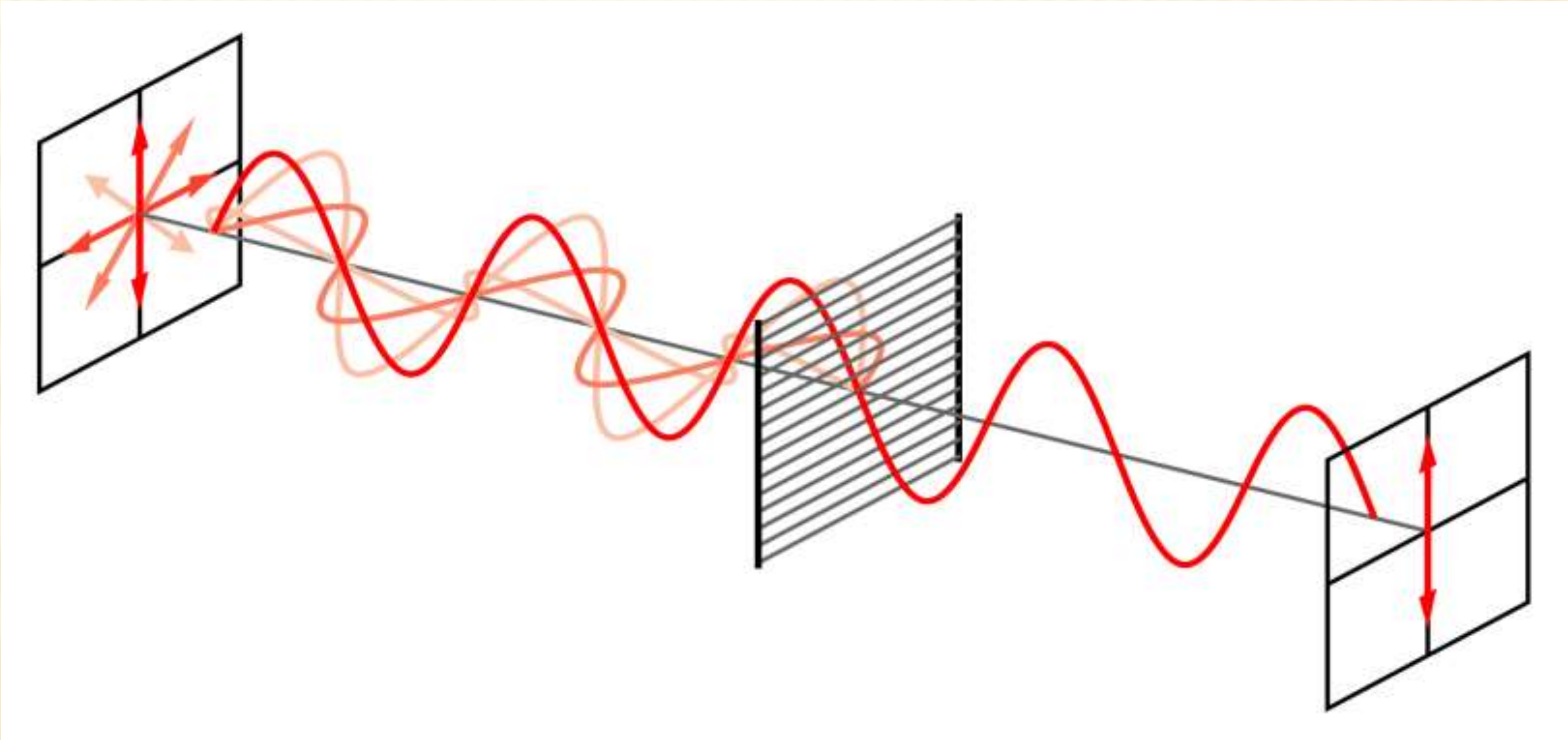
E-Content On Polarization
For B.Sc Third Semester

