UNIT: III
POLARIZATION

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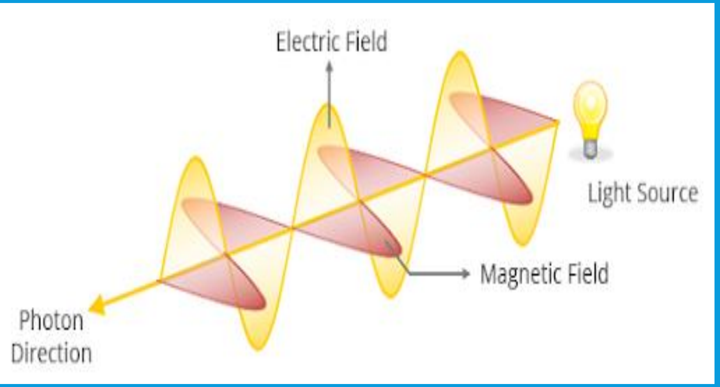
UNPOLARIZED AND POLARIZED LIGHT:

- Light wave is transverse electromagnetic wave made up o ,fluctuating electric and magnetic fields

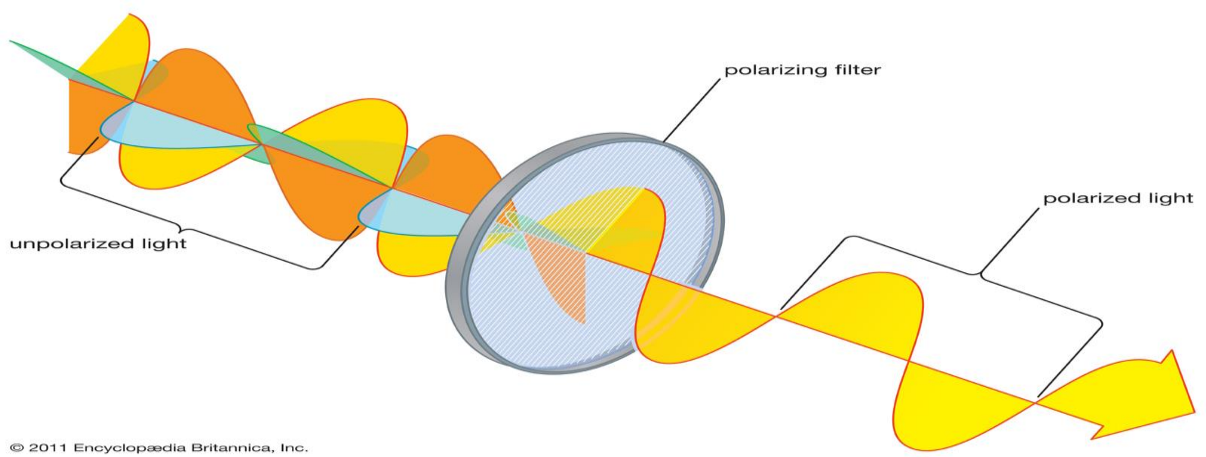


- Natural light is unpolarized

- Polarization of em waves refers to
- Orientation of its electric field vector E
- Unpolarized light: A light wave in which E –vector oscillates in more than one plane
- Examples: Light emitted by the Sun , incandescent lamp or by candle flame

UNPOLARIZED AND POLARIZED LIGHT:

- Polarized light is not produced naturally
- Obtained by using optical elements
- Process of transforming unpolarized light into polarized called Polarization
- Polarized wave is the light wave with definite direction of E- vector(in single plane)
- Polarized light contains waves that only fluctuate in one specific plane



UNPOLARIZED AND POLARIZED LIGHT:

Unpolarized light

- A light wave in which E –vector oscillates in more than one plane
- Symmetrical about ray direction
- Produced by conventional light sources
- May be regarded as resultant of two incoherent waves of equal intensity

Polarized light

- A light wave in which E –vector oscillates in single plane
- Asymmetrical about ray direction
- Obtained from unpolarized light with the help of polarizers

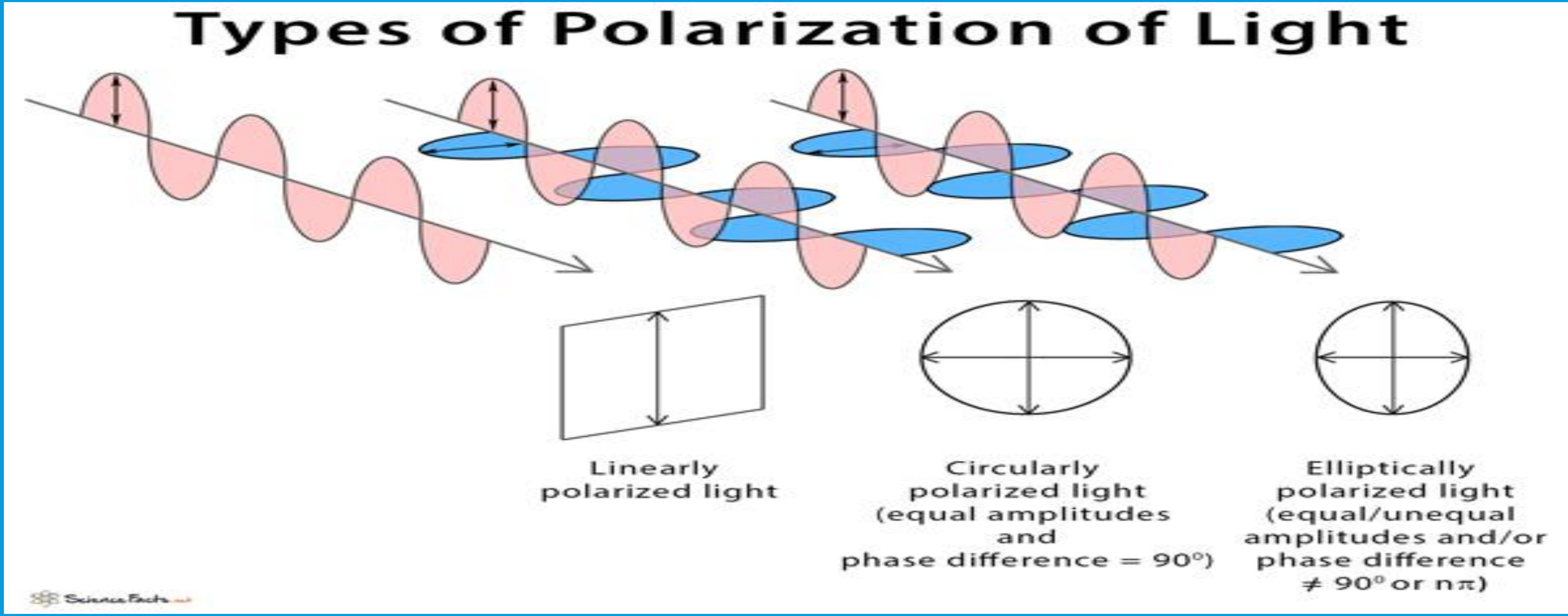
May be regarded as resultant of two mutually perpendicular coherent waves

POLARIZATION OF LIGHT

POLARIZATION OF LIGHT

- Transforming unpolarized light into polarized light
- Restriction of electric field vector E in a particular plane so that vibration occurs in a single plane
- Characteristic of transverse wave
- Longitudinal waves can't be polarized; direction of their oscillation is along the direction of propagation

TYPES OF POLARIZATION:



PRODUCTION OF PLANE POLARIZED LIGHT:

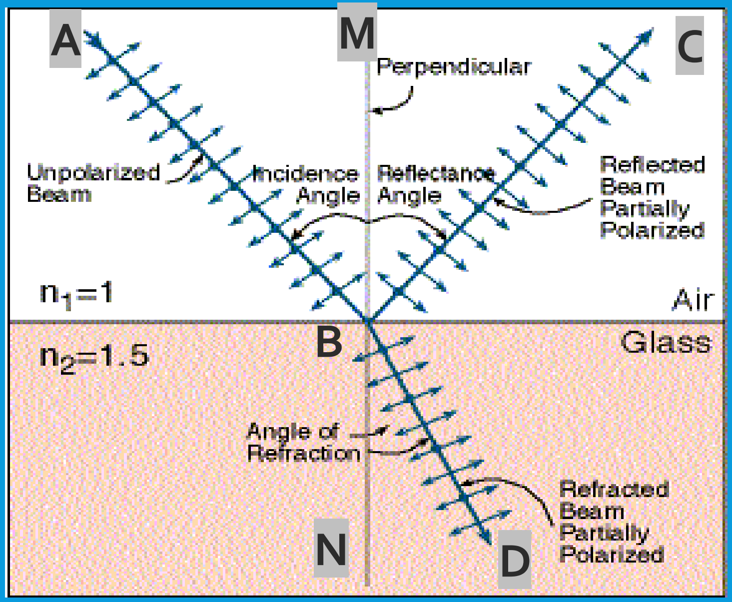
- Methods :
- 1. Polarization by Reflection
- 2. Polarization by Refraction
- 3. Polarization by Scattering
- 4. Polarization by Selective Absorption (Dichorism)
- 5. Polarization by Double Refraction

PRODUCTION OF PLANE POLARIZED LIGHT BY REFLECTION:

- Discovered by E.L.Malus in 1808
- Noticed when natural light is incident on smooth surface , at certain angle the reflected beam is plane polarized.
- The extent of polarization occurs depends on
- 1. Angle at which light incident on the surface
- 2. Nature of material
- Metallic surfaces reflects light with variety of vibrational direction (Unpolarized)
- Light reflected from dielectric surffaces such as water is plane polarized

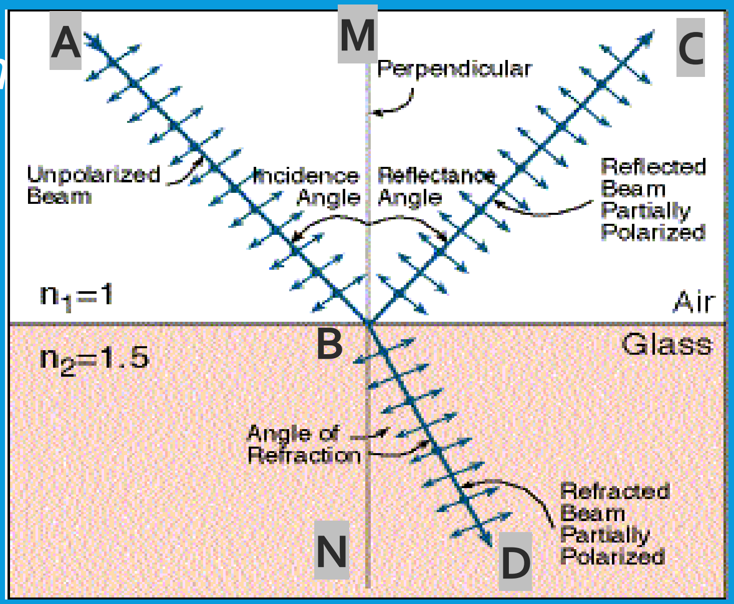
PRODUCTION OF PLANE POLARIZED LIGHT BY REFLECTION:

- If extent of plane polarization is large, receives Glare
- When light wave incident on boundary between two dielectric material, part of it is reflected and a part is transmitted
- From fig. AB is unpolarized beam of light
- AB and normal MBN define plane of incidence
- Electric vector E - of ray AB resolve two components
- 1. one perpendicular to plane of incidence
- 2. other lying in the plane of incidence



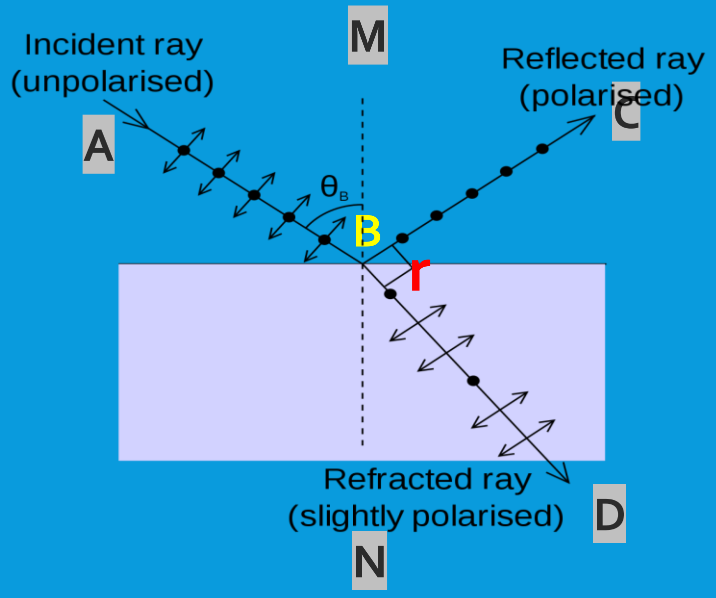
PRODUCTION OF PLANE POLARIZED LIGHT BY REFLECTION:

- Perpendicular represented by (.) **dot** called *s-components*
- Parallel components represented by ⟷ **arrow** called *p-components*
- In the case of unpolarized light both components are equal magnitude
- At particular angle θ_B reflection beam not contain *p-componen*
- It contains only s- components and totally plane polarized
- Angle θ_B is called **polarizing angle** or **Brewster's angle**



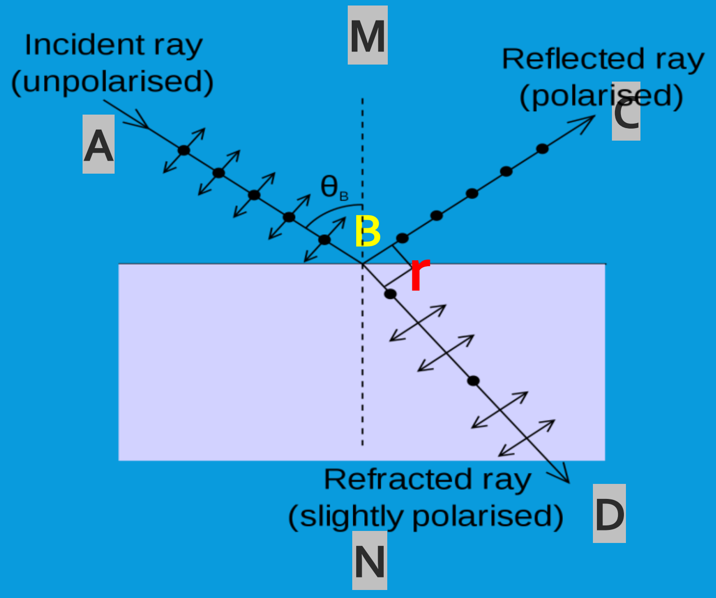
BREWSTER'S LAW:

- Brewster performed series of experiments on polarization by reflection on number of surfaces
- Found polarizing angle depends on RI of medium
- **Statement:** The tangent of angle at which polarization is
- obtained by reflection is numerically equal to RI of medium
- $\mu = tan\theta_B$ ---(1)
- When natural light is incidence on smooth surface at polarizing angle ,reflected along BC and refracted along BD
- Maximum polarization of reflected ray occurs when right angle to refracted ray i.e. $\theta_B + \mathrm{r} = 900$

