixed points in a plane normal to the wave propagation doesnot vary with time, then the wave is said to exhibit spatial coherence. It is also known as lateral coherence. In fig:- $SP_1 = SP_3$ and ∴ the fields at points P_1 and P_3 would have the same phase. Thus an ideal point source exhibits spatial coherence, as the waves produced by it are likely to have the same phase at points in space, which are equidistant from the source.

④ Polarization ①

Waves :-

(1) Longitudinal waves - A wave in which particles of the medium oscillates to & fro along the direction of propagation

(2) Transverse waves - A wave in which every particle of the medium oscillates up and down at right angles to the direction of propagation.

- Transverse waves only exhibit polarization
- Polarized light is the light that contains waves that only fluctuate in one specific direction.

Types of polarization

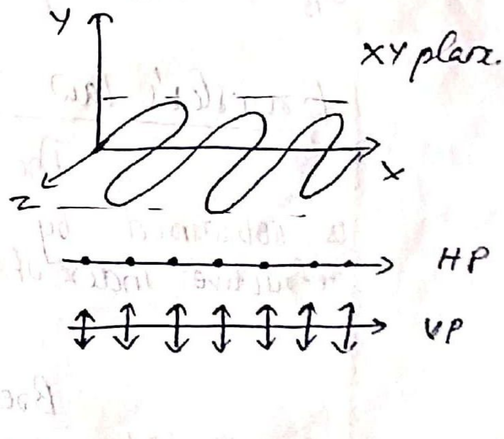
a) Plane or linear polarization
b) Elliptical polarization
c) Circular polarization.
d) Partial polarization.

1) Plane polarized light

- light waves in which the oscillations occur in a single plane. The oscillations of electric field vector E are strictly confined in a single plane ⊥^{r} to the direction of propagation.

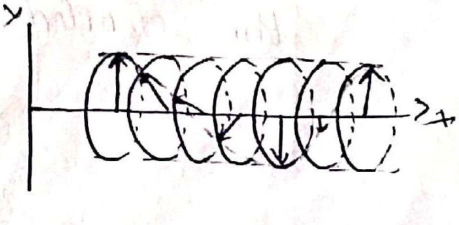
If the field is pointing up or down
→ vertical polarization

If the field is pointing right or left
→ horizontal polarization.



2) Circularly polarized light

The magnitude of the electric vector E stays constant but it rotates at a constant rate about the direction of propagation and sweeps a circular helix in space.



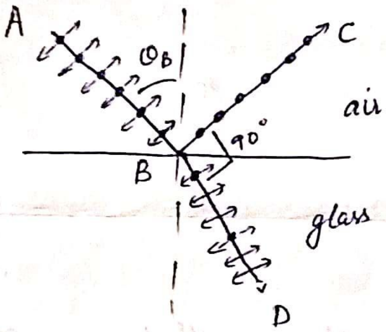
If the rotation of the tip of E is clockwise (2)
- right circularly polarized.
If the rotation of the tip of E is anticlockwise
- left - circularly polarized.

3) Elliptically polarized light

If the magnitude of electric vector E changes with time and the vector E rotates about the direction of propagation and sweeps a flattened helix in space. (right & left elliptically polarized light).

Polarization by reflection

When light wave is incident on a boundary b/w 2 dielectric materials, part of it is reflected and part of it is transmitted.



AB is an unpolarized light beam. The electric vector E of the ray AB contains 2 components dot & arrows (s & p components). At a particular angle θ_B, the reflection coefficient for p-component goes to zero and the reflected beam doesnot contain again p-component. It contains only s-component and is totally plane polarized. The angle θ_B is called polarizing angle / Brewster's angle.

Brewster's law

The tangent of the angle at which polarization is obtained by reflection is numerically equal to the refractive index of the medium.

$$\mu = \tan \theta_B.$$

Brewster found that the maximum polarization of reflected ray occurs when it is at right angles to the refracted ray. $\theta_B + r = 90°$

According to Snell's law

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

$\mu_2 \rightarrow$ refractive index of reflecting surface
$\mu_1 \rightarrow$ " of surrounding medium.