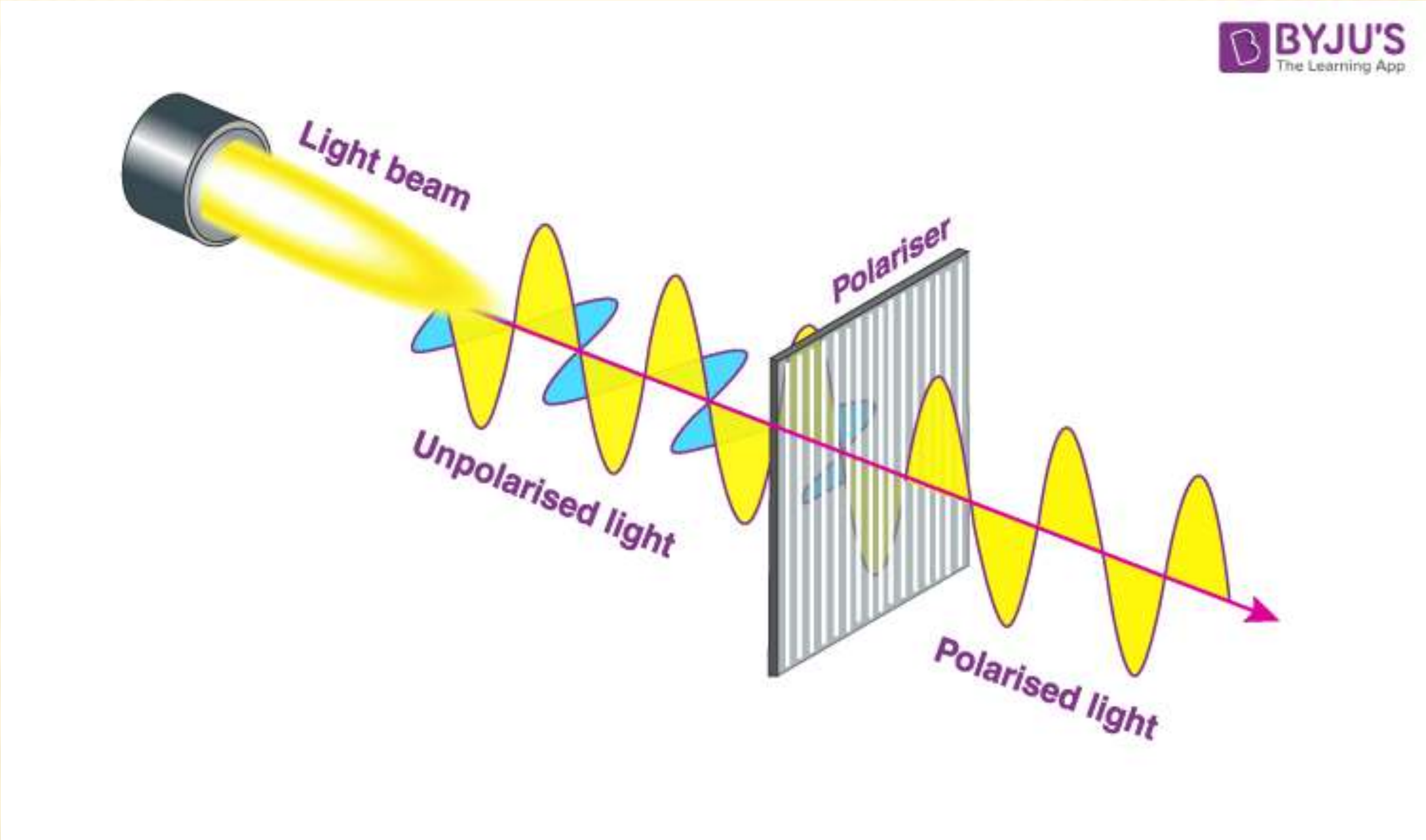
Created By : Pooja Tyagi
C. L. Jain College, Firozabad



What is Polarisation?

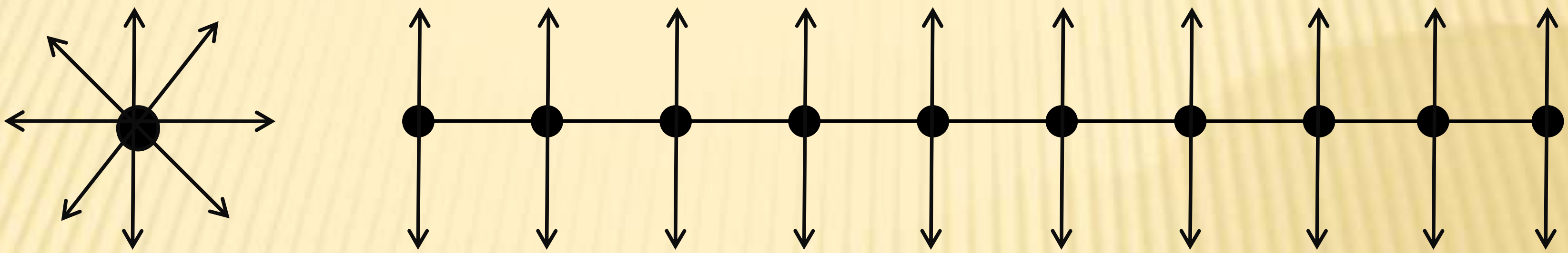
- Interference and Diffraction tell that the light is a form of wave.
- The above phenomenon does not tell about the nature of wave.
- Polarization gives the answer to this question.
- It showed that light is definitely transverse in nature.
- Light is electromagnetic in nature.
- Electric and magnetic vector are perpendicular to each other and also to the direction of propagation.
- This wave need more than one plane to travel in space and called unpolarized light.
- Eg: Light emitted by Sun, Tube or lamp
- If the wave need only one plane to travel it is called Polarized wave and the phenomenon is called Polarization.

Polarization Of Light beam



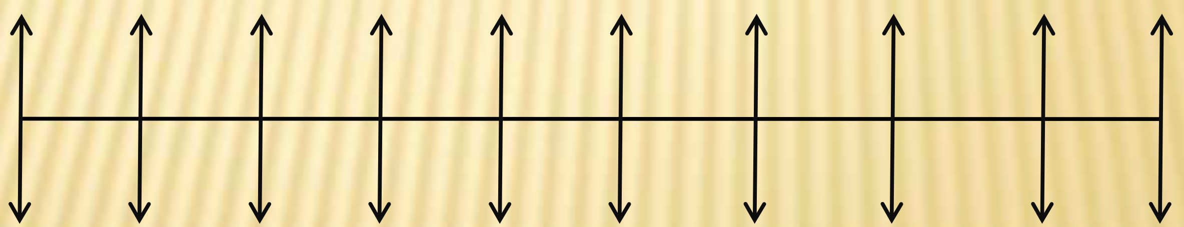
Unpolarized Light

Ordinary light from a source is called unpolarized light. It consists of a very large number of wavelengths and vibrations in all possible planes .