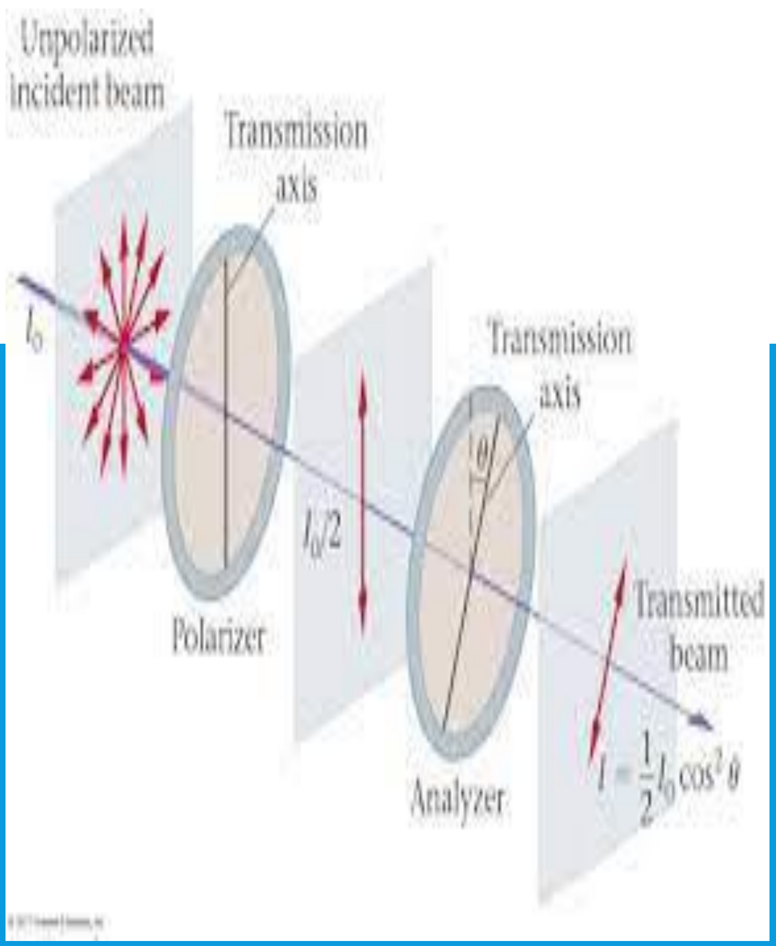


BREWSTER'S LAW:

- $\theta_B + \text{r} = 900$
- $\therefore \quad r = 900 - \theta_B$
- From Snells law $\frac{\sin\theta_B}{\sin r} = \frac{\mu_2}{\mu_1}$ ---(2)
- μ_2 -absolute RI of reflecting surface and μ_1 -RI of surrounding
- From 1 and 2
- $\frac{\sin\theta_B}{\sin(90^0 - \theta_B)} = \frac{\mu_2}{\mu_1}$
- $\frac{\sin\theta_B}{Cos\theta_B} = \frac{\mu_2}{\mu_1}$
- $\tan\theta_B = \frac{\mu_2}{\mu_1}$

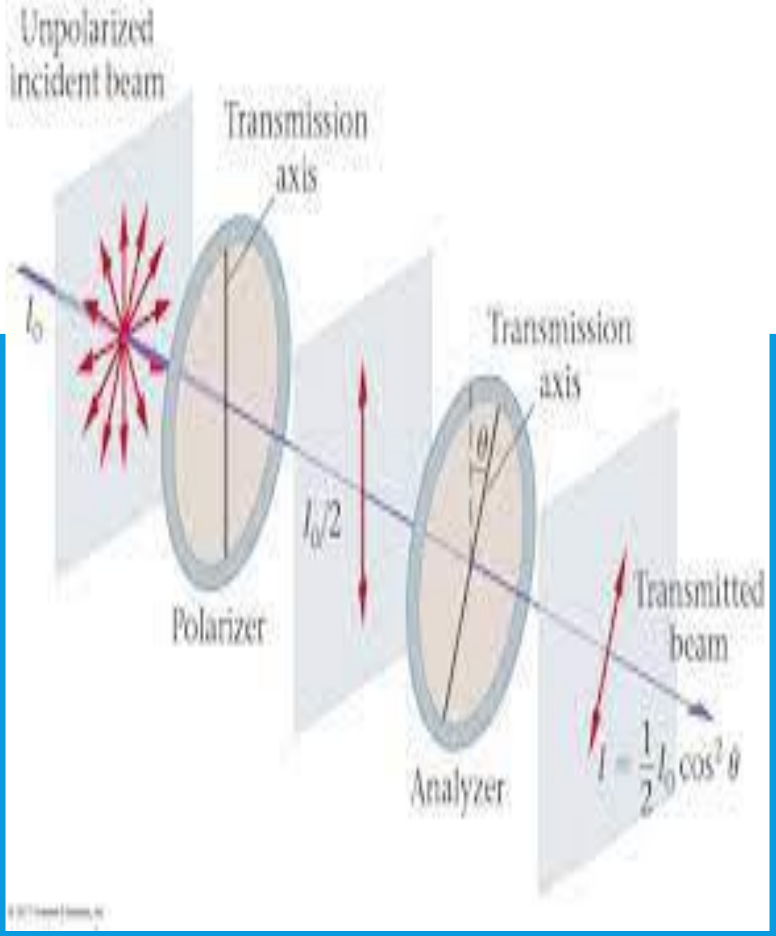


MALU'S LAW



- **Statement:** Intensity of polarized light transmitted through polarizer is proportional to square of cosine of angle between plane of polarization of light and transmission axis of the polarizer
- If unpolarized light of intensity I_O is incident on polarizer
- Plane polarized light of intensity $I_0/2=I_1$ is transmitted
- This light passes through analyser
- Intensity of light transmitted through analyser is
- $I = E_1^2 cos^2\theta = I_1\ cos^2\theta = \frac{1}{2} I_0\ cos^2\theta$
-

MALU'S LAW



- $I = E_1^2 cos^2\theta = I_1\, cos^2\theta = \frac{1}{2} I_0\, cos^2\theta$
- Light transmitted through analyzer at specific settings are
- Case 1: If θ is 0° Axes are parallel $I = I_1 = \frac{1}{2} I_0$
- Case 2: If $\theta = 90^0$ Axes perpendicular $I = 0$
- Case 3: If θ=180° Axes are parallel $I = I_1 = \frac{1}{2} I_0$
- Case 4: If $\theta = 270^0$ Axes perpendicular $I = 0$
- Two positions of maximum intensity and
- Two positions of Zero intensity
-

ANISOTROPIC CRYSTALS:

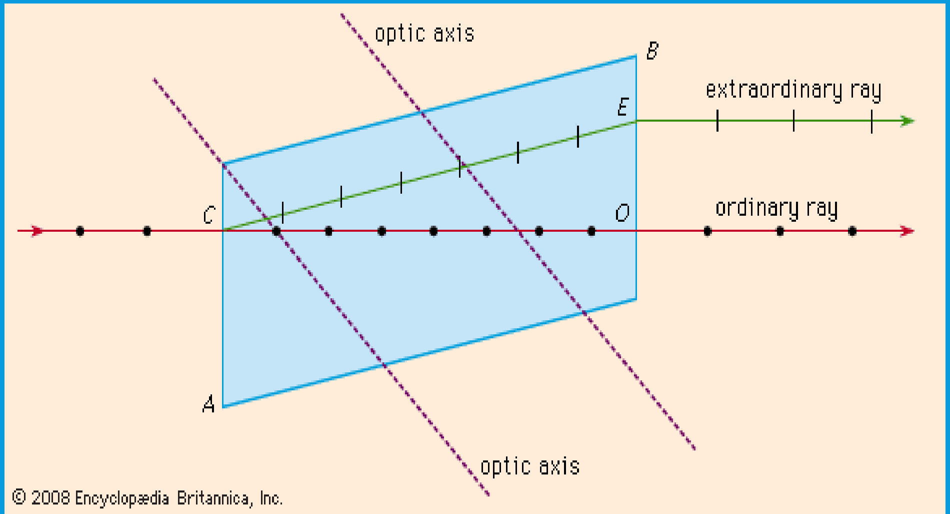
- Isotropic crystals: Atoms are arranged in a regular periodic manner
- Refract single ray
- Index of refraction is same in all direction
- Examples : Water , glass , air
- Anisotropic crystals: Arrangements of atoms are different directions within crystals
- Physical properties varies with direction
- Index of refraction is different directions
- Anisotropic crystals are divided into two classes
- Uniaxial and Biaxial

