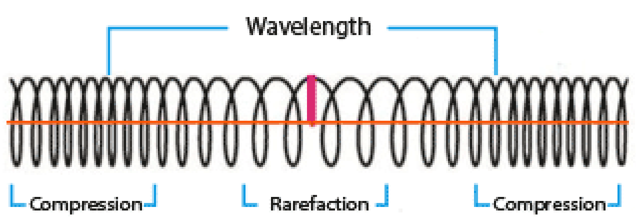
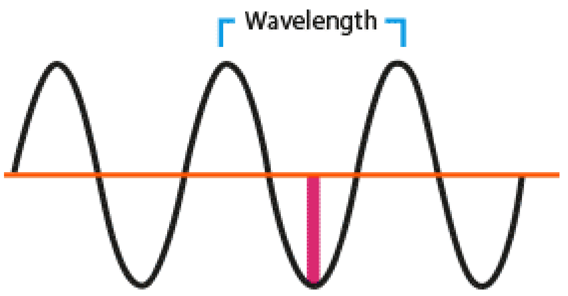
Polarization

Dr. A. R. Deshmukh

Longitudinal and Transverse Waves

LONGITUDINAL WAVE AND TRANSVERSE WAVE



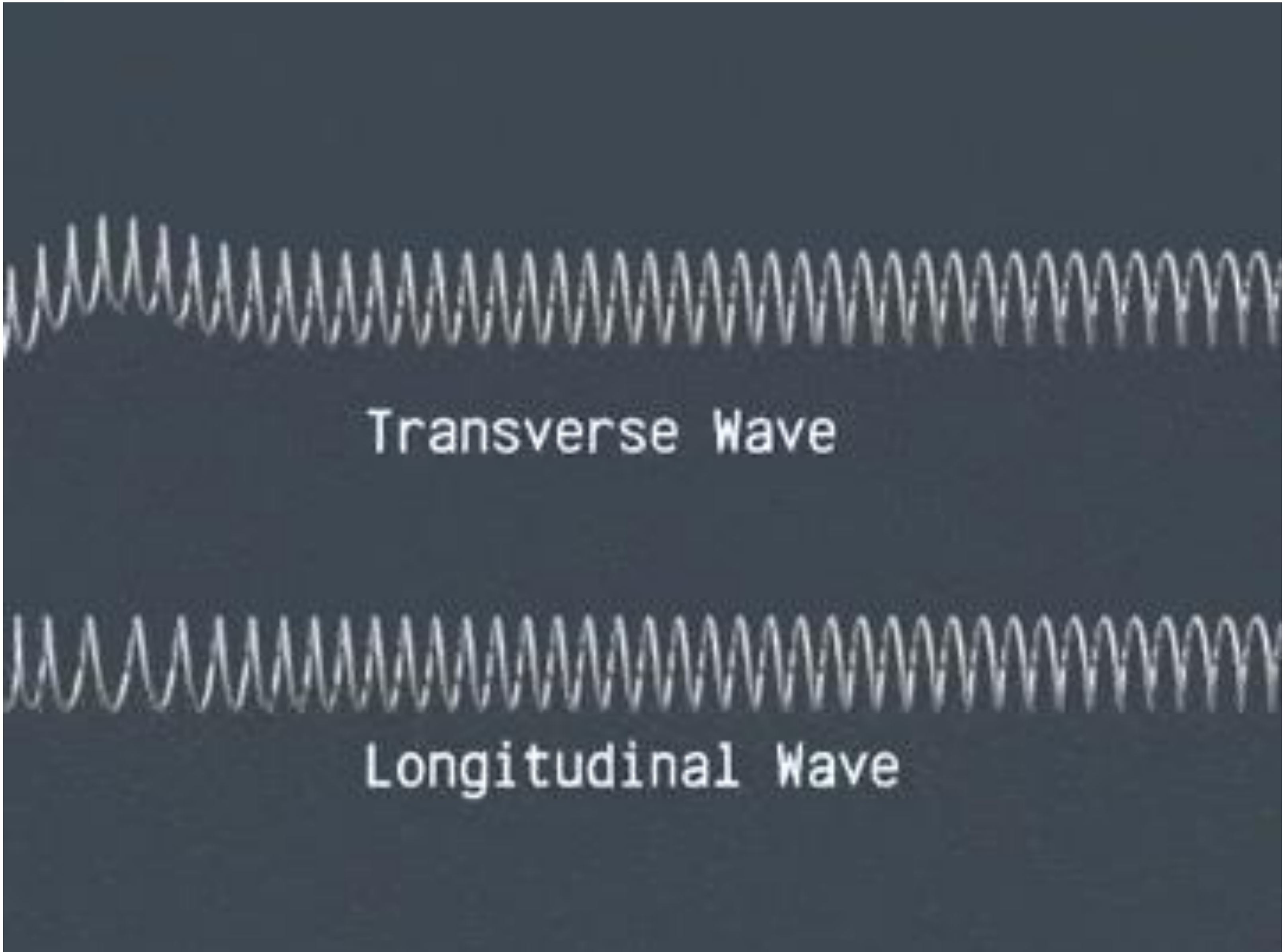


LONGITUDINAL WAVE

Longitudinal waves are those waves in which the particles of the medium move parallel to the propagation of the wave. For example, sound waves are longitudinal waves

TRANSVERSE WAVE

Transverse waves are those waves in which the particles of the medium move perpendicular to the direction of the propagation of the wave. For example, ripples formed on the surface of the water, is a transverse wave.


Transverse Wave
Longitudinal Wave

Introduction

What is light?

