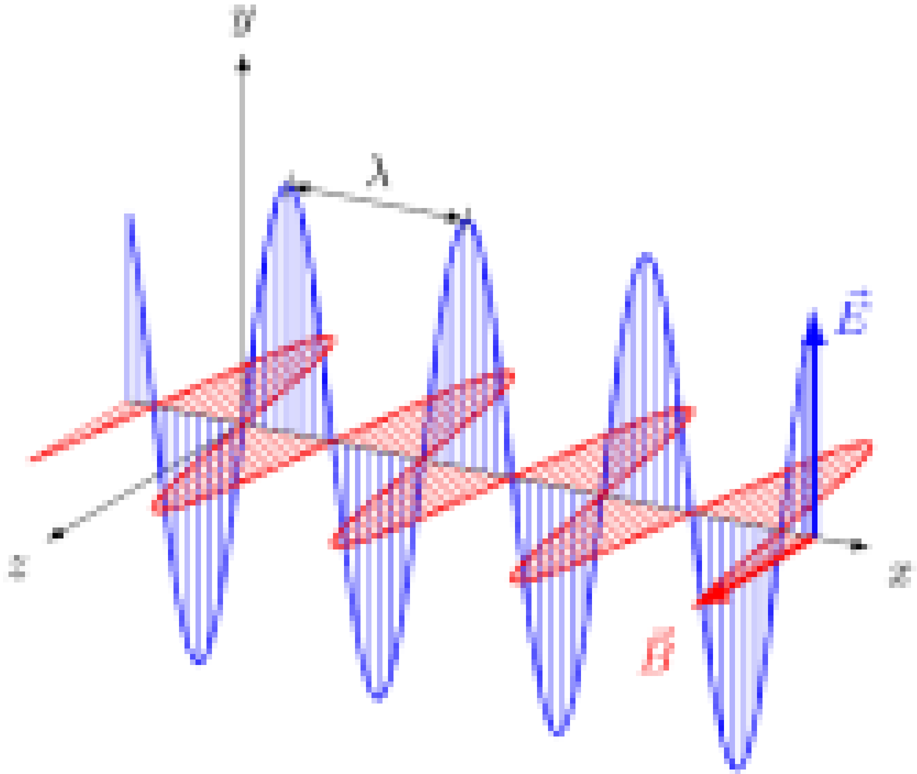
CBSE-Class 12 -Wave Optics

POLARISATION

1. POLARISATION OF LIGHT

Light waves are transverse in nature

Light is an electromagnetic wave.



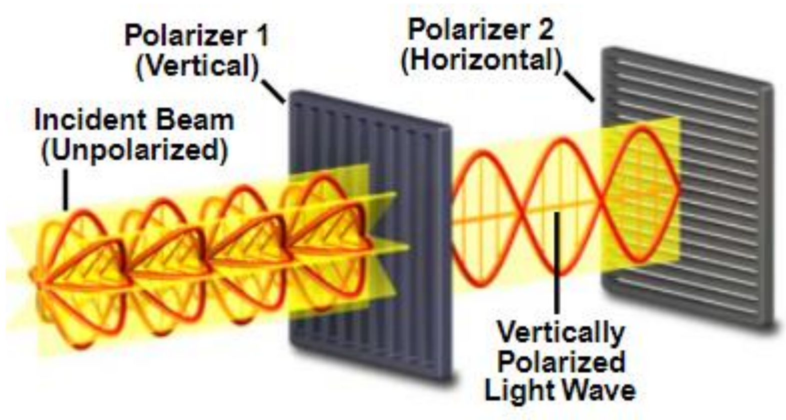
In the figure electric field vector is confined to a plane perpendicular to the direction of propagation of wave

The illustrated wave has the electric vector confined to the -y direction.

This is said to be linearly polarised light.

The word polarization here means all electric vectors to lie in the x-y plane.

Sunlight and almost every other form of natural and artificial illumination produces light waves whose electric field vectors vibrate in all planes that are perpendicular with respect to the direction of propagation. If the electric field vectors are restricted to a single plane by filtration of the beam with specialized materials, then the light is referred to as **plane** or **linearly polarized** with respect to the direction of propagation, and all waves vibrating in a single plane are termed **plane parallel** or **plane-polarized**.