ANISOTROPIC CRYSTALS:

- Uniaxial crystals : One of refracted rays is ordinary and other extraordinary
- Examples : Calcite, tourmaline and quartz
- Biaxial crystals: Both refracted rays are extraordinary rays
- Examples: mica, topaz and aragonite

DOUBLE REFRACTION:

- When ray of light incident on face of calcite, split into two rays o- rays (fast) and e-rays(slow)
- O rays does not deviates in crystal, e rays refracted at some angle
- As opposite faces of crystal are parallel, emergent rays are parallel to incident
- Within the crystal o-rays lies in plane of incidence e-ray does not
- Velocity of propagation of o-ray is same in all directions whereas e-ray changes with direction
- O-rays obeys laws of refraction e –ray not
- Both are plane polarized.

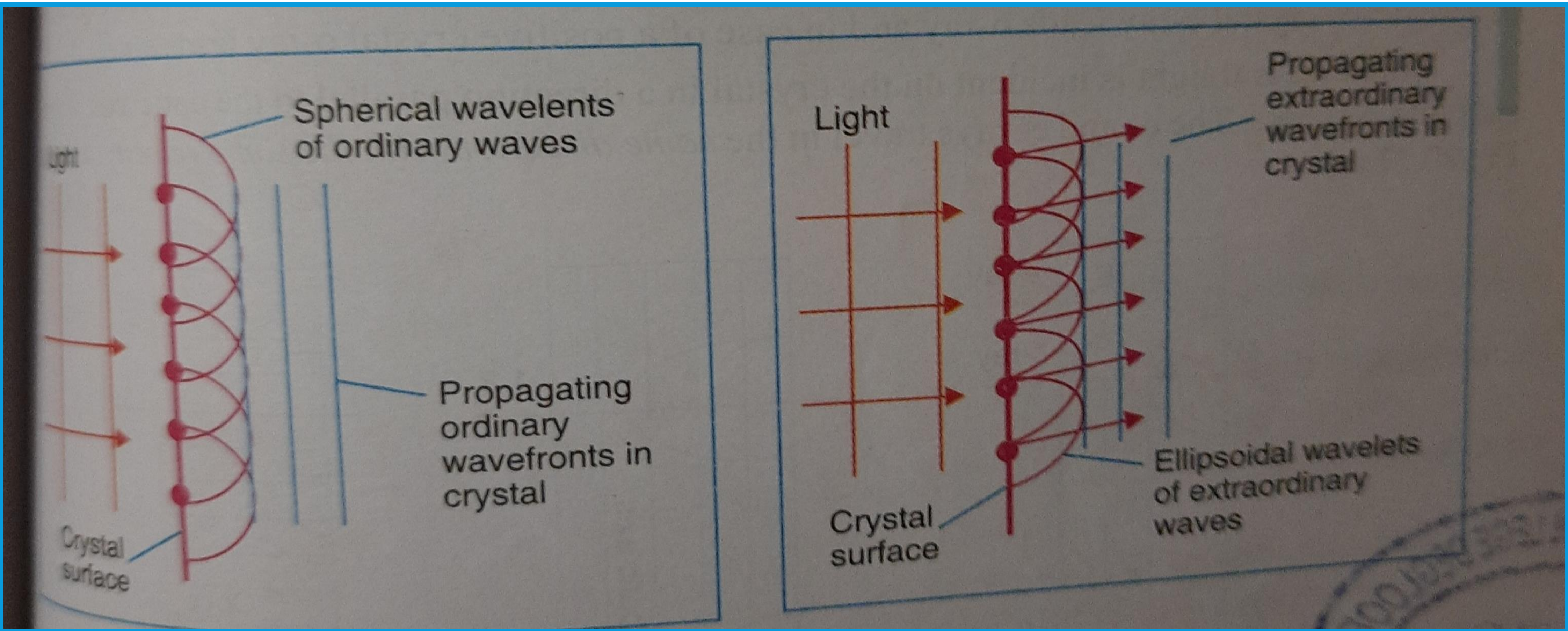


DOUBLE REFRACTION:

Huygen's theory of double refraction in uniaxial crystals

1. The incident wave disturb all the points on the face of the crystal on which it is incident. Thus every point on the surface originates the two wave fronts, one the ordinary and other the extraordinary.
2. Shape of the wave front corresponding to the ordinary wavelets is spherical because of the constant velocity of O-ray in all directions.
3. Shape of the wave front corresponding to the extraordinary wavelets is ellipsoidal because E-ray has different velocities in all directions.
4. The direction of line joining these two wave fronts i.e., sphere and ellipsoidal is the optic axis.

HUYGEN'S EXPLANATION OFDOUBLE REFRACTION:



NICOL PRISM:

CONSTRUCTION:

Polarizing device fabricated from double refracting crystal

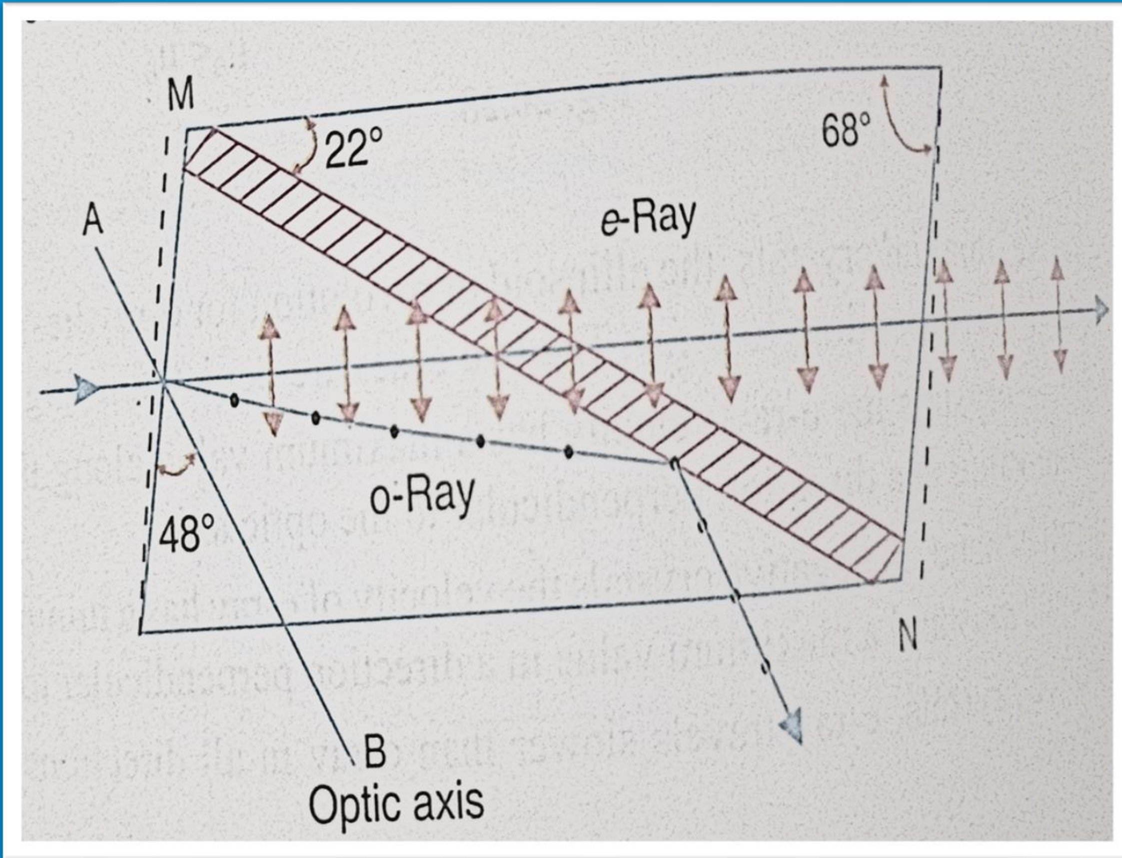
Made up from calcite crystal

A rhomb of calcite crystal 3 times longer than thickness

Ends of rhombohedron ground until make angle of 68° instead 71° with longitudinal edge