Plane Polarized Light

Plane Polarized light may be defined as the light in which the light vector (electric vector) vibrates along a fixed straight line in a plane perpendicular to the direction of propagation.

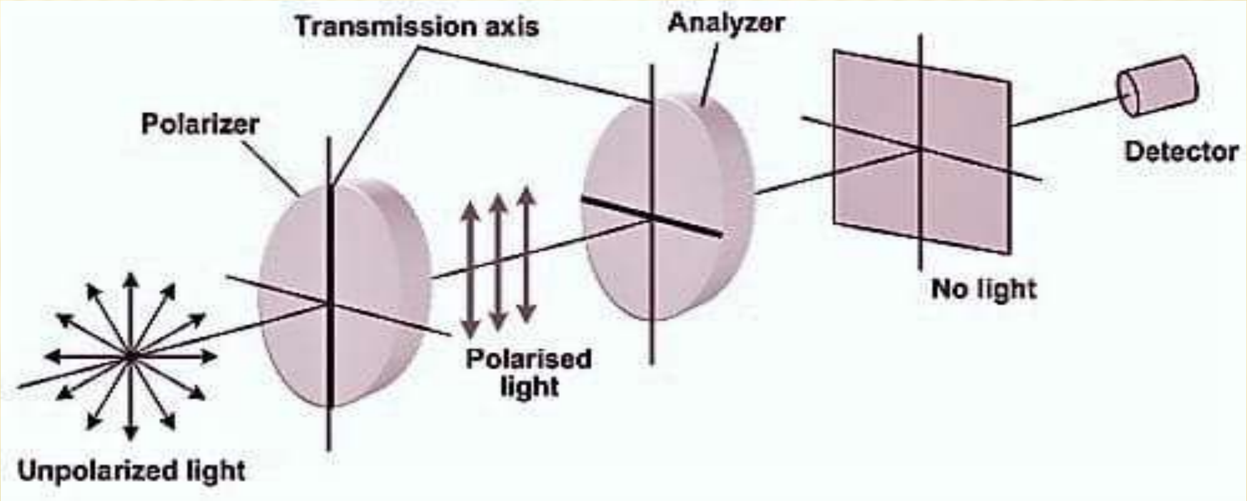


Plane polarised vibrations parallel to the plane of paper

Plane polarised vibrations perpendicular to the plane of paper

Polariser And Analyser

Polariser and Analyser are a type of optical instruments that use plane polarised light. A polarizer can filter light waves in order to generate polarization of light. In other words, a polarizer can generate plane polarized light from light waves coming from a normal light source. The analyzer acts as a second polarizer. Polarizers and analyzers are used in polarized light microscopy. Although both polarizers and analyzers are used as light filters, there are differences in their applications. The main difference between polarizer and analyzer is that polarizer produces plane polarized light whereas analyzer can be used to check whether the light has been polarized or not.



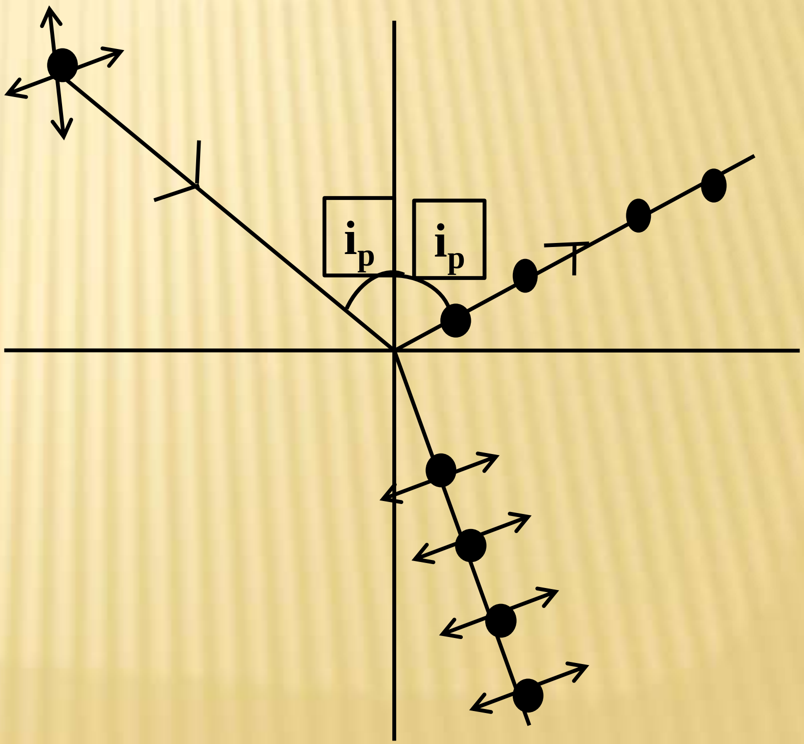
Source: https://qsstudy.com/polarizer-and-analyzer/

Methods Of Producing Plane Polarised light

- By Reflection
- By Refraction
- By Double Refraction
- By selective absorption by crystal (polaroids)

Polarisation By Reflection

When ordinary light is incident on a transparent medium , reflected and refracted rays becomes partially plane polarised and for a particular angle of incidence (angle of polarisation $\mathbf{i_p}$) the reflected ray becomes plane polarised with vibrations perpendicular to the plane of incidence.