The human eye lacks the ability to distinguish between randomly oriented and polarized light, and plane-polarized light can only be detected through an intensity or color effect, for example, by reduced glare when wearing polarized sun glasses.

In effect, humans cannot differentiate between the high contrast real images observed in a polarized light microscope and identical images of the same specimens captured digitally (or on film), and then projected onto a screen with light that is not polarized.

The basic concept of polarized light is illustrated in **the above figure** for a non-polarized beam of light incident on two linear polarizers. *Electric field vectors are depicted in the incident light beam as sinusoidal waves vibrating in all directions* (360 degrees; although only six waves, spaced at 60-degree intervals, are included in the figure).

In reality, the incident light electric field vectors are vibrating perpendicular to the direction of propagation with an equal distribution in all planes before encountering the first polarizer.

The polarizers illustrated in **the above Figure** are actually filters containing long-chain polymer molecules that are oriented in a single direction.

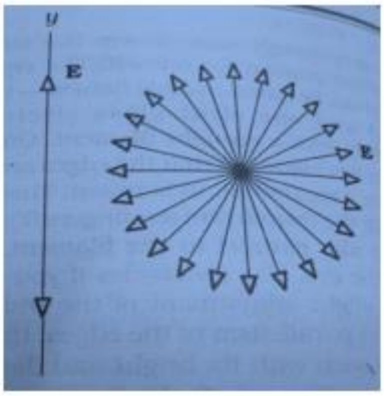
Only the incident light that is vibrating in the same plane as the oriented polymer molecules is absorbed, while light vibrating at right angles to the polymer plane is passed through the first polarizing filter.

The polarizing direction of the first polarizer is oriented vertically to the incident beam so it will pass only the waves having vertical electric field vectors. The wave passing through the first polarizer is subsequently blocked by the second polarizer, because this polarizer is oriented horizontally with respect to the electric field vector in the light wave.

The concept of using two polarizers oriented at right angles with respect to each other is commonly termed **crossed polarization** and is fundamental to the concept of polarized light microscopy.

In the figure below only the electric field vectors are drawn.

This illustrates Polarised light where the E vector is along the y axis

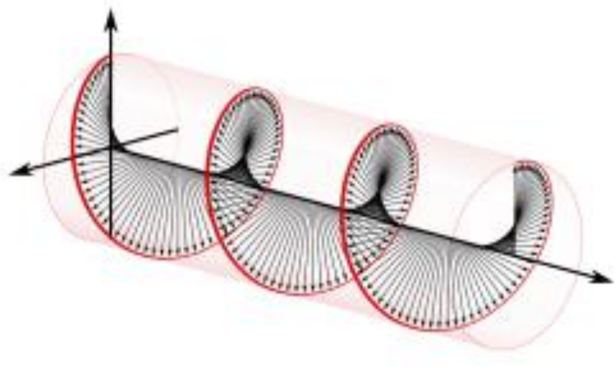


or unpolarised light where E vector could be in any direction perpendicular to the direction of propagation.

A light wave is transverse but unpolarized that is, there is no preferred plane of polarization.

Other than plane polarized light, can we have other restrictions on the electric vector

In the following figure, the electric vector executes circles and is called circularly polarised light.



You can have **elliptically polarised light** as well.

Only plane polarised light is dealt with in the chapter

The same would be true if the magnetic vector of the em wave was being considered?

Polarization refers only to the electric vector as electric field vector is much larger as $E/B = 3 \times 10^8$ m/s

Watch

https://www.youtube.com/watch?v=PJHCADY-Bio

2. POLAROIDS OR POLARIZERS

A transparent crystal which is such that: when un-polarized light is incident on it, the emergent light is polarized.
Calcite are natural polarizers.
Synthetic substances can be used as polaroids.
Eg. Thin plastic sheets, called polaroids or polaroid sunglasses.
A polaroid consists of long chain molecules aligned in a particular direction.
The electric vectors (associated with the propagating light wave) along the direction of the aligned molecules get absorbed.