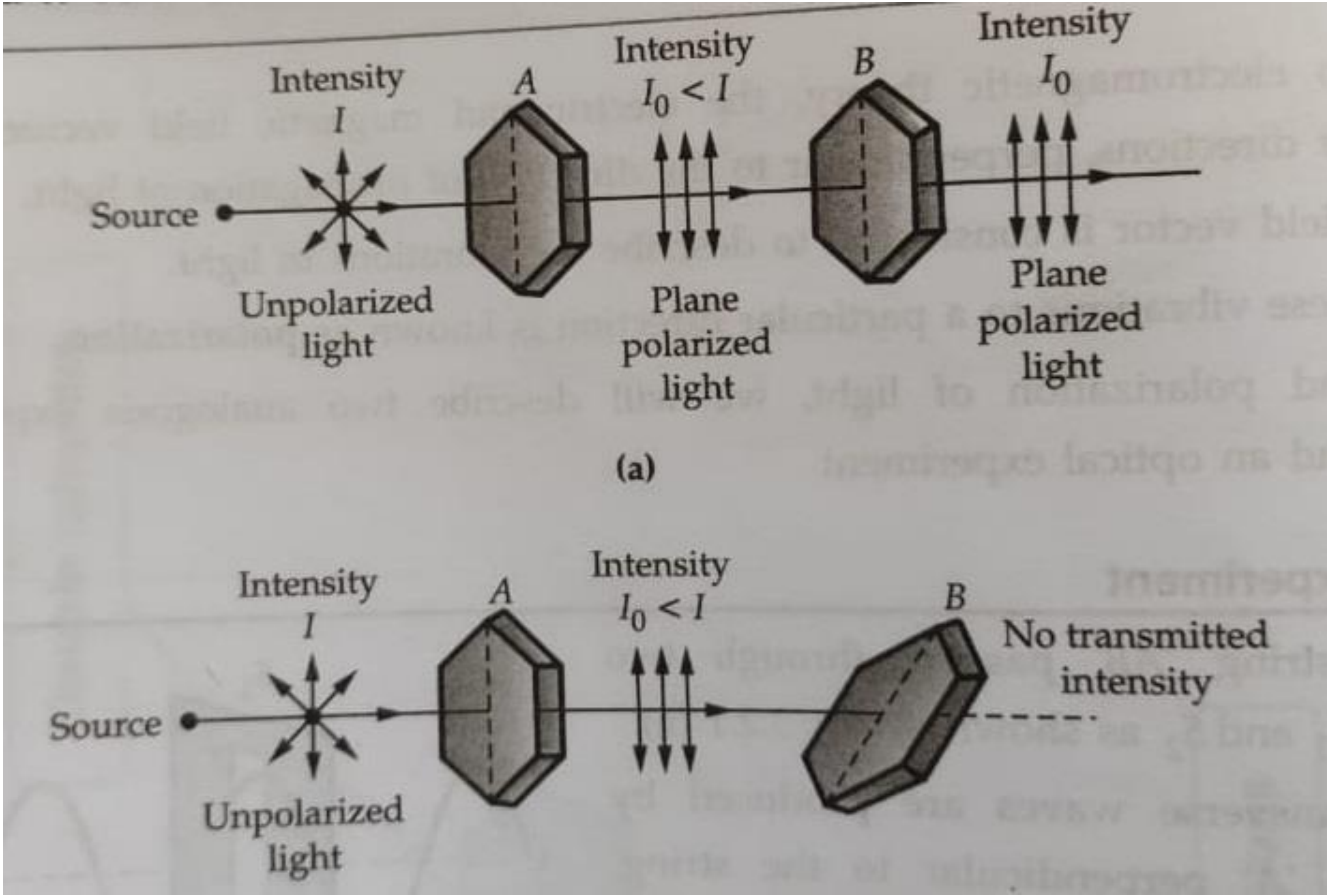
A light ray is nothing but an **electromagnetic wave** having **transverse** wave nature.

while sound waves are **longitudinal** in nature.

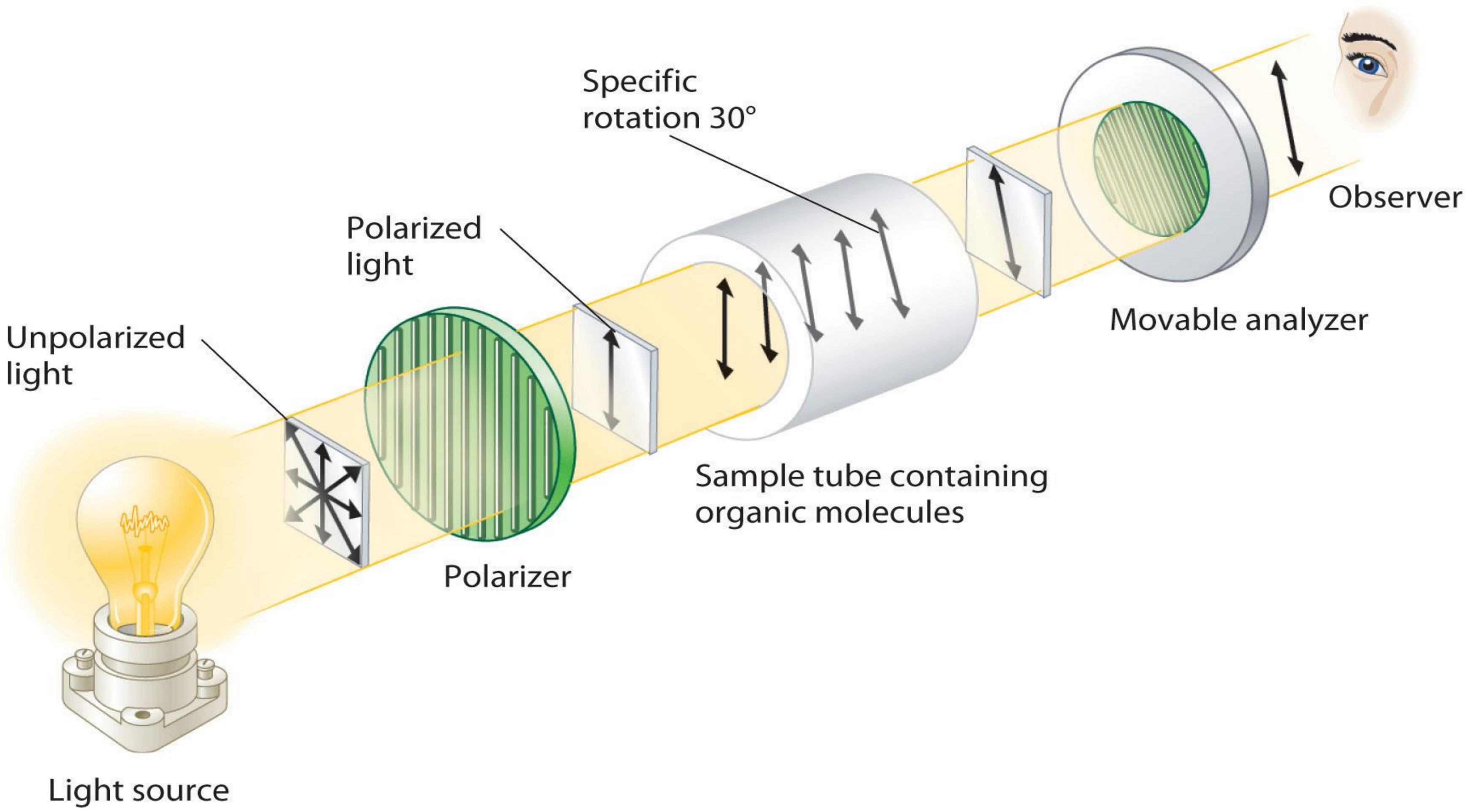
The **wave nature** of light can be proved by **interference and diffraction** phenomenon.