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$$\frac{\sin \theta_B}{\sin(90-\theta_B)} = \frac{\mu_2}{\mu_1}$$

$$\frac{\sin \theta_B}{\cos \theta_B} = \frac{\mu_2}{\mu_1}$$

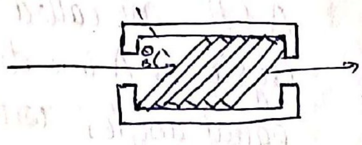
$$\tan \theta_B = \frac{\mu_2}{\mu_1}$$

Applications of Brewster's law

1) Can be used to determine refractive indeces of opaque materials
2) can be used to find polarizing angle needed for total polarization of reflected light.
3) In gas lasers two glass plates are arranged at Brewster angle at the ends. They are called Brewster windows. The light beam travels b/w the mirrors and reflection takes places

Polarization by refraction - pile of plates

If natural light is transmitted through a single plate, the transmitted beam is only partially polarized. If a stack of glass plates is used, reflections from successive surfaces occur leading to the filtering of the s-component in the transmitted ray. Ultimately, the transmitted ray consists of p-component alone.
This arrangement is called pile of plates.

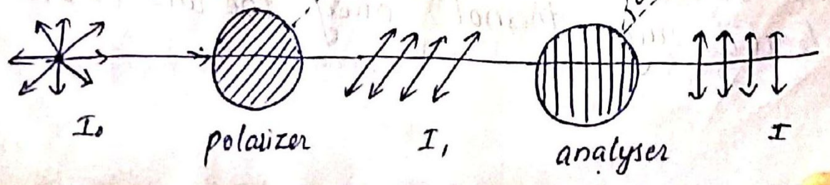


Polarizer :- is an optical filter that lets light waves of a specific polarization pass and blocks light waves of other polarizations.

Analyzer :- A device which is used to examine whether light is polarized or not is an analyser.

Malus's' law

The amount of light transmitted through a polarizer at an arbitrary angle is given by Malus' law.



(4) It states that the intensity of polarized light transm. through a polarizer is proportional to the square of cosi. of the angle b/w the plane of polarization of the light and the transmission axis of analyzer.

$$I \propto \cos^2\theta$$

$$I = I_m \cos^2\theta.$$

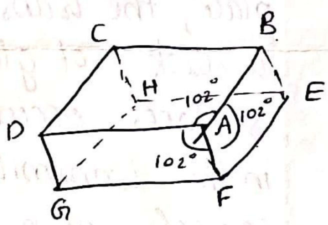
If unpolarized light of intensity I_0 is incident on a polarizer, plane polarized light of intensity $I_0/2$ is transmitted by it. $\therefore I_1 = \frac{I_0}{2}$ $\therefore I = \frac{I_0}{2}\cos^2\theta.$

If $\theta = 0^\circ$ $I = I_0/2$ If $\theta = 180^\circ$ $I = \frac{I_0}{2}$

If $\theta = 90^\circ$ $I = 0$ If $\theta = 270^\circ$ $I = 0.$

Thus we obtain two positions of maximum intensity and two positions of zero intensity when we rotate the axis of the analyser w.r.t polarizer.

Optical axis:-

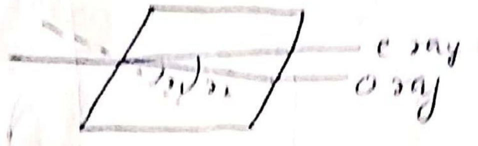


At the 2 opposite corners A & H of the rhombo-hedron all the angles of the faces are obtuse. The corners A & H are called blunt corners of the crystal. A line drawn through A and making equal angles with each of the 3 edges gives the direction of optic axis. Any line $\|^{el}$ to optical axis is again an optical axis.

Double refraction

It is an optical property in which a single ray of unpolarized light entering an anisotropic medium is split into 2 rays, each travelling in a different direction. which vibrate in $\perp^r$ planes. One ray obeys the laws of refraction and its velocity in the crystal is the same in all directions This ray is called ordinary ray (o-ray). The other refracted ray doesnot obey the law of refraction and it

travels through the crystal with different velocities in different
(5) directions. These are called extraordinary ray (e-ray).
Along the optical axis both rays travel with the same velocity.



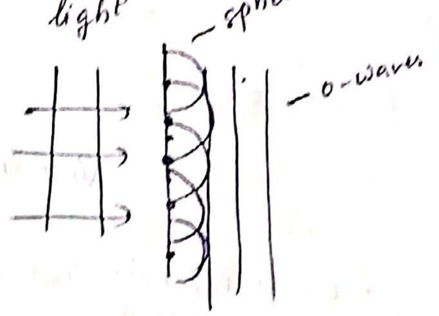
The e-ray and o-ray are linearly polarized in ⊥' direction.