Brewster's Law

Brewster found that if angle of incidence is equal to angle of polarisation , the angle between refracted and reflected ray is $\pi/2$. This observation shows that tangent of angle of polarization i_p is numerically equal to the refractive index μ of the reflecting medium. This is called Brewster's Law.

$\mu = \tan i_p$

$$\mu = \frac{\sin ip}{\cos ip}$$

Also from Snell's law

$$\mu = \frac{\sin ip}{\sin r}$$

From above two equations

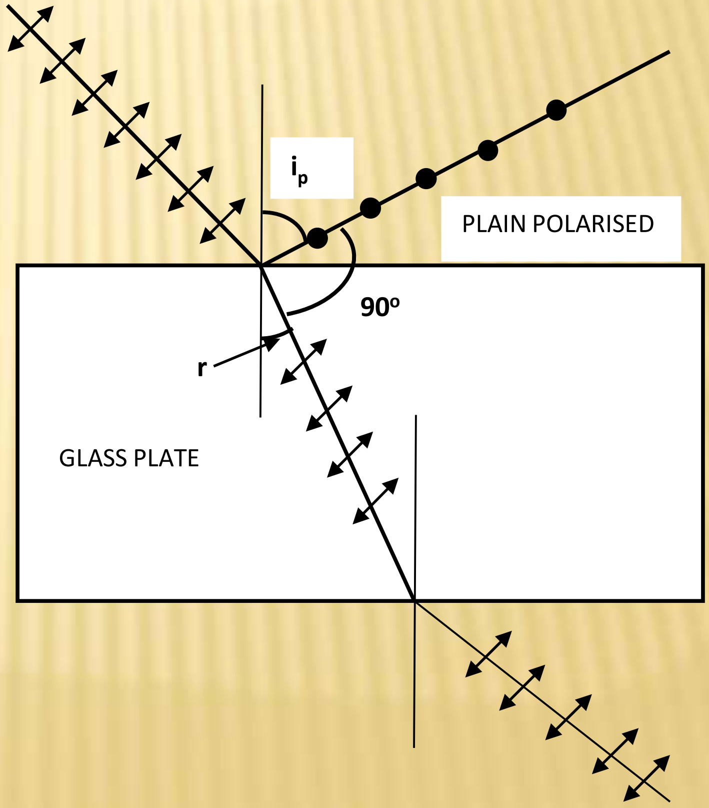
$$\frac{\sin ip}{\cos ip} = \frac{\sin ip}{\sin r}$$

$$\sin(\pi/2 - i_p) = \sin r$$

$$\pi/2 - i_p = r$$

$$i_p + r = \pi/2$$

i.e at polarizing angle the reflected ray is at right angle to the refracted ray.



Law Of Malus

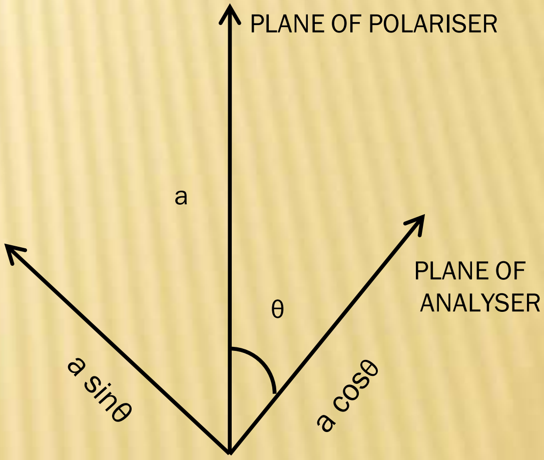
When a completely plane polarised light beam is incident on an analyser, the intensity of the emergent light varies as the square of the cosine of the angle between the planes of transmission of the analyser and polariser . This is known as law of Malus. It holds when the light incident on the analyser is completely plane polarized.

The parallel component a cosθ is transmitted by the analyser and the perpendicular component a sinθ is reflected. So the intensity of transmitted light through the analyser $I_\theta = (a \cos\theta)^2 = a^2 \cos^2\theta = I_0 \cos^2\theta$

Where I_0 is the intensity of the plane polarized light incident on the analyser.

If $\theta = 0$ implies $I_\theta = I_0$ i.e Intenity of emergent light is maximum when plane of polariser and analyser are parallel.

If $\theta = \square/2$ implies $I_\theta = 0$ i.e Intensity will be minimum when plane of polarizer and analyser are at right angle to each other.