But **Transverse nature** of light can be proved only by the phenomenon of **polarization.**

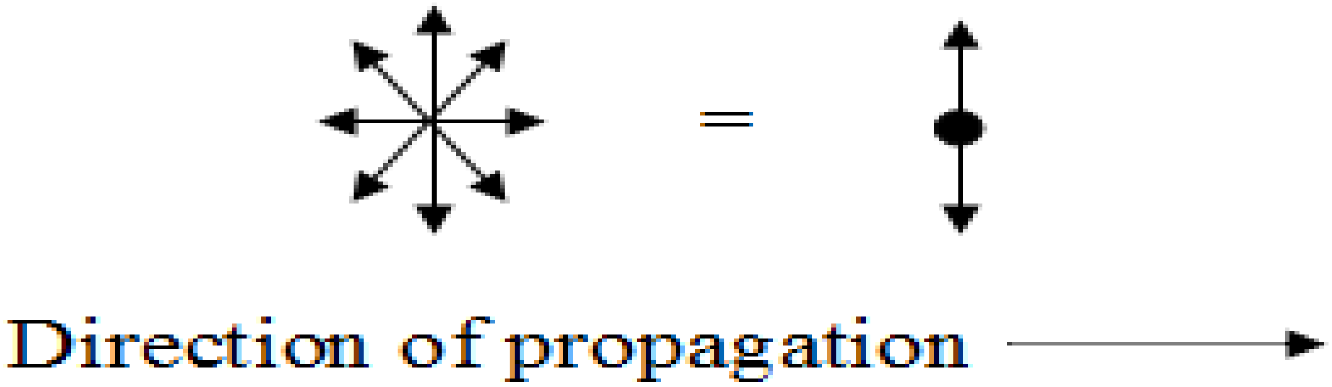
Polarization



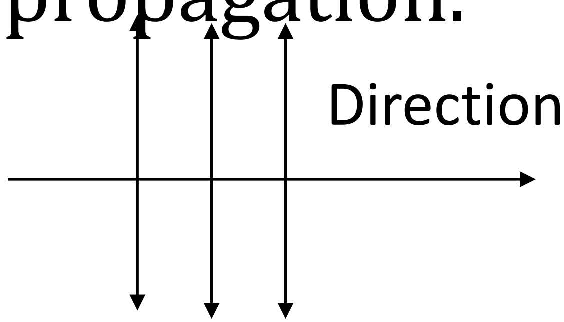
Polarization



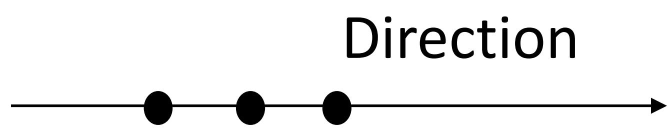
- **Unpolarized light:** Ordinary light beam having vibrations along all possible planes perpendicular to the direction of propagation is said to be unpolarized.



- **Plane polarized light:** The plane polarized light is the light in which the light vectors vibrate along a fixed straight line in a plane perpendicular to the direction of propagation.