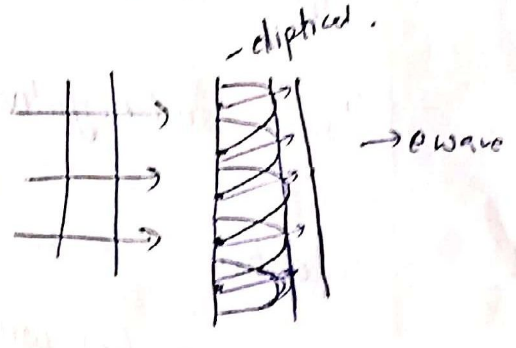
The refractive index corresponding to o-ray is a constant and is designated by μ_o. The refractive index corresponding to e-ray varies and is denoted by μ_e. The difference b/w the refractive indices is known as amount of double refraction / birefringence.

$$\Delta\mu = \mu_e - \mu_o.$$

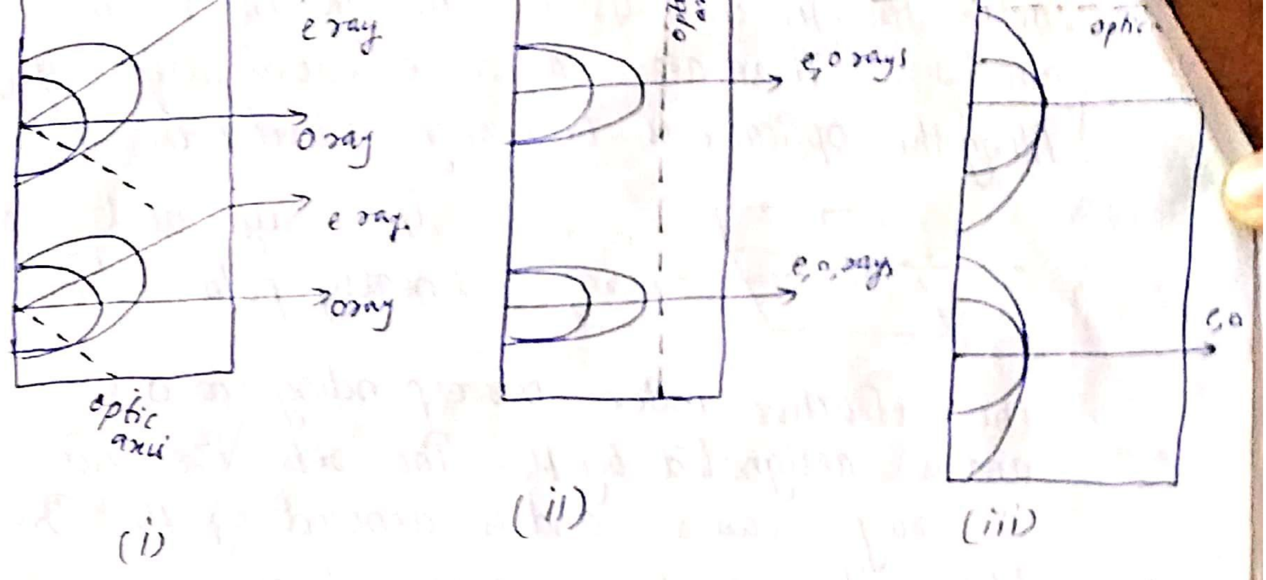
Huygen's explanation of double refraction

Hugen postulated that the incident light excites 2 seperate wavelets within the crystal, one spherical wavelet associated with the ordinary waves and one ~~epp~~ ellipsoidal wavelet associated with the e-waves. If the plane wavefront incident normally on the crystal surface generates spherical as well as ellipsoidal wavelets





The spherical wavelets propagate equally quickly in all directions. The tangent to these waves lies straight ahead and thus the plane wave propagates straight ahead with speed v which are o-waves. The line from the point of generation of each ellipsoid to the tangent point on that ellipsoid is off at an angle and defines the direction of travel of the e-wavefronts. Thus as the light propagates through the crystal, the two wave surfaces travel in different directions in the crystals. Ultimately, 2 refracted rays emerge from the crystal.



(i) → When natural light is incident on an anisotropic crystal at an angle to the optic axis, o & e rays travel in different directions with different velocities.

(ii) → If incident ⊥ʳ to optic axis, e & o rays propagates in same directions with different velocities

(iii) → If incident ∥ᵉˡ to optic axis, they travel in same ~~diffe~~ direction with same velocities.

The distinction of o & e rays exists only within the crystal. Once they emerge from the crystal, they travel with same velocity.