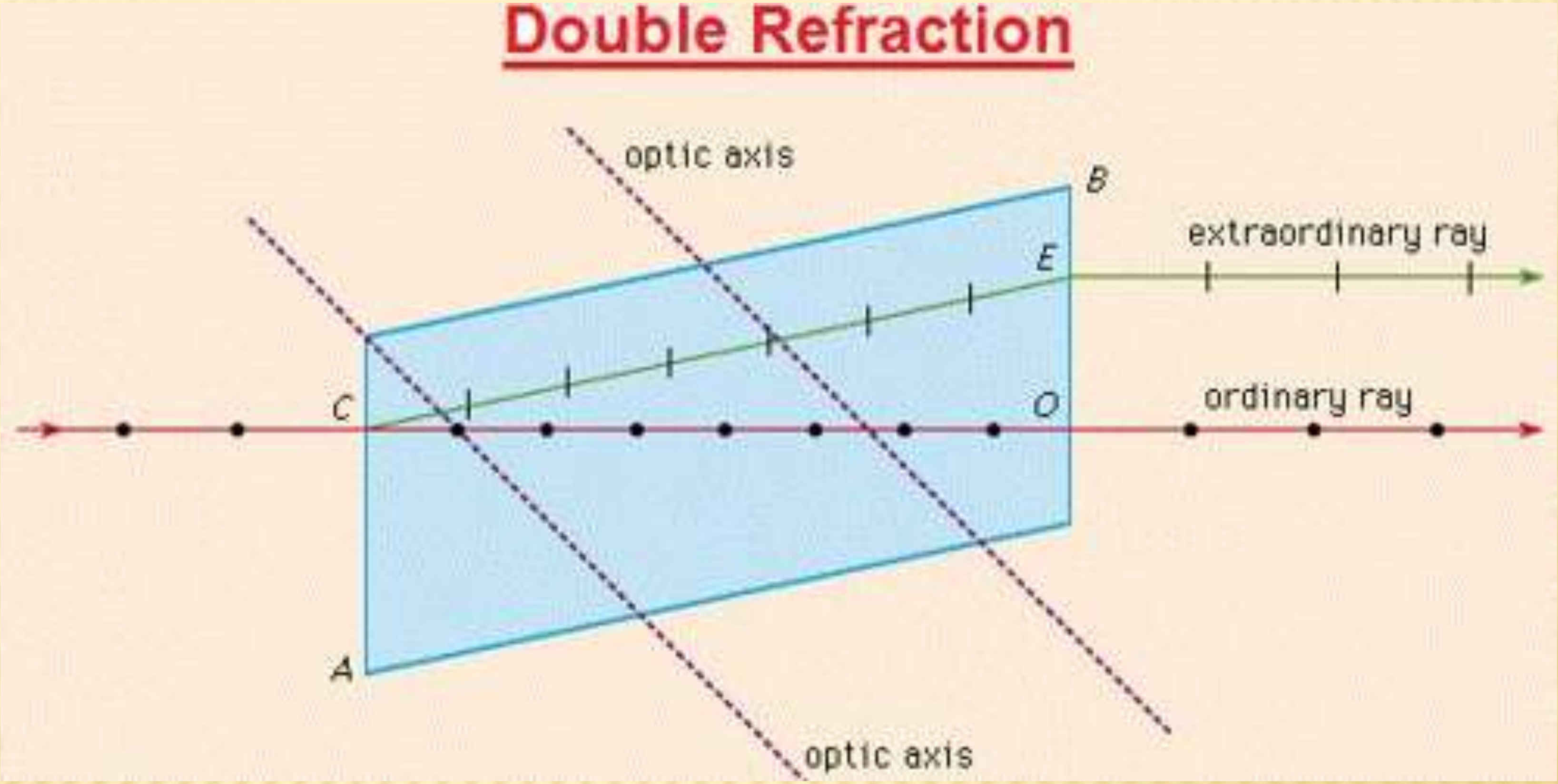


Double Refraction OR Birefringence

Huygens discovered that when a single ray of unpolarised light enter into an anisotropic medium, it splits into two rays. Each of these rays travel in different direction. This phenomenon is called double refraction or birefringence and the crystal showing this optical property are called doubly refracting crystals or birefringent crystals. The crystal of calcite, quartz demonstrate this phenomenon.

The two refracted rays are -

1. **Ordinary Ray-** Obeys the laws of refraction i.e the incident ray, normal and refracted ray are in same plane and ray has same speed in different direction. It passes undeviated through the crystal. Gives spherical wave front (not polarised). Denoted by O-ray.
2. **Extraordinary Ray-** Does not follow the laws of refraction i.e incident ray, normal and refracted ray are not in same plane and has different speed in different directions. It deviated after refraction. Gives ellipsoidal wave front (plane polarised). Denoted by E-ray.



The optic axis of a crystal is the direction that the light propagates through the crystal without facing double refraction. All the light waves that are parallel to this axis do not undergo double refraction.