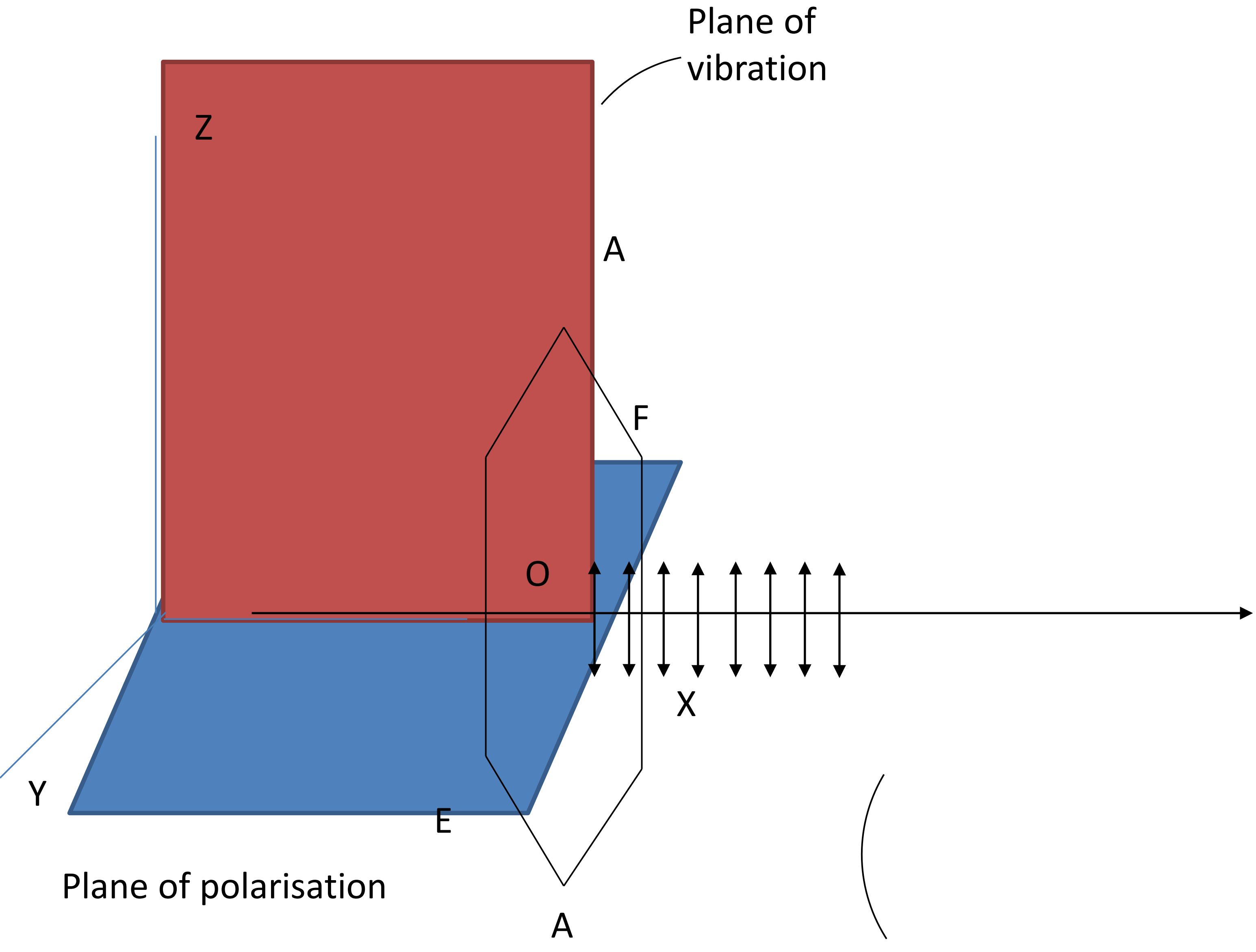


Parallel to plane of paper



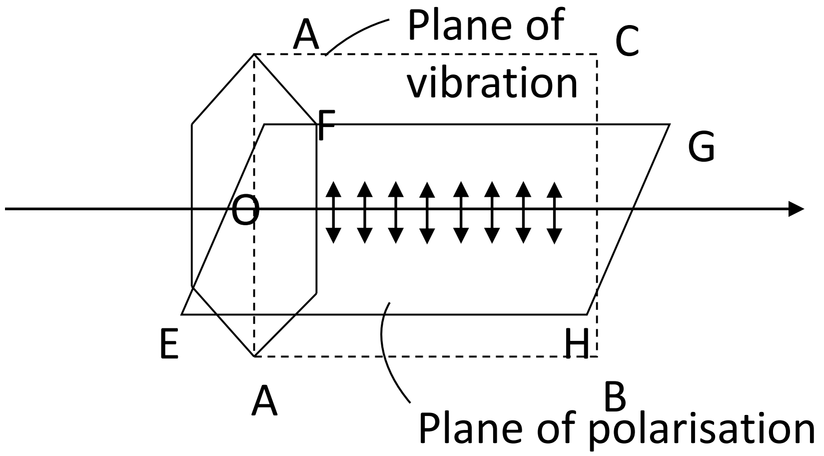
Perpendicular to plane of paper

Plane of Polarization & Plane of Vibration



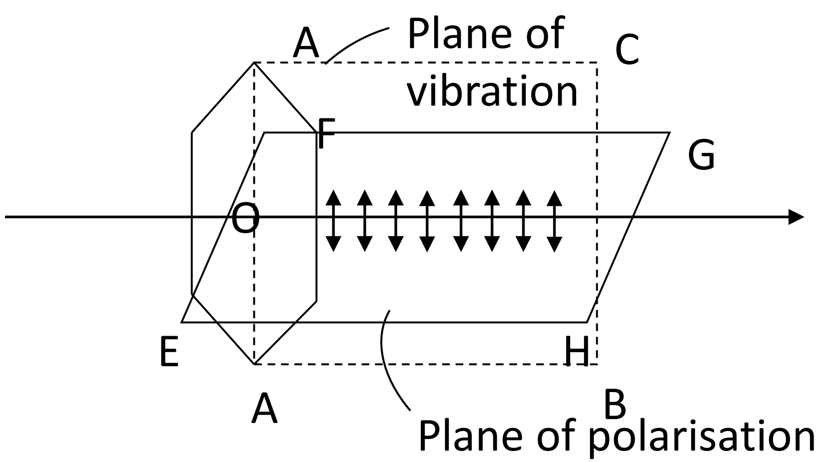
Plane of Polarization

- The plane containing the direction of propagation of light but containing no vibrations is known as plane of polarization.
- The plane perpendicular to the plane of vibration is known as the plane of polarization and is shown by the plane EFGH in fig.



Plane of vibration

- The plane containing the direction of vibration and direction of propagation of light is known as the plane of vibration and is shown by the plane ABCD in fig.
- The plane of polarization is always perpendicular to the plane of vibration

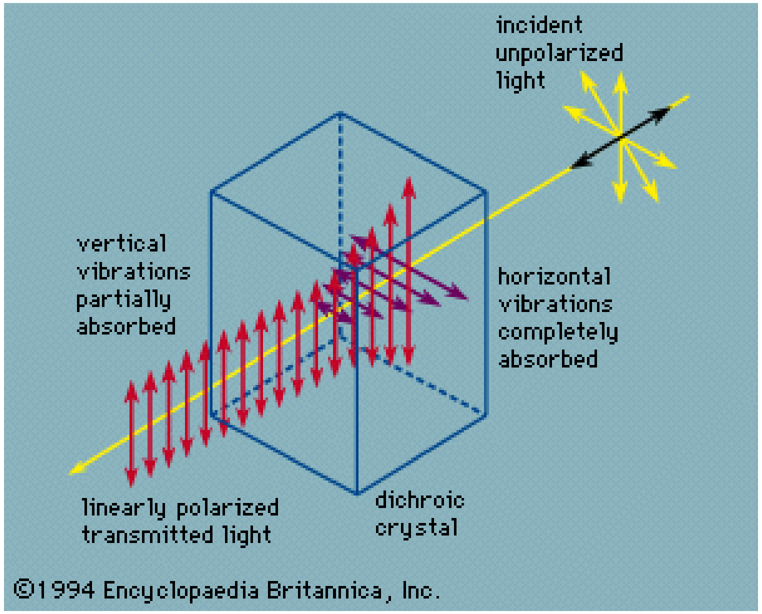


Different methods to produce plane polarized light (PPL)

- By reflection
- By refraction
- Double refraction
- Dichroism (selective absorption)

Production of plane polarized light by selective absorption (Dichroism)

- Certain double refracting crystals have the property of absorbing
- Either O or the E-wave to a larger extent than other
- This property is known as dichroism
- Ex: Tourmaline crystal absorbs the O-waves to a larger extent than the E-wave
- Transmitted light will be only the E-wave which is plane polarized
- Thus plane polarized light can be obtained using selective absorption



- "The phenomenon of absorbing one of the doubly refracting beams and transmitting other beam as plane polarized light in double refracting materials is known as selective absorption or dichroism."