Say, if at any instant consider the components of all electric vectors, only in two directions x-y and x-z for a light wave moving along x direction.
This means consider components of all the electric vectors in two mutually perpendicular directions.
They should both have equal intensity.
So if I_0 is the total intensity each of these will have an intensity of $I_0/2$.

Polaroid filters are made of a special material that is capable of blocking one of the two planes of vibration of an electromagnetic wave, resulting in blocking half the intensity

All polarizers can be used to check out if a particular light beam is polarized, and the second polarizer used for checking is called an analyzer

It may be noted that the phenomenon of interference and diffraction illustrate the wave nature of light, *the transverse nature is demonstrated by the phenomenon of polarization.*

Polarized light can be produced from the common physical processes that deviate light beams, including **absorption, refraction, reflection, diffraction (or scattering), and the process known as** birefringence **(the property of double refraction).**

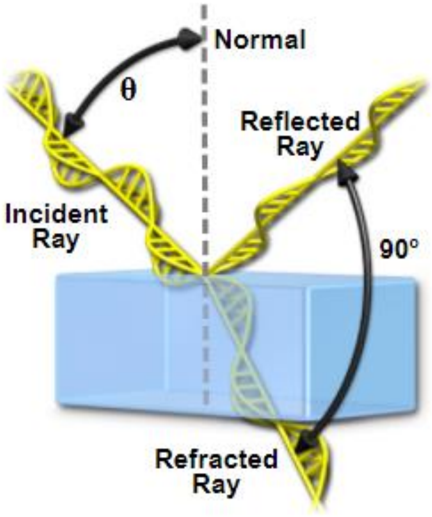
Mirrors are not good polarizers, although a wide spectrum of transparent materials act as very good polarizers, but only if the incident light angle is oriented within certain limits.

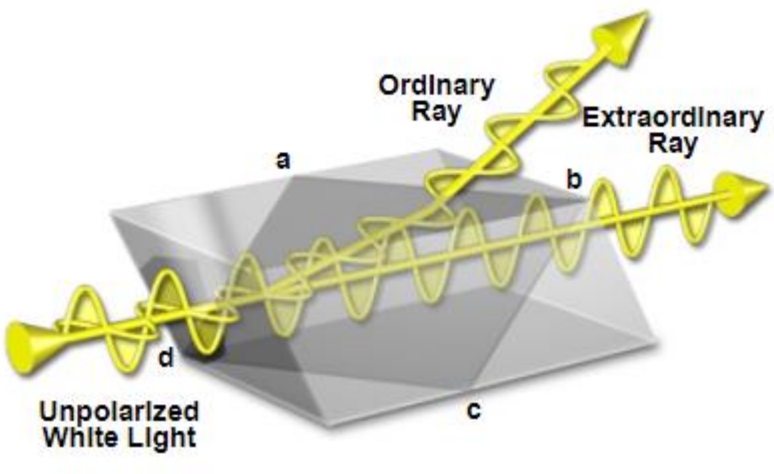
An important property of reflected polarized light is that the degree of polarization is dependent upon *the incident angle of the light*, with the increasing amounts of polarization being observed for decreasing incident angles.

This angle is commonly referred to as **Brewster's angle**, and can be easily calculated utilizing the following equation for a beam of light traveling through air:

$$n = \sin(\theta_i)/\sin(\theta_r) = \sin(\theta_i)/\sin(\theta_{90-i}) = \tan(\theta_i)$$