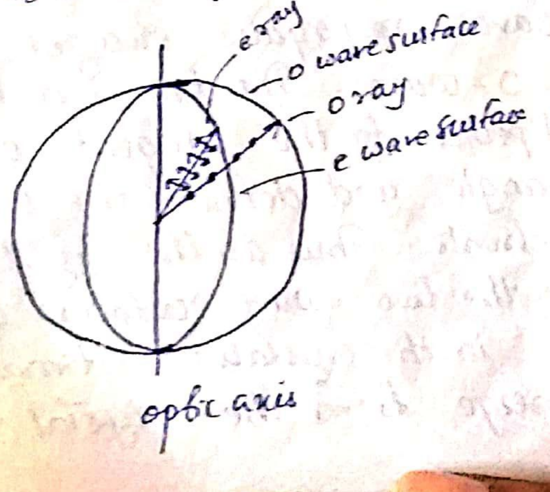
Positive and negative crystals

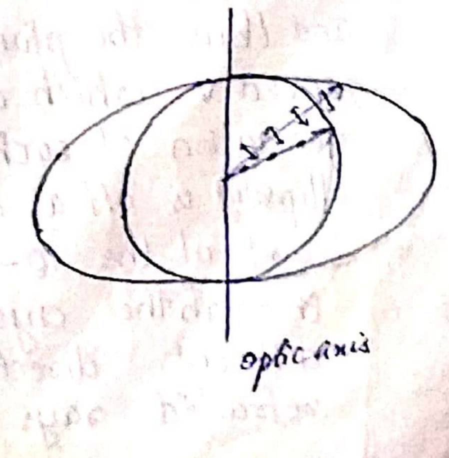
Positive

- e-wavefront lies within the o-wavefront
- eg:- Quartz crystal.

Negative

- o-wavefront lies within the e-wavefront
- Calcite crystal





(45)

- called as positive b'coz refractive index for e ray is > than that of o ray ($\mu_e > \mu_o$)
- called as -ve, b'coz $\mu_e < \mu_o$

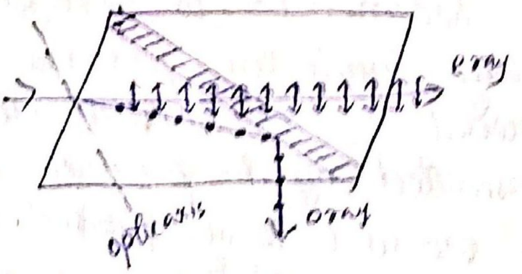
- e ray velocity has a maximum value along the optical axis and minimum value in a direction ⊥ʳ to the optical axis.
- e ray velocity has minimum value along the optic axis and ~~min~~ maximum value in a direction ⊥ʳ to optic axis

- $V_e = V_o$ → ∥ᵉˡ to optic axis
  $V_e < V_o$ → other directions
- $V_e = V_o$ → ∥ᵉˡ to optic axis
  $V_e > V_o$ → other directions

- Birefringence is +ve ($\Delta\mu$)
- Birefringence is -ve.

Nicol prism

Nicol prism is a polarizing device based on double refraction. A rhombohedral calcite crystal whose edges are at an angle of 68° is cut into two along a plane ⊥ʳ to the principal axis. The two parts are ~~ce~~ then cemented together with canada balsam, whose refractive index lies b/w the refractive indices of calcite for o ray & e ray.