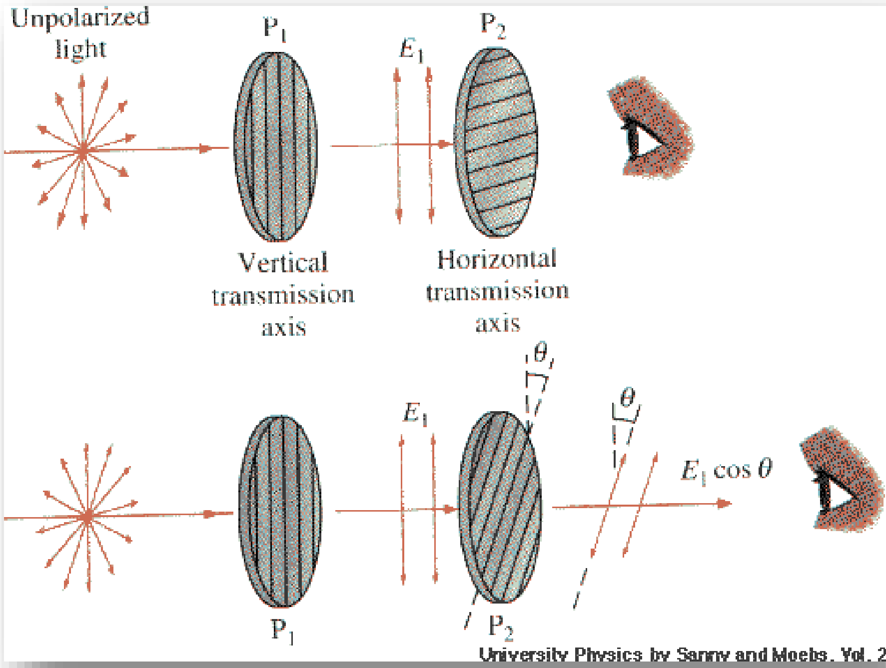
Law of Malus

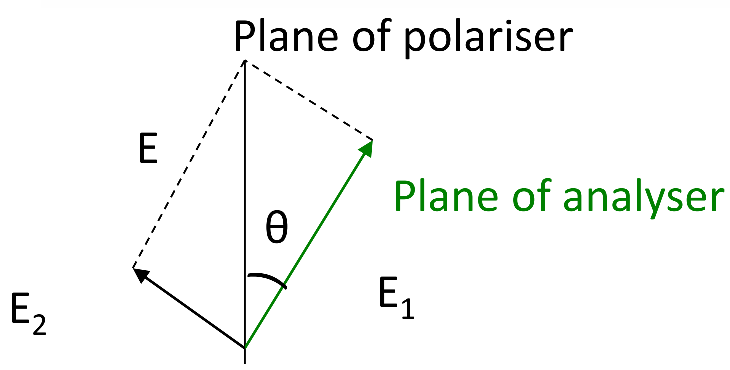
The intensity of the polarised light transmitted through the analyser varies as the square of the cosine of the angle between the plane of transmission of the analyser and the plane of the polariser

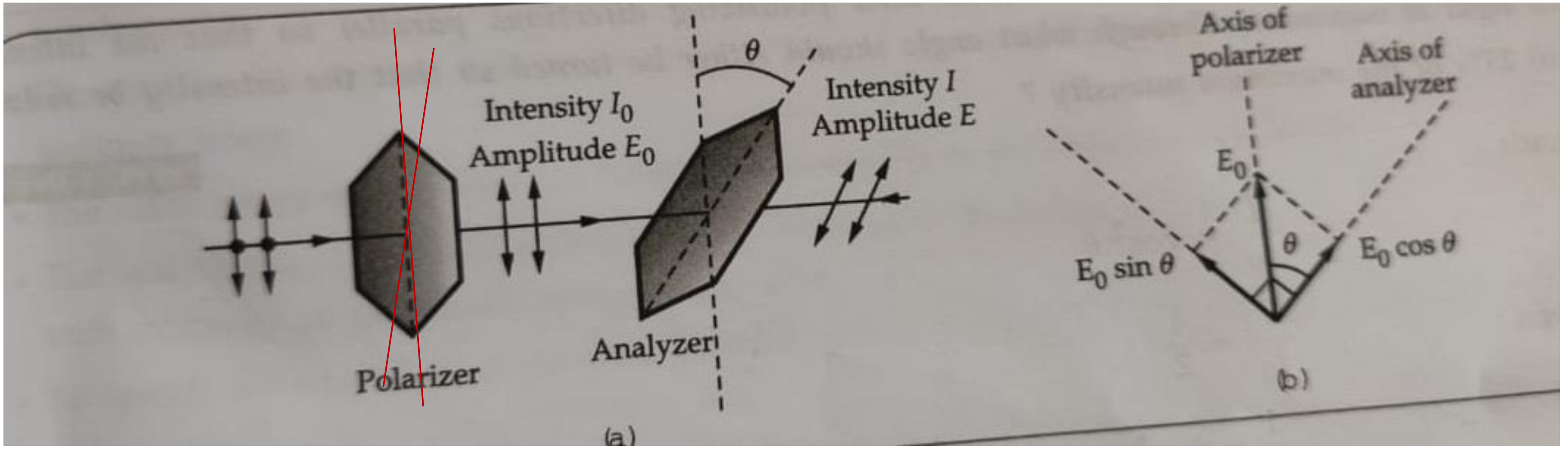
$E_1 = E \cos\theta$

$I_1 = E_1^2 = E^2\cos^2\theta = I_o\cos^2\theta$

$I_1 \ \alpha \ \cos^2\theta$







When unpolarized light is incident on polarizer, the ratio of intensity of light transmitted By analyzer to intensity transmitted by polarizer is equal to square of the cosine of the Angle between the axes of polarizer and analyzer

$$\frac{I}{I_0} = Cos^2\theta$$

$I = Intensity\ transmitted\ by\ analyzer$
$I_0 = Intensity\ transmitted\ by\ polarizer$
$\theta =$ Angle between axes of polarizer and analyzer