Illustration of Brewster's Angle





Nicole Polarizing Prism

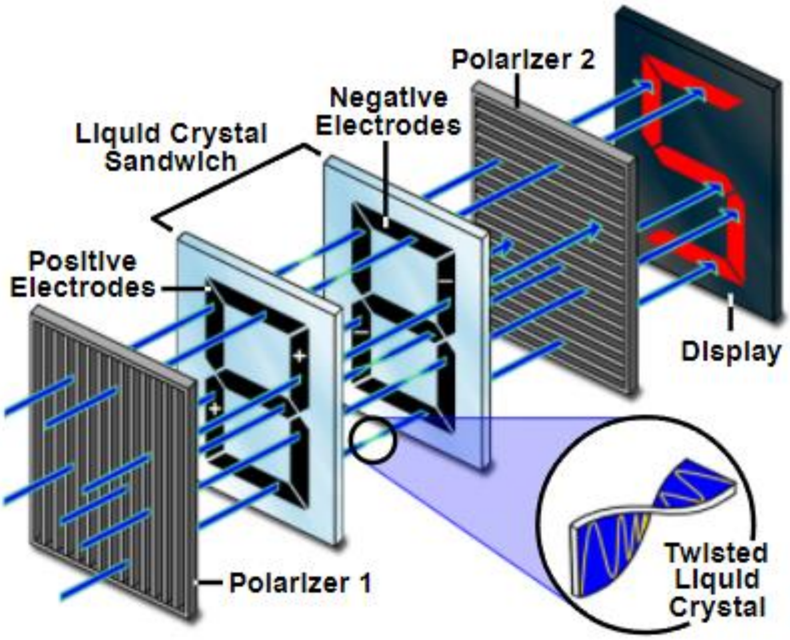
Nicol prisms were first used to measure the polarization angle of birefringent compounds, leading to new developments in the understanding of interactions between polarized light and crystalline substances.

Fig illustrates the construction of a typical Nicol prism. A crystal of doubly refracting (birefringent) material, usually calcite, is cut along the plane labeled **a-b-c-d**and the two halves are then cemented together to reproduce the original crystal shape. A beam of non-polarized white light enters the crystal from the left and is split into two components that are polarized in mutually perpendicular directions. One of these beams (labeled the ordinary ray) is refracted to a greater degree and impacts the cemented boundary at an angle that results in its total reflection out of the prism through the uppermost crystal face. The other beam (extraordinary ray) is refracted to a lesser degree and passes through the prism to exit as a plane-polarized beam of light.

Applications of Polarized Light

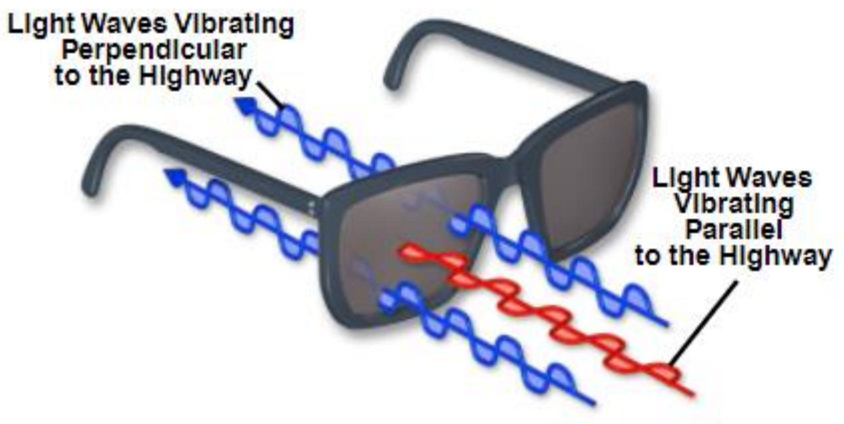
One of the most common and practical applications of polarization is the liquid crystal display (LCD) used in numerous devices including wristwatches, computer screens, timers, clocks, and a host of others. These display systems are based upon the interaction of rod-like liquid crystalline molecules with an electric field and polarized light waves.

The liquid crystalline phase exists in a ground state that is termed **cholesteric**, in which the molecules are oriented in layers, and each successive layer is slightly twisted to form a spiral pattern ([**Figure below**]).
When polarized light waves interact with the liquid crystalline phase the wave is "twisted" by an angle of approximately 90 degrees with respect to the incident wave. The exact magnitude of this angle is a function of the **helical pitch** of the cholesteric liquid crystalline phase, which is dependent upon the chemical composition of the molecules (it can be fine-tuned by small changes to the molecular structure).