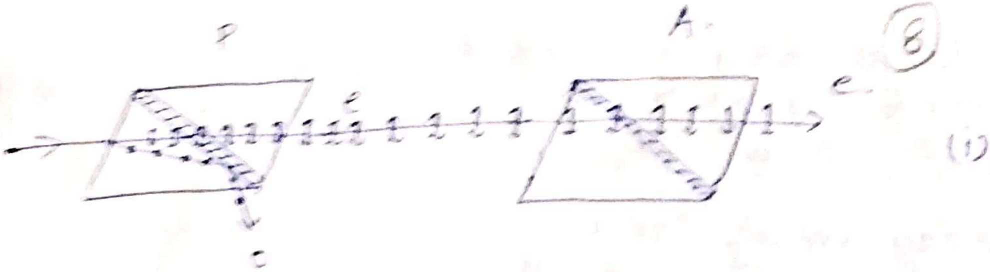


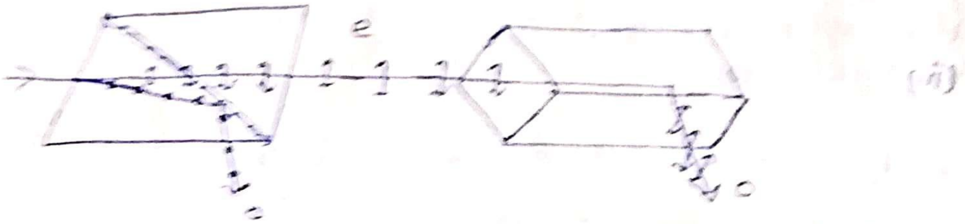
When unpolarized light fall on the crystal, it suffers double refraction & splits into o ray and e-ray. The values of the refractive indices and the angles of incidence at the canada balsam layer are such that the e-ray is transmitted while the o-ray is internally reflected. The face where the o-ray is incident is blackened so that the o-ray is completely absorbed. Then we get only the plane-polarized e-ray coming out of the Nicol.

Nicol prism as a polarizer and analyzer

When 2 Nicol prisms P & A are placed adjacent to each other, one of them acts as a polarizer and the other acts as an analyzer.

(8)





If unpolarized ray of light is incident on the Nicol prism P, a linearly polarized e-ray emerges from P with its vibration direction lying in the principal section of P. The state of the polarization of the light emerging from polarizer P can be examined with another polarizer A, which is called analyzer. ~~The~~ Let ~~when~~ now this ray be incident on A whose principal section is ∥^{el} to P. Then the ray is transmitted unhindered through the analyzer A.

If the prism A is gradually rotated, the intensity of the e ray decreases with Malus law. When its principal section becomes ⊥^{r} to that of P, the ray behaves as o-ray inside the prism A and is totally internally reflected by the Canada balsam layer. Hence no light is transmitted by the prism A. In this condition the prisms are said to be crossed. If A is further rotated through 90°, the intensity of light emerging from A will go on increasing. Thus P produces linearly polarized light while A detects it.

Quarter wave plate

It is a plate of doubly refracting uniaxial crystal of calcite or quartz whose refracting faces are cut ∥^{el} to the direction of the optic axis. Its thickness is adjusted such that it introduces a quarter-wave ($\lambda/4$) path difference (phase diff- 90°) b/w e-ray & o-ray

propagating through it. The incident plane polarized light is
(9) $\perp^r$ to its surface and o & e rays travel along the same direction with different velocities. Thus they emerge with a ~~pha~~ path difference

$$(\mu_o - \mu_e)d = \lambda/4 \qquad d \rightarrow \text{thickness}$$

Half wave plate

It is a plate of doubly refracting uniaxial crystal whose refracting faces are cut $\parallel^{el}$ to the direction of the optic axis. Its thickness is adjusted such that it introduces a half-wave ($\lambda/2$) path difference (path diff. 180°) b/w e & o ray propagating through it.

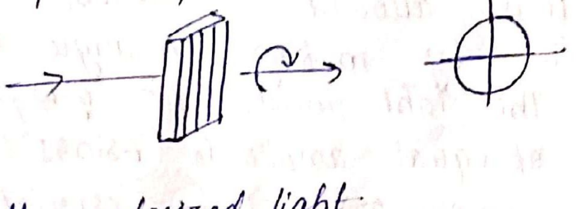
$$(\mu_o - \mu_e)d = \lambda/2.$$

Production and detection

a) Plane polarized light.

Unpolarized light is passed through the nicol prism. While passing through the nicol prism, the beam is splitup into e & o ray. The o ray suffers total internal reflection while the e ray passes through nicol prism. The emergent beam is thus plane polarized.

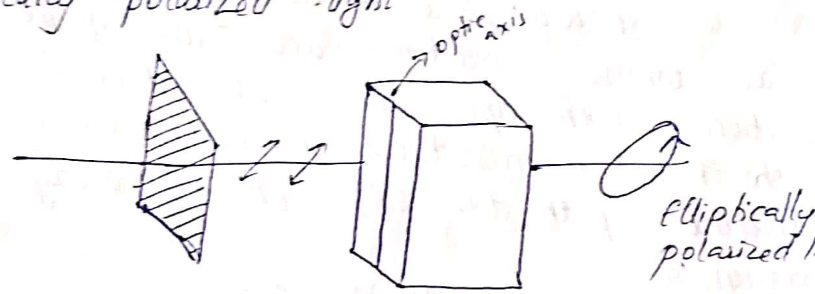
To detect, the light of unknown polarization is allowed to fall normally on a polarizer. The polarizer is slowly rotated through a full circle and the intensity of the transmitted light is observed. If the intensity of the transmitted light is extinguished twice in one full rotation of the polarizer, then the incident light is plane polarized.



b) Elliptically polarized light.