Amplitude E of light transmitted by analyzer is

$$E = E_0 \cos\theta$$

$$E^2 = E_0^2 \cos^2\theta$$

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

$$\frac{I}{I_0} = Cos^2\theta$$

Double refraction

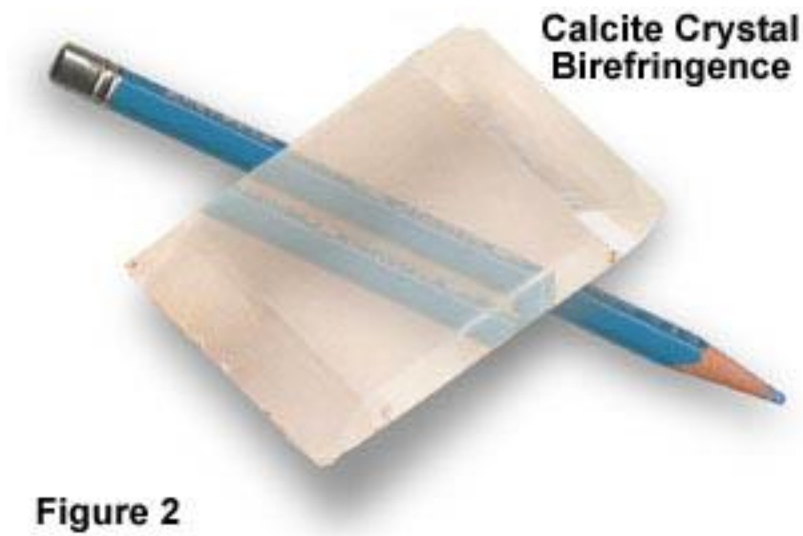
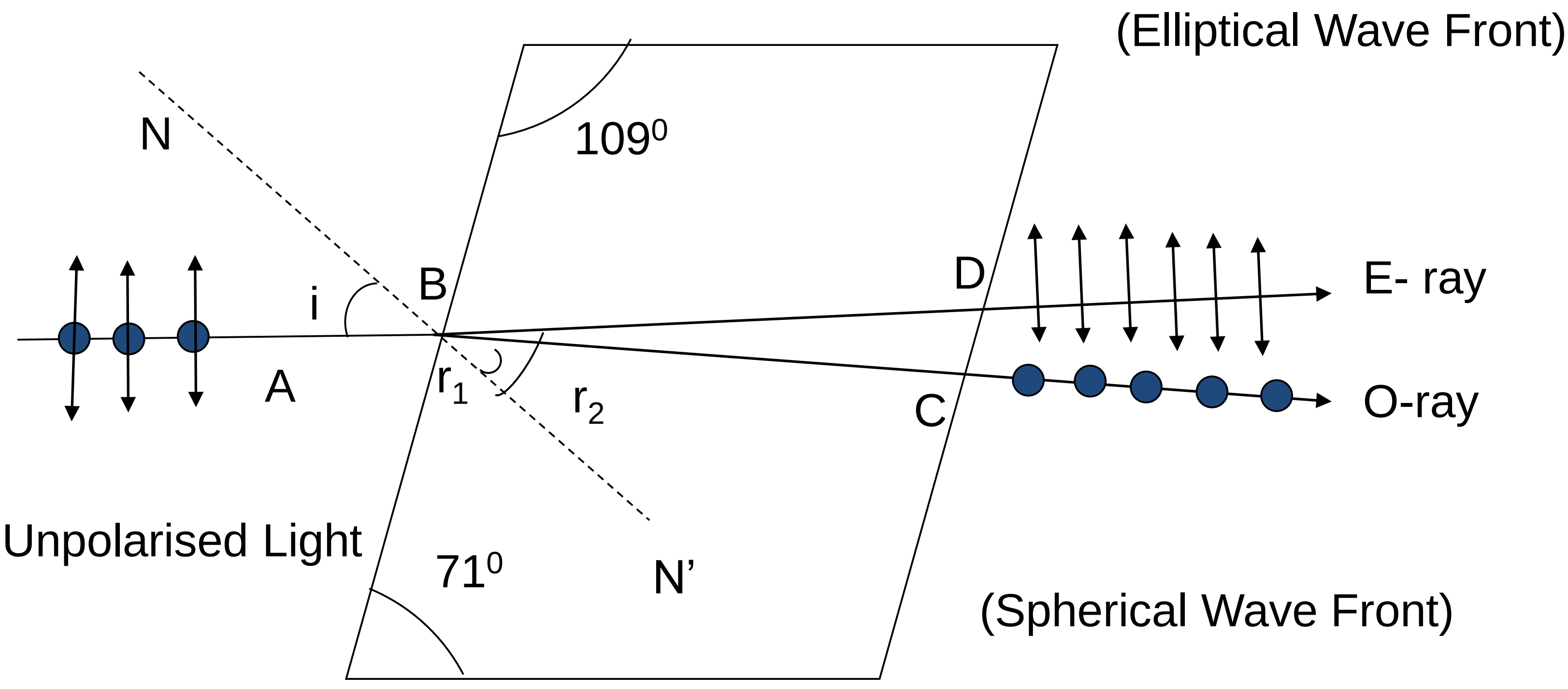


Figure 2

Huygen's Theory of Double Refraction



Phenomenon of Double Refraction

- If a narrow beam of unpolarized light be incident normally on a double refracting crystal , it splits up into two refracted rays.
- Out of the two refracted rays one which obeys the ordinary laws of refraction is known as ordinary ray (O-ray) and the other which behaves extra ordinarily and does not follow laws of refraction i.e. Snell's law is known as extra ordinary ray (E-ray).

Phenomenon of Double Refraction

- The velocity of O-ray is same in all directions within the crystal because refractive index(μ) is constant.
- For E- ray μ varies with the angle of incidence and its velocity is different in different directions within the crystal.

Huygen's Theory of Double Refraction

1. When a beam of unpolarized light be incident on a double refracting crystal, it produces two wave fronts corresponding to two polarized refracted ray.
2. The O-ray travels with same velocity v_0 in all directions and hence the corresponding wavefront is spherical.
3. The velocity of E-ray varies with direction and hence the corresponding wavefront is ellipsoid.
4. The speed of both the rays is same along the optic axis. Hence the sphere and ellipse touch each other at points on the optic axis

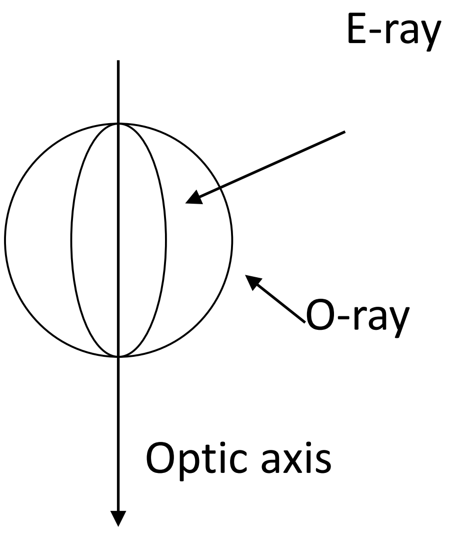
Huygen's Theory of Double Refraction

5. In certain crystals such as calcite, tourmaline etc. the ellipse is outside the sphere i.e.$v_e > v_0$. Hence for such crystals $\mu_e < \mu_0$. such crystals are called negative crystals.
6. In certain crystals such as quartz,ice etc. the ellipse lies within the sphere i.e.$v_o > v_e$. Hence for such crystals $\mu_0 < \mu_e$. such crystals are called positive crystals.

Difference between positive and negative crystal

Positive crystal

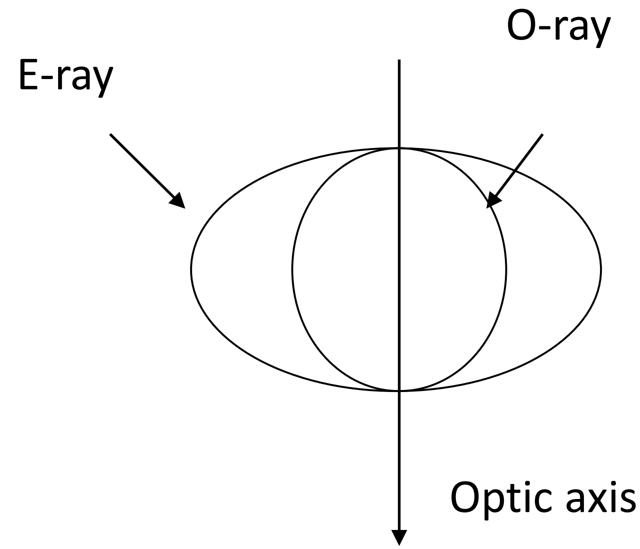
1. Spherical wavefront (o-wavefront) is outside ellipsoidal wavefront (e-wavefront).
2. For positive crystals, $v_o > v_e$ and $\mu_o < \mu_e$.
3. Examples; Quartz, Ice etc.