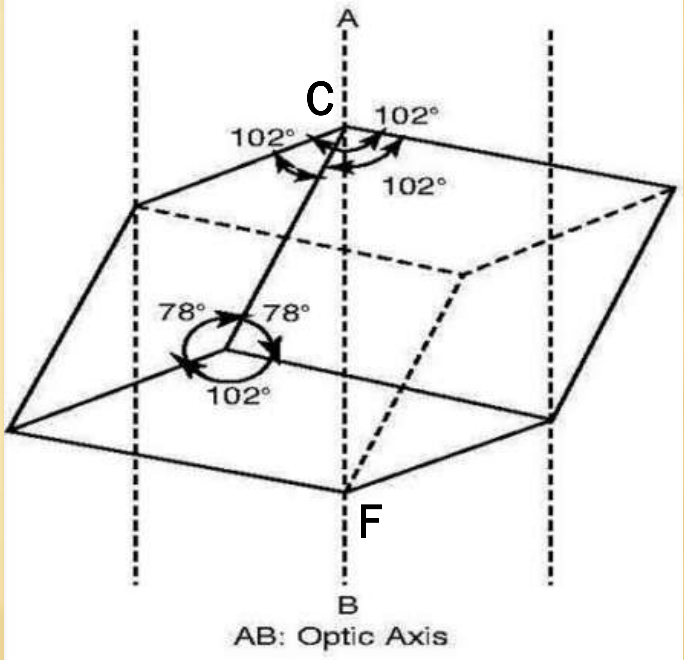
Source: https://qsstudy.com/double-refraction/

Two types of Doubly refracting crystals

1. **Uniaxial Cryatals** – These types of cryatals have only one such direction along which the incident ray is not split in two rays (having one optic axis). One O-ray and one E-ray is obtained after double refraction. Eg- Calcite and Quartz etc. Used in waveplates, polarizers, retardation plates
2. **Biaxial Cryatals** – These types of cryatals have two such directions along which the incident ray is not split in two rays (having two optic axis). Two E-rays and one O-ray are obtained after double refraction. Eg- Topaz, Aragonite etc. Used in optical filters, polarizing beam splitters etc.

Geometry of Calcite Crystals

- Chemically Calcite is colourless transparent substance. Its chemical formula is $CaCO_3$.
- It is transparent to visible as well as ultravoilet light.
- It can be reduced to a rhombohedron by cleavage or breakage.
- All the six faces of this rhombohedron are parallelograms having angles of 78^o (sayα) and 102^o (say β) nearly.
- Each of the face is having two α angle and two β angle.
- So in a calcite crystal there are 12 α angle and 12 β angles.
- At the two diametrically opposite corners C and F , the three angles of faces meeting their are all obtuse.
- The corners C and F are called blunt corners.
- One angle is obtuse and other two are acute at remaining four corners.

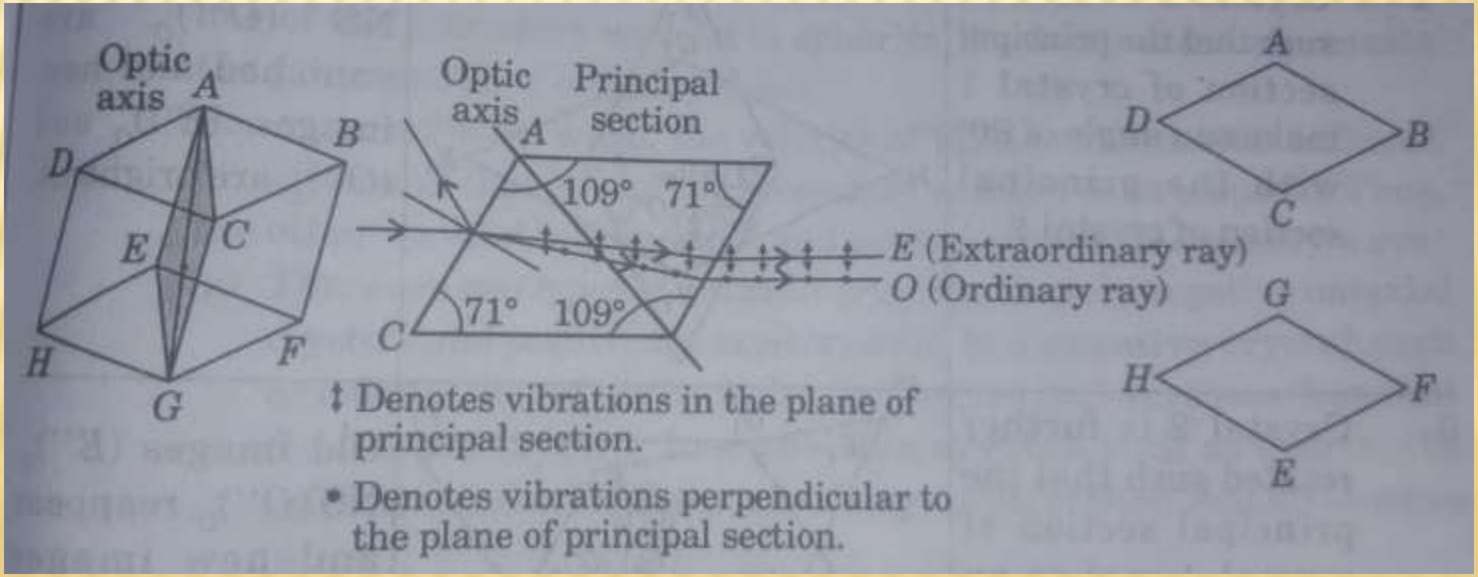


There are three important geometric element of this crystal structure.

1. Optic Axis – It is a line passing through any of the blunt corners and equally inclined with the three faces of the crystal. The crystal is symmetrical about this axis. Optic axis is a direction not a line.