Piece cut into two along plane perpendicular to principal axis

Two parts of crystal cemented together with **Canada balsam**



NICOL PRISM:

RI of Canada balsam lies between RI of o-ray and e-ray

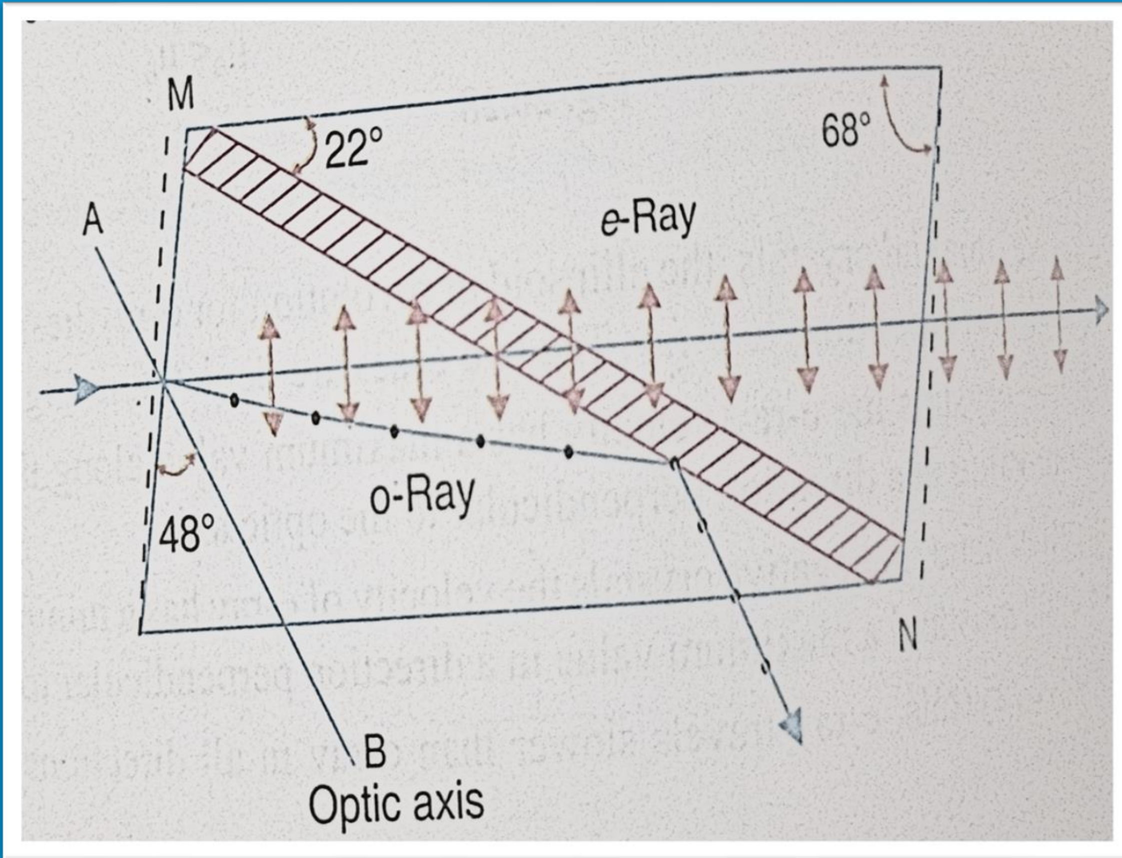
μ_o=1.66 μ_e=1.486 $\mu_{Canada\ balasm}$=1.55

RI of e –ray depends on direction of propagation in crystal

Difference in RI of o ray and e ray increases with angle between the two rays in crystal

When angle between two rays is 90° ,the difference is maximum

For fixed μ_o the μ_e has its maximum or minimum



NICOL PRISM:

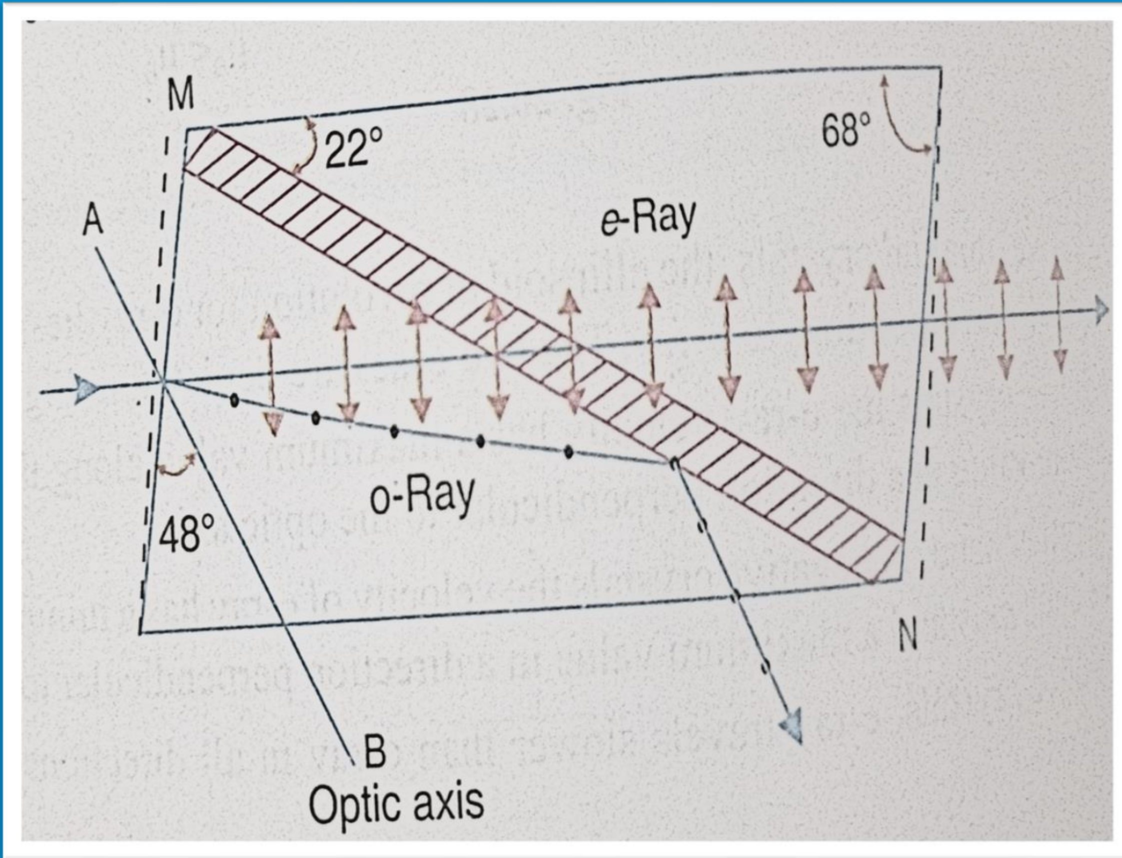
WORKING:

When unpolarized light fall on crystal at about 15⁰ ,after entering crystal suffers double refraction and split up into o rays and e rays.