Difference between positive and negative crystal

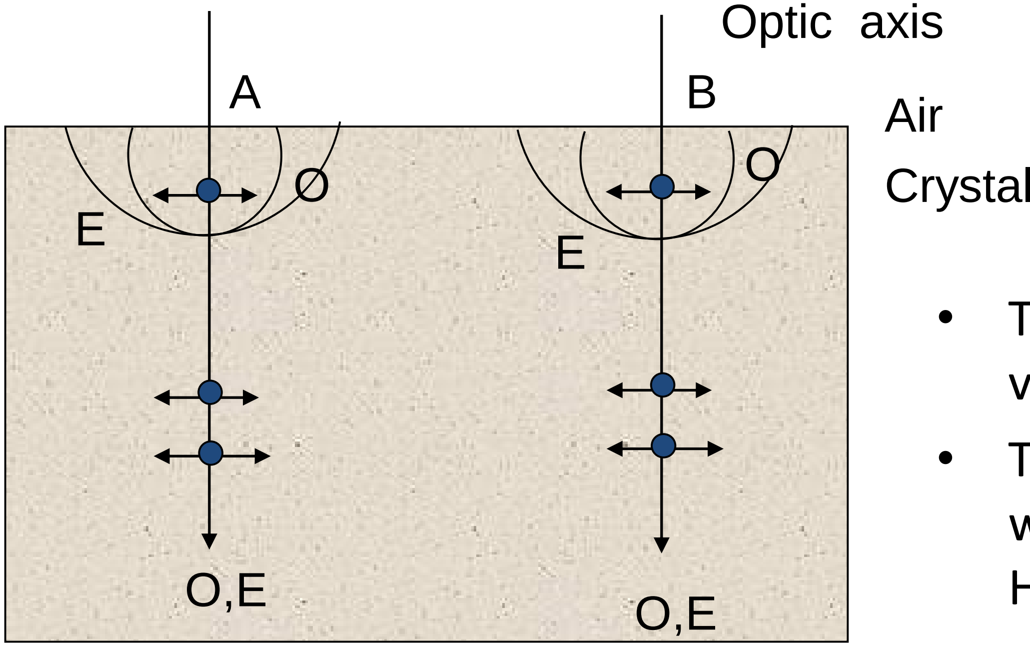
Negative crystal

1. Spherical wavefront (o-wavefront) is inside ellipsoidal wavefront (e-wavefront).
2. For negative crystals $v_o < v_e$ and $\mu_o > \mu_e$.
3. Examples: Tourmaline, Calcite etc.



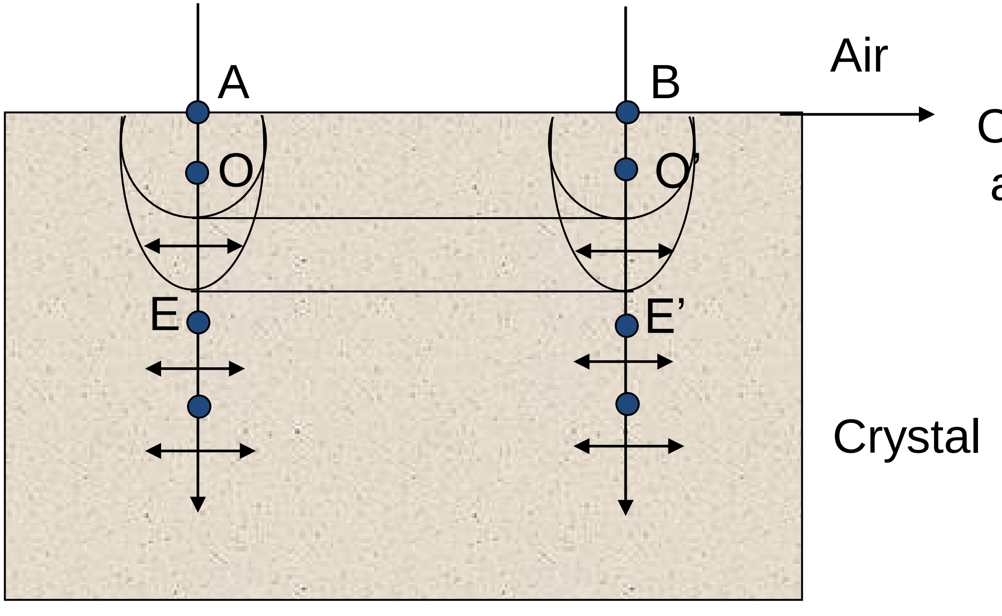
Propagation of Light in Doubly Refracting Crystals

1. Optic axis perpendicular to crystal surface



- The O and E rays travel with the same velocity in the same direction.
- The ordinary and extra-ordinary wavefronts coincide at all instants. Hence double refraction is not observed

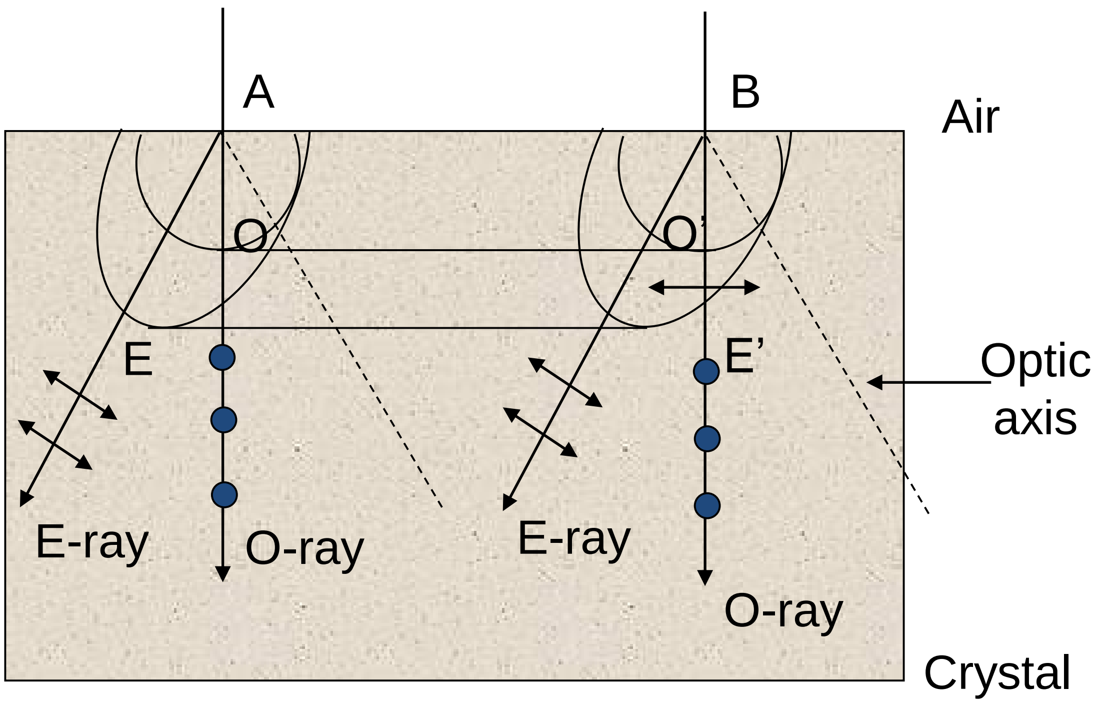
2. Optic axis parallel to the crystal surface and lying in the plane of incidence