Unpolarized light is first converted to plane polarized light by allowing it to pass through a polarizer

(10) The plane polarized light is then made incident on quarter wave plate. The q-w plate is rotated such that $\vec{E}$ of plane polarized light makes an angle ($\theta \neq 45$) with the optic axis of q-w. The incident ray divides into o-ray & e-ray of amplitude $E\sin\theta$ & $E\cos\theta$. When they emerge out of the crystal they will have a path difference $\lambda/4$. When they combine, they produce elliptically polarized light.

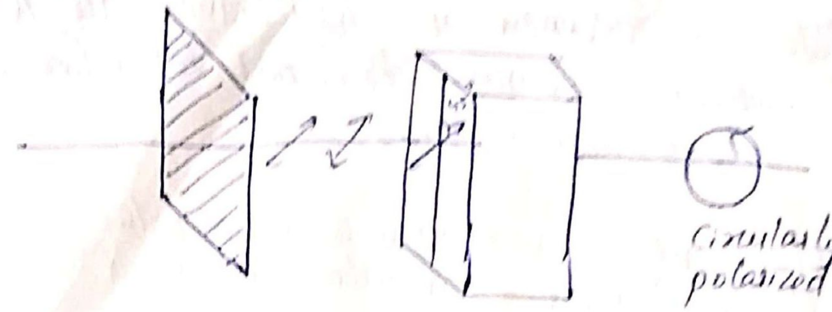


For detection another polarizer is adjusted after q-w plate and light intensity is observed with its rotation. The intensity of the emerging beam varies from a maximum to a minimum value, but never reaching zero. This indicates the light can be elliptically or partially polarized. The 2 cases may be distinguished by inserting a quarter wave plate in the path of light before it falls on the analyser. If the light wave is elliptically polarized, it turns into plane polarized light wave which on examining with an analyzer, light will be extinguished twice in one full rotation.

c) Circularly polarized light:

Unpolarized light is first converted to plane polarized light by allowing it to pass through a polarizer. It is allowed to incident on the quarter wave plate by making an angle of 45° with the optic axis. The light incident on q-w plate splits into two rays of equal amplitude ($E\sin 45°$ & $E\cos 45°$). When they emerge out of the crystal they will have a path diff. $\lambda/4$. When they combine, they produce circularly polarized light.

(11)



For the detection another nicol prism is adjusted after q.w plate. And Intensity is observed with its rotation. In this case, intensity doesnot change with the rotation which confirms that light wave is either circularly polarized or un-polarized. The two cases may be distinguished by inserting a q-w plate in the path of light before it falls on the analyzer. If the light wave is circularly polarized, it turns into plane polarized light wave which on examining with an analyzer, light will be extinguished twice in one full rotation.

Questions

1) Calculate the thickness of a half wave plate of quartz for a wavelength of 5000 A° ($\mu_E = 1.553$ & $\mu_o = 1.544$)

2) Unpolarized light falls on 2 polarizing sheets placed one on top of the other. What must be the angle b/w the characteristic directions of the sheets if the intensity of the transmitted light is one-third intensity of the incident beam?

3) Plane-polarized light passes through a double refracting crystal of thickness 40 µm and emerges out as circularly polarized light. If the birefringence of the crystal is 0.00004, find the wavelength of the incident light.

4) It is desired to use a plate of glass to obtain polarized light. If the refractive index of glass is 1.5, which what is the polarizing angle?

5) What will be the Brewster angle for a glass slab ($n=1.5$) immersed in water ($n=4/3$).

6) Calculate the thickness of a half wave plate for light of wavelength 580 nm. Principal refractive indices are $n_o = 1.544$ and $n_e = 1.553$

7) Light of intensity I_0 is incident on a polarizer. What is the intensity of the resultant beam if
i) incident light is unpolarised
ii) incident light is plane polarised with its electric field vector making an angle of 30° with the axis of the polarizer

8) Plane-polarized light of wavelength 5400 Å is incident ⊥r on an quartz plate cut with faces ||el to optic axis. Find the thickness of quartz plate which introduces phase diff of 60° b/w e & o rays

9) Plane polarized light is incident on a piece of quartz cut ||el to the axis. Find the least thickness for which the o & e rays combine to form plane polarized light.

10) Calculate the thickness of a double refracting plate capable of producing a path difference $\lambda/6$ b/w e & o waves ($\mu_o = 1.68$, $\mu_e = 1.45$)