2. Principal Section – It is a plane containing the optic axis and normal to a pair of opposite faces. In case of calcite crystal there are three principal sections. A principal section always cut the surfaces of a calcite crystal in a parallelogram with angles 71^o and 109^o .

3. Principal Plane – Any plane parallel to principal section is known as principal plane.



Huygen's Theory of Double Refraction in Uniaxial Crystals

- Huygens used thr principle of secondary wavelets to explain the phenomenon of double refraction in uniaxial crystals.
- In doubly refracting crystals, every point of incident wavefront becomes the point of two secondary wavelets.
- Any radial vector from the point of source to a point on secondary wavelet gives the magnitude of velocity of light in that direction.
- The secondary wavelet for ordinary wave is spherical in shape because the velocity of light for ordinary wave is same in all directions.
- The secondary wavelet for e-ray is an ellipsoid because the velocity of light for e-ray is different in different direction.
- There are two types of uniaxial crystals – negative uniaxial crystals and positive uniaxial cryatals
- In negative crystals such as calcite $\mu_e < \mu_o$
- In positive crystals such as quartz $\mu_e > \mu_o$

- In negative crystals, the velocity of e-ray is greatest in the direction perpendicular to the optic axis and least along the direction of optic axis.
- In positive crystals, the velocity of e-ray is least in the direction perpendicular to the optic axis and greatest along the direction of optic axis.
- In both the crystals the velocity of e-ray and o-ray are equal along the direction of optic axis.
- At the end of the passage through the doubly refracting crystals, o-ray and e-ray recombine and propagate in isotropic medium as a single wave.

Nicol Prism

- It is an optical device for producing and analysing plane polarised light.
- It is made up of calcite crystal.
- Its action is based on the phenomenon of double refraction.
- When light passes through a doubly refracting crystal it splits in two rays

1. Ordinary ray with its vibrations perpendicular to the principal section.
2. Extraordinary ray with its vibrations parallel to the principal section.

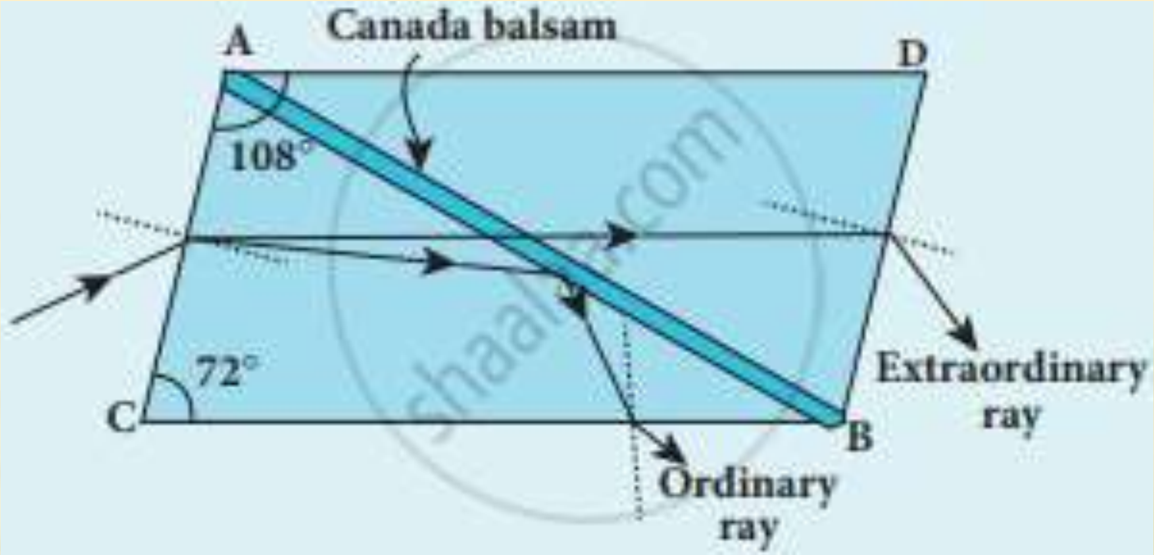
- Both of these rays are plane polarised having vibrations perpendicular to each other
- To get a beam of plane polarised light one of these rays should be get rid off.
- Nicol prism is designed in such a way so as to eliminate the ordinary ray by total internal reflection.
- Hence only extra ordinary ray is transmitted.