RI and angle of incidence at Canada balsam such that e-ray transmitted and o ray internally reflected .

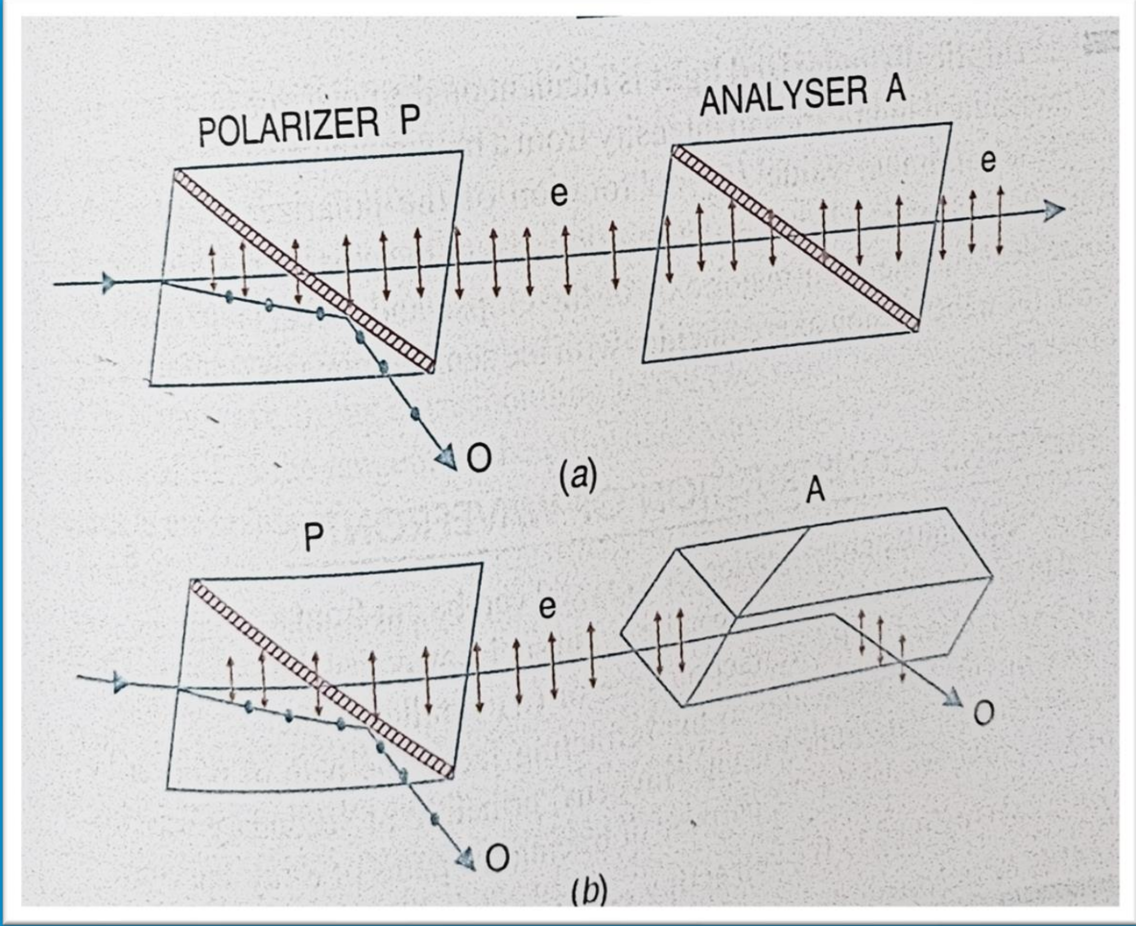
At outage, o-ray blackened and e- ray is plane polarized out of Nicol prism

Nico prism as polarizer



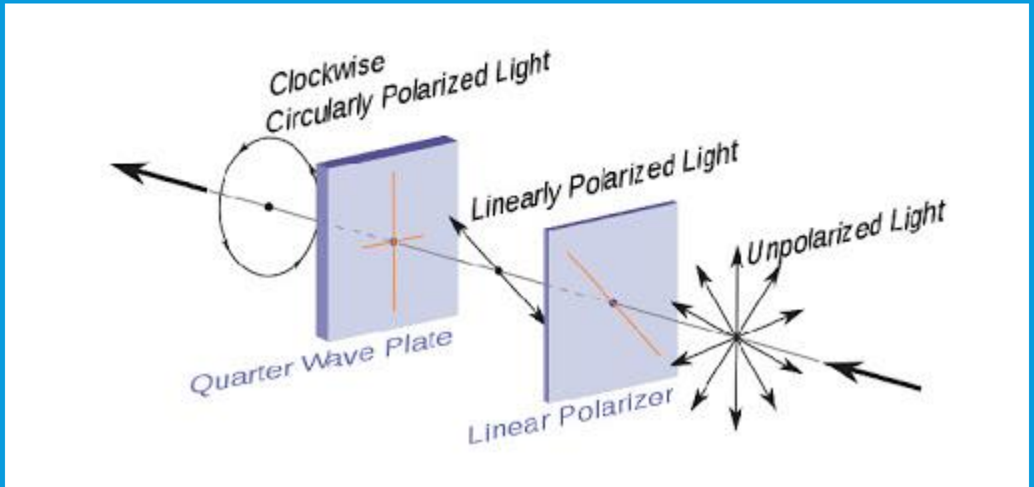
NICOL PRISM AS POLARIZER AND ANALYZER :

Nicol prism can be worked as Polarizer as well as analyzer
When unpolarized light is incidence on P , linearly polarized e- ray emerges from P with vibrations lying in principal section of P
Now incidence on second Nicol prism A whose principal section is parallel to P
Transmitted unhindered through A
When A is gradually rotated intensity gradually decreases and when principal section becomes perpendicular to P , no light is transmitted



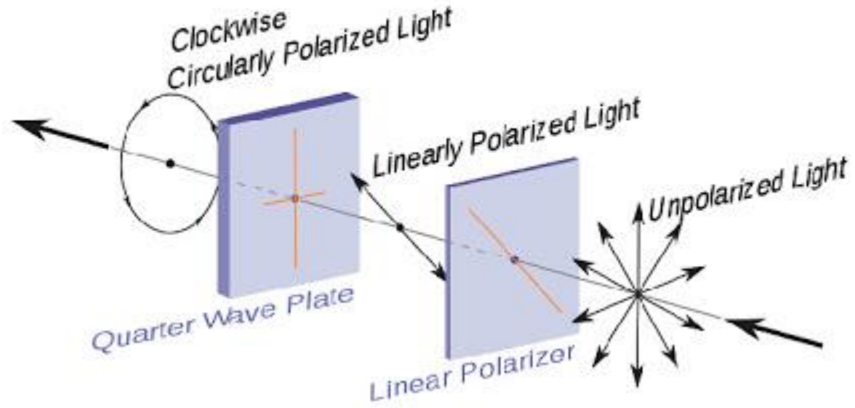
RETARDERS :

Retarders : Uniform plate of birefringent material
Optic axis lies in plane of plate
Retarders are : Quarter wave plate, Half wave plate and full wave plate
Divide incident wave two polarized waves travels perpendicular to plate with different speeds
Phase retardation is introduced by crossing thickness d of plate
Used to produce circularly or elliptically polarized light



RETARDERS (QUARTER WAVE PLATE)