Seven-Segment Liquid Crystal Display (LCD)

Action of Polarized Sunglasses



This light can be blocked by polarizing filters oriented in a vertical direction, as illustrated in **Figure** with a pair of polarized sunglasses.
The lenses of the sunglasses have polarizing filters that are oriented vertically with respect to the frames.
In the figure, the blue light waves have their electric field vectors oriented in the same direction as the polarizing lenses and, thus, are passed through.
In contrast, the red light wave vibration orientation is perpendicular to the filter orientation and is blocked by the lenses.
Polarizing sunglasses are very useful when driving in the sun or at the beach where sunlight is reflected from the surface of the road or water, leading to glare that can be almost blinding.

3. METHODS OF POLARISATION

It is possible to transform unpolarised light into polarized light

The process of transforming unpolarised light into polarized light is known as polarization

There are three methods of polarizing light:

(i) Polarization by Transmission

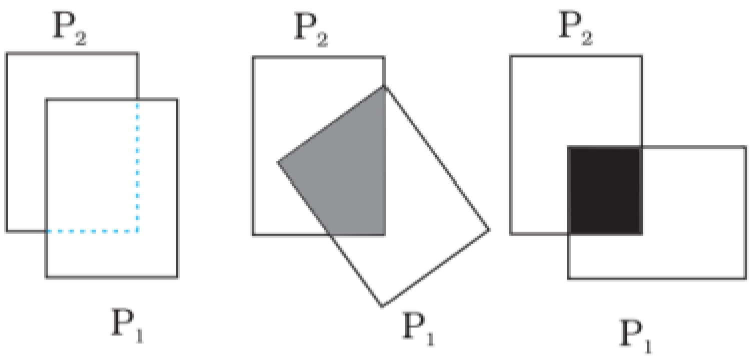
(ii) Polarization by Reflection

(iii) Polarization by Scattering

3.1. Polarization By Transmission

Use of a Polaroid Filter The most common method of polarization involves the use of a Polaroids.

If the light from an ordinary source (like a sodium lamp) passes through a polaroid sheet P1, it is observed that its intensity is reduced by half.



Passage of light through two polaroids P_2 and P_1. Rotating P_1 has no effect on the transmitted beam and transmitted intensity remains constant

LDR- Light Dependent Resistances can be used to check the drop in intensity.

The LDR resistance will change according to the light falling on it, consequently changing the current in a circuit.

Other methods to measure intensity can also be used.

Now, let an identical piece of polaroid P_2 be placed before P_1. As expected, the light from the lamp is reduced in intensity on passing through P_2 alone. But now rotating P_1 has a dramatic effect on the light coming from P_2.

In one position, the intensity transmitted by P_2 followed by P_1 is nearly zero.

When turned by 90º from this position, P1 transmits nearly the full intensity emerging from P

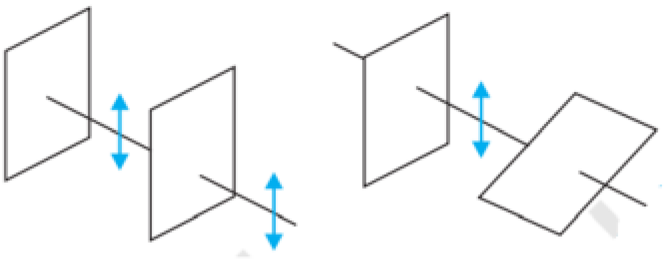
The transmitted fraction falls in intensity from I_0 to 0 as the angle between the two polaroid pass axis varies from

0º to 90º to 180° to 360°

Notice that the light seen through a single polaroid P1 does not vary with angle

The transmitted polarization is the component parallel to the polaroid axis or parallel to the pass axis

The double arrows show the oscillations of the electric vector



Behaviour of the electric vector when light passes through two polaroids

The above experiment can be easily understood by assuming that light passing through the polaroid P_2 gets polarised along the pass-axis of P_2

If the pass-axis of P_2 makes an angle θ with the pass-axis of P_1, then when the polarised beam passes through the polaroid P_2, the component E cos θ (along the pass-axis of P2) will pass through P_2.

Thus, as we rotate the polaroid P1 (or P2), the intensity will vary as:

$I = I_0 \cos^2\theta$ where I_0 is the intensity of the polarized light after passing through P_1

. This is known as MALUS' LAW.

https://www.youtube.com/watch?v=utY72MD-Ii4