2. Optic axis parallel to the crystal surface and lying in the plane of incidence

- The wavefronts OO’ and EE’ are parallel.
- The E and O rays travel along the same direction with different velocities. Both these beams are polarised at right angles to each other.
- Due to different velocities certain path difference is introduced two waves which depends on thickness of the crystal.
- Such crystal plates are called as retardation plates

3. Optic axis inclined to the crystal surface



- The O and E rays travel with the different velocity in the different direction.
- Hence double refraction is observed

Polaroids

- Polaroids are polarizing sheets used to produce plane polarised light.
- They are constructed using dichroic crystals of iodosulphate of quinine. A paste of these crystals is prepared in nitrocellulose and then squeezed through a set of parallel slits.
- A thin sheet is obtained in which the crystals are arranged with their axes parallel to each other. This sheet is then sandwiched between two glass or plastic sheets.

Polaroid Applications

- They are used as a polarizer and analyzer.
- Polaroids are used in photographic cameras.
- In sunglasses to cut off the glare of light.
- In head lights and visors of cars.
- To control the intensity of light entering in trains and aeroplanes.
- To view 3D pictures.

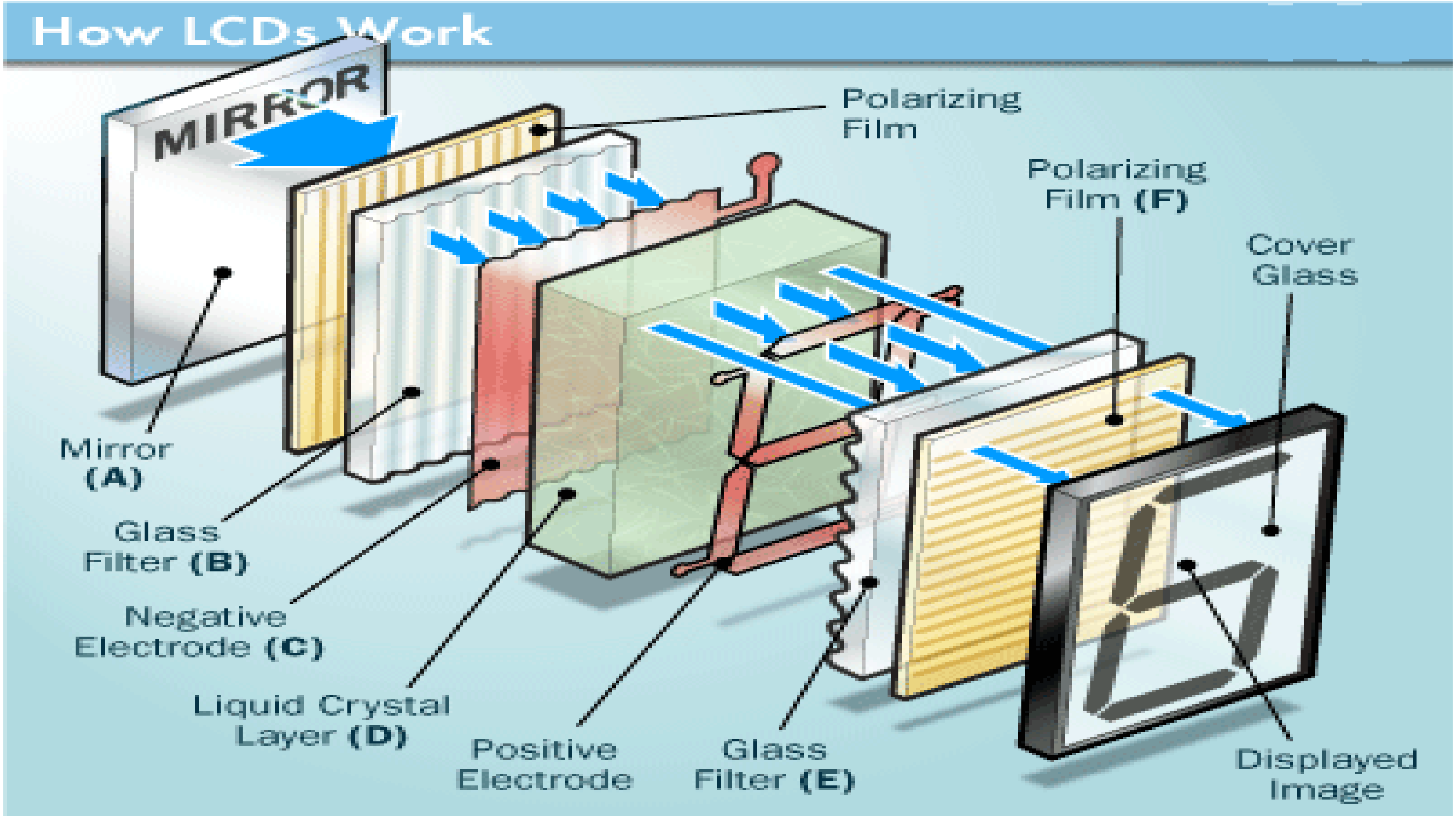
What are Liquid Crystals?

- **A liquid crystal is a liquid substance that has solid-like properties.**
- **There are many types of liquid crystals and each having different properties but typically are rod-shaped molecules which are free to move about, as in an ordinary liquid, but they are of a certain orientation as in a solid.**

Liquid crystal

- **Liquid crystal substances exist as solid crystals at low temperatures, and upon heating, they will slowly become a liquid while retaining some of their crystalline properties.**
- **At higher temperatures, they become completely liquid.**

LCD


How LCDs Work
MIRROR
Polarizing Film
Polarizing Film (F)
Cover Glass
Mirror (A)
Glass Filter (B)
Negative Electrode (C)
Liquid Crystal Layer (D)
Positive Electrode
Glass Filter (E)
Displayed Image