Quarter wave Plate: Birefringent crystal
Optic axis parallel to refracting face
Thickness adjusted to introduce quarter wave path difference ($\lambda/4$) (Phase difference 90°) between o and e rays
When plane polarized light is incident on negative birefringent crystal ,wave spilits into o and e rays
Two waves travels along same direction with different velocities
Emergent rays optical PD of ($\lambda/4$)
Used for producing elliptically and circularly

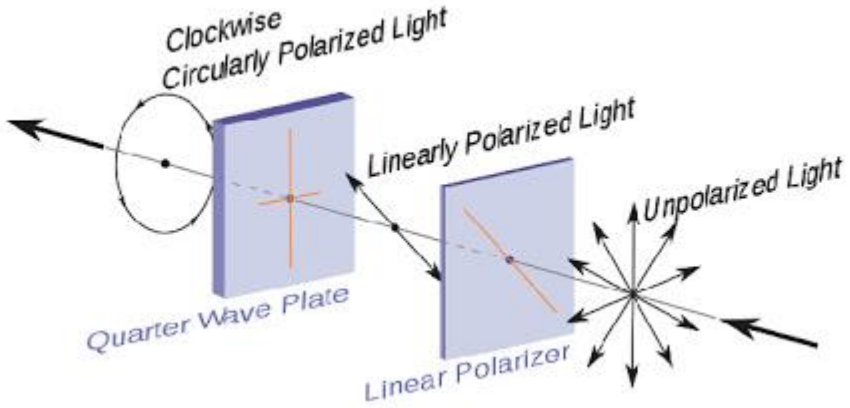


$$(\mu_0 - \mu_e)d = (\lambda/4)$$

$$d = \frac{\lambda}{4(\mu_0 - \mu_e)}$$

RETARDERS (HALF WAVE PLATE)

Quarter wave Plate: Birefringent crystal
Optic axis parallel to refracting face
Thickness adjusted to introduce quarter wave path difference ($\lambda/2$) (Phase difference 180^{0}) between o and e rays
When plane polarized light is incident on negative birefringent crystal ,wave spilits into o and e rays
Two waves travels along same direction with different velocities
Emergent rays optical PD of ($\lambda/2$)
Used for producing elliptically and circularly polarized

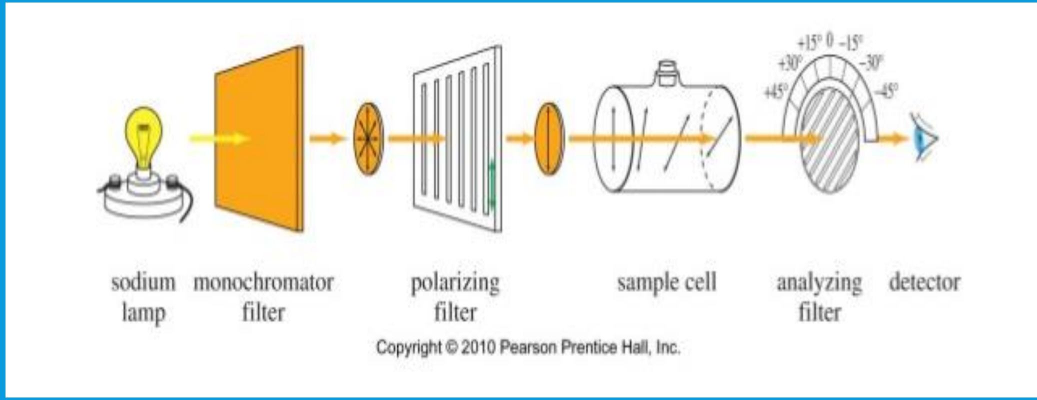


$$(\mu_0 - \mu_e)d = (\lambda/2)$$

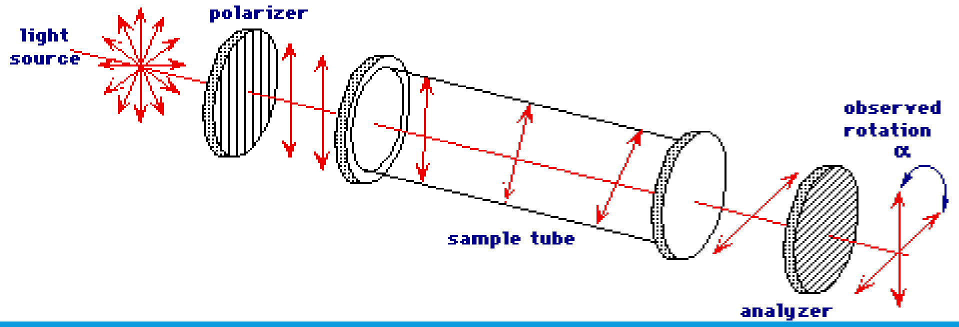
$$d = \frac{\lambda}{2(\mu_0 - \mu_e)}$$

OPTICAL ACTIVITY:

Natural ability to rotate plane of polarization about direction of polarization
Due to twisted arrangement of atomic layers wtr one another
In liq. And solution due to certain structural symmetry in molecules
Found un bigger organic molecules



OPTICAL ROTATION:



When beam of plane polarized light propagate through quartz crystal along optic axis , plane of polarization turns about direction of beam

Ability to rotate plane of polarization of plane polarized by certain substances called optical activity

Substances called optically active substances

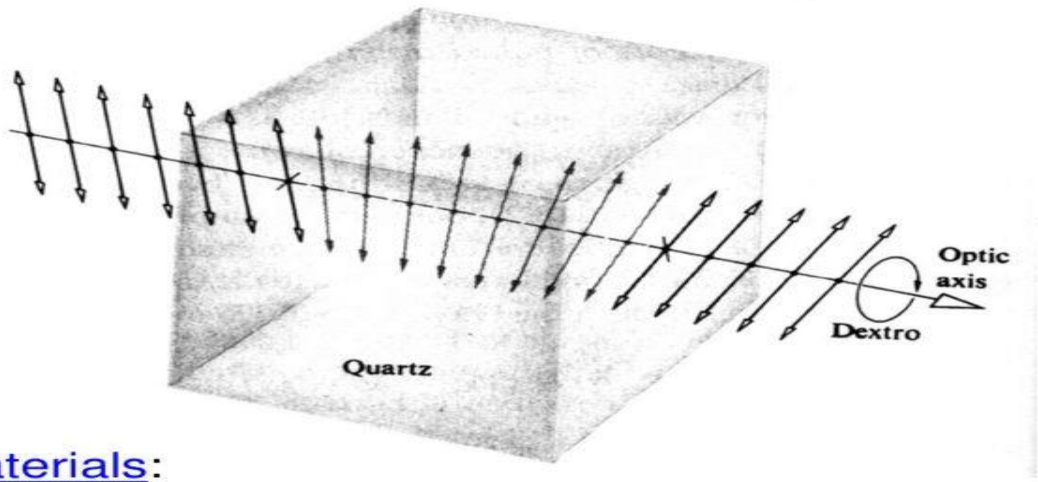
Quartz ,Cinnabar are examples of optically active crystals

Solutions of sugar , tartaric acid

OPTICAL ROTATION:

Optical Activity

Linearly polarized light when incident on an optically active material will emerge as a linearly polarized light but with its direction of vibration rotated from the original.