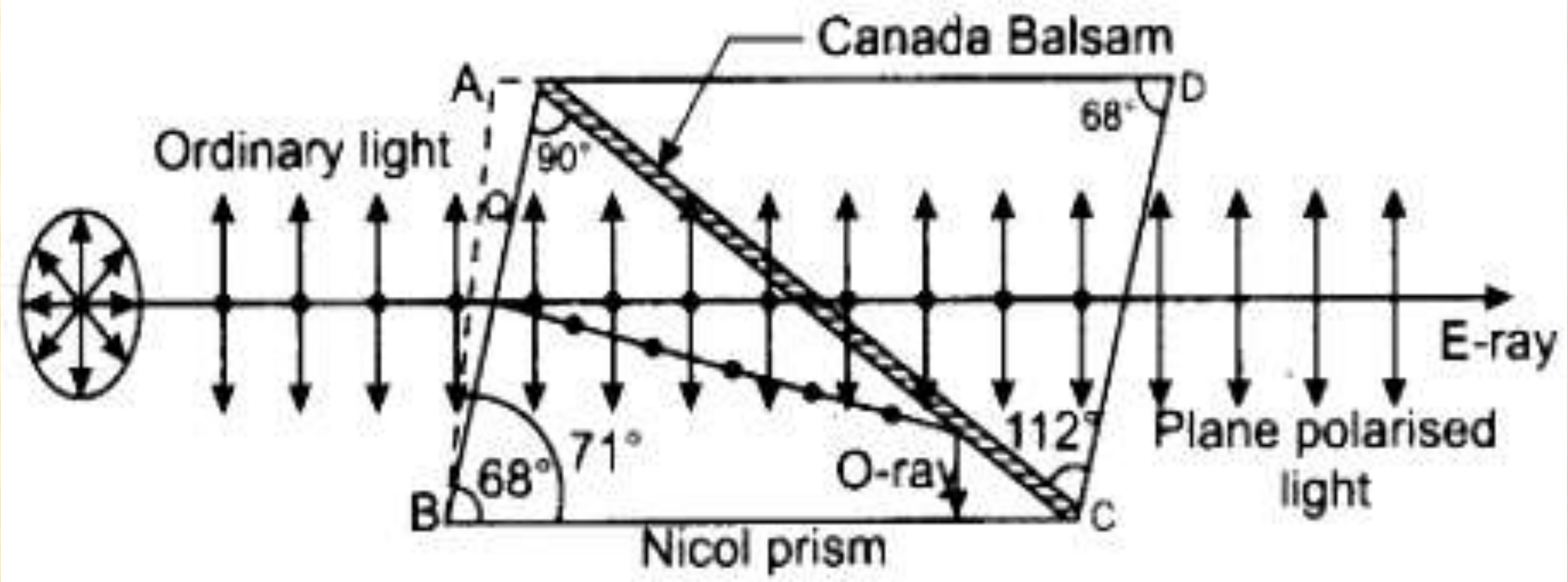
Construction

- Nicol prism is made by taking a calcite crystal whose length is three times its breadth. It is cut into two halves along the diagonal so that their face angles are 72^o and 108^o. And the two halves are joined together by a layer of canada balsam, a transparent cement.
- Calcite is used because of its clarity, stability, high spectral transmission range (200-500nm) and high birefringence.
- The refractive index for canada balsam is 1.550 for both rays.

Working

- Unpolarized light enters through the left face of the crystal and is split into two orthogonally polarized, differently directed rays by the birefringence property of the calcite.
- The ordinary ray experiences a refractive index of 1.658 in the calcite and it undergoes total internal refection at the calcite-glue interface because its angle of incidence at the glue layer (refractive inde= 1.55) exceeds the critical angle for the interface.
- The extraordinary ray experiences a lower refractive index 1.486 % in the calcite, and is not totally refectedat the interface because it strikes the interface at a sub-critical angle.





https://www.sarthaks.com/682083/

- It undergoes a slight refraction, or bending, as it passes through the interface into the lower half of the prism.
- It finally leaves the prism as a ray of plane polarized light, undergoing another refraction as it exits the far right side of the prism.
- The two exiting rays have polarizations orthogonal (at right angles) to each other, but the E-ray is more commonly used because it is again traveling in the original horizontal direction, assuming that the calcite prism angles have been properly cut.
- The direction of O-ray is quite different from its original direction because it alone suffers total internal refection at the glue interface as well as a final refraction on exit from the upper side of the prism .
- o-ray has vibrations perpendicular to principal section. RI of calcite for o-ray is 1.658 and RI of canada balsam is 1.55. Thus for o-ray the calcite crystal is denser medium. It is totally refected by canada balsam and absorbed by blackened surfaces.
- RI of the crystal for e-ray is 1.486. Calcite behaves as rarer medium. So it is transmitted by canada balsam and finally emerges out of the crystal as polarised beam of light.

Dichroism : Polarisation By Selective Absorption By Crystals

- There are certain doubly refracting crystals which have the property of absorbing one of the two refracting rays more than the other ray.
- This property of selective absorption is is known as Dichroism.
- The materials which show this property are called Dichroic eg: Tourmaline
- When unpolarised light is passed through a tourmaline crystal, it is split up into two rays (o-ray and e-ray)
- The vibrations of the above two rays are perpendicular.
- when passed through the crystal the o-ray is completely absorbed but e-ray is transmitted.

Polaroids

- Polaroids are the devices based on the principal of Dichroism.
- The crysyals of **herapthide** are highly dichroic prodeuced by W.H. Herapath.
- A paste of nitrocellulose with these crystals is prepared, then it is squeezed out through a fine slit.
- Now herapthide cryatals are arranded side by side such that their optic axis are parallel.

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- This works as a single crystal of large dimension.
- This sheet of tiny crystals is mounted between two thin glass sheets.
- this sheet is known as Polaroid.
- Large sized polaroids are formed by stretching a film of polyvinyl alcohol. These are known as **H-Polaroid**.
- If the stretched film is heated with a dehydrating agent like HCl, it darkens ut shows strong dichroism. These are known as **K-Polaroids**.

THANK YOU