Viewing beam head-on:

clockwise rotation
(*dextrorotatory; right-handed*)

anti-clockwise rotation
(*levorotatory; left-handed*)

Examples of optically active materials:

solids (quartz, sugar crystals)

liquids (turpentine, sugar solution)

SPECIFIC ROTATION:

Specific Rotation for given wavelength of light at a given temperature is defined as rotation produced by one decimeter long column of solution containing 1 gm of optically active material per c.c. of solution

$$[S]_{\lambda,t} = \frac{\theta}{l\ c} = \frac{Rotation\ in\ degree}{length\ in\ decimeter\ x\ conc.in\ gm/cc}$$

If optically active material is between two crossed polarizers , field of view becomes bright, to make dark analyser rotated through angle

Depends upon

Thickness of substance

Density of material

Wavelength of light

Temperature

SPECIFIC ROTATION:

Amount of rotation θ caused by crystline material is

$\theta = \alpha l$

α is rotational constant

Amount of rotation

$\theta = s\ c\ l$

c is concentration and s is specific rotation

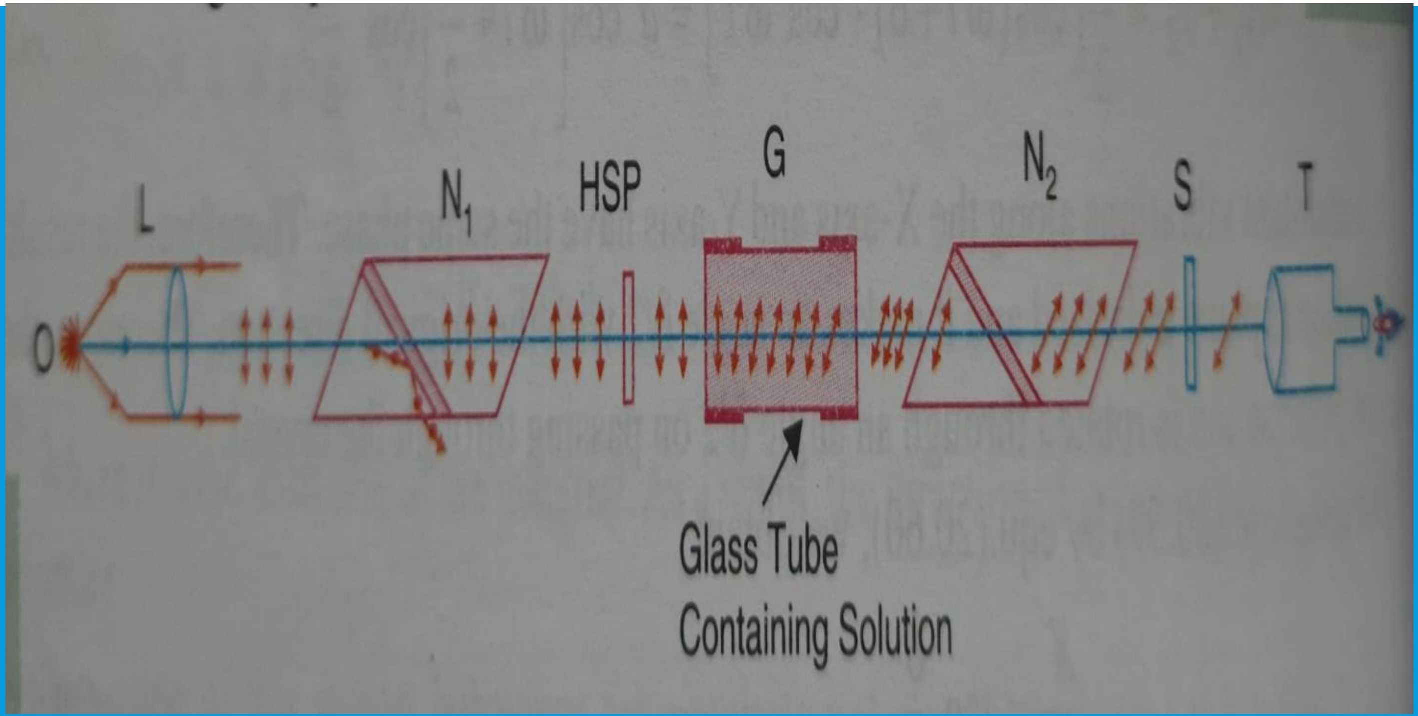
LAURENT'S HALF SHADE POLARIMETER:

Polarimeter is optical instrument used for determining optical activity

When used for determining optical solution of sugar called saccharimeter

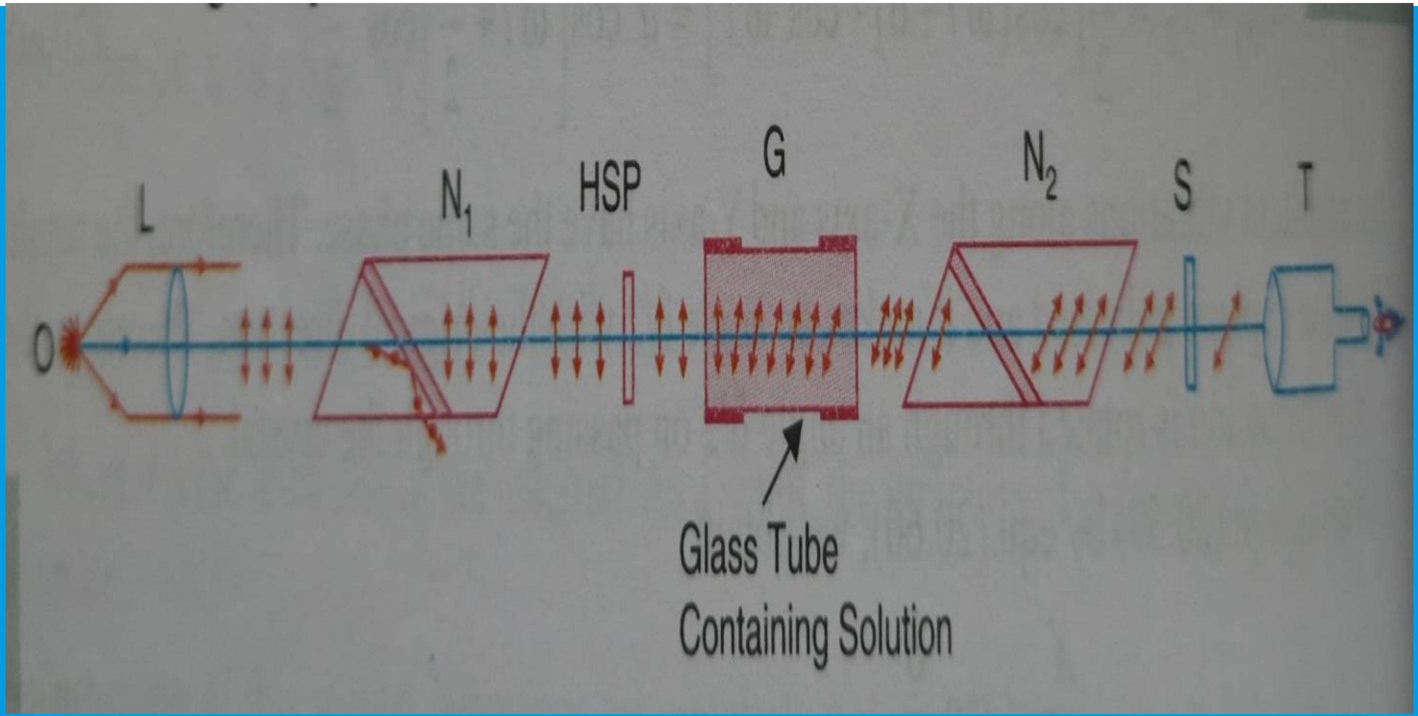
Construction: **G-** Glass tube for holding solution between crossed Nicol Prisms

HSP – half shade plate – accurately adjusting two Nicols for crossed position



LAURENT'S HALF SHADE POLARIMETER:

L –lens
Light transmitted by polarizer is plane polarized
Passes through HSP and G
Emerging light incident on analyzer N2
Light observed through Telescope
N2 can be rotated about axis of tube
Rotation can be measured with the help of circular scale



LAURENT'S HALF SHADE POLARIMETER:

Working:
Analyzer first adjusted such that field of view is completely dark
Glass field with solution
Field of view becomes illuminated
Field of view again made dark by rotating analyzer through certain angle with optical axis