Polarisation

Objectives

After going through this module, the learner will be able to :

- Understand the meaning of term Polarisation
- Explain the meaning of plane polarised light
- Know methods of polarisation of light
- Check whether specific light is plane polarised using another polariser
- Appreciate Malus law and Brewster/s law
- Know that scattering polarised light
- Appreciate application of plane polarised light and polaroids

Content Outline

- Unit syllabus
- Module wise distribution of unit syllabus
- Words you must know
- Introduction
- Polarisation of light
- Polaroids or polarizers
- Methods of Polarisation
- Application of Polaroids
- Summary

Unit syllabus

Unit 6: Optics

Chapter–9: Ray Optics and Optical Instruments

Ray optics: Reflection of light; spherical mirrors; mirror formula; refraction of light; total internal reflection and its applications; optical fibers; refraction at spherical surfaces; lenses; thin lens formula; lens maker's formula; magnification power of a lens; combination of thin lenses in contact; refraction and dispersion of light through a prism.

Scattering of light – blue color of sky and reddish appearance of the sun at sunrise and sunset

Optical instruments – microscopes and astronomical telescopes (refracting and reflecting) and their magnifying powers

Chapter-10: Wave Optics

Wave optics: Wavefront and Huygens principle, reflection and refraction of plane wave at a plane surface using wavefronts, proof of laws of reflection and refraction using Huygens's principle, Interference, Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light; diffraction due to a single slit width of central maximum; resolving power of microscope and astronomical telescope, Polarisation, plane polarised light, Malus's law, Brewster's law, uses of plane polarised light and polaroid.

Module Wise Distribution Of Unit Syllabus 15 Modules

Module 1	• Introduction • How we will study optics • Light facts • Ray optics, beams • Light falling on surfaces of any shape and texture • Peculiar observations
Module 2	• Reflection of light • Laws of reflection • Reflection of light by plane and spherical surfaces • Spherical Mirrors aperture, radius of curvature, pole and principal axis • Focus, Focal length, focal plane • Image – real and virtual • Sign convention • The mirror equation, magnification • To find the value of image distance v for different values of object distance u and find the focal length of a concave mirror • Application of mirror formula
Module 3	• Refraction of light • Optical density and mass density • Incident ray, refracted ray and emergent ray • Angle of incidence, angle of refraction angle of emergence

	• To study the effect on intensity of light emerging through different colored transparent sheets using an LDR • Refractive index • Oblique incidence of light, Snell's law • Refraction through a parallel sided slab, Lateral displacement, factors affecting lateral displacement • To observe refraction and lateral displacement of a beam of light incident obliquely on a glass slab • Formation of image in a glass slab
Module 4	• Special effects due to refraction • Real and apparent depth • To determine the refractive index of a liquid using travelling microscope • Total internal reflection • Optical fibres and other applications
Module 5	• Refraction through a prism • Deviation of light -angle of deviation • Angle of minimum deviation • Expression relating refractive index for material of the prism and angle of minimum deviation • To determine the angle of minimum deviation for given prism by plotting a graph between angle of incidence and angle of deviation • Dispersion, spectrum
Module 6	• Refraction at spherical surfaces • Radius of curvature • Refraction by a lens • Foci, focal plane, focal length, optical center, principal axis • Formation of images: real and virtual • Lens maker's formula • Lens formula and magnification • Sign convention

	• Application of lens formula • Power of lens • Combination of thin lenses in contact
Module 7 A and 7 B	After going through the module the learner will be able to: **7A** • Know the optics laboratory equipment • Understand the principle for the following experiments • To Study the nature and size of image formed by a i) convex lens ii) concave mirror using a candle and a screen • To Determine the focal length of convex lens by plotting graphs between u and v , between 1/u and 1/v • To Determine the focal length of concave mirror by plotting graphs between u and v , between 1/u and 1/v **7 B** • To determine the focal length of a convex mirror using a convex lens • To find the focal length of a concave lens using a convex lens • To find the refractive index of a liquid by using a convex lens and a plane mirror
Module 8	• Scattering of light – • Blue color of sky • Reddish appearance of the sun at sunrise and sunset • Dust haze
Module 9	• Optical instruments • Human eye • Microscope • Astronomical telescopes reflecting and refracting • Magnification • Making your own telescope
Module 10	• Wave optics

	• Wavefront • Huygens's principle and shapes of wavefront • Plane wavefront • Refraction and reflection of plane wavefront using Huygens's principle • Verification of Laws of refraction and reflection of light using Huygens's principle
Module 11	• Superposition of waves • Coherent and incoherent addition of waves
Module 12	• Interference of light • Young's double slit experiment • Expression for fringe width • Graphical representation of intensity of fringes • Effect on interference fringes in double slit experiment • Black and white or colored fringes
Module 13	• Diffraction • Diffraction at a single slit • Width of the central maxima • Comparison of fringes in young's experiment and those in diffraction from a single slit
Module 14	• Diffraction in real life • Seeing the single slit diffraction pattern • Resolving power of optical instruments • Validity of ray optics • Fresnel distance
Module 15	• Polarisation • to observe polarization of light using two polaroid • Plane polarised light • Polariser analyser Malus law • Brewster/s law • Polarisation due to scattering

	• Uses of plane polarised light and polaroids

Module 15

Words You Must Know

Let us remember the words we have been using in our study of this physics course.

- **Incident ray**: path of light from a source in any preferred direction of propagation
- **Reflected ray**: path of light bounced off from a surface at the point of incidence
- **Refracted ray**: path of light when it propagates from one transparent medium to another.
- **Normal at the point of incidence**: normal to the surface at the point of incidence; it is important when the surface is spherical or uneven.
- **Converging and diverging rays**: rays of light may converge to or seem to diverge from a point after reflection or refraction; such rays are called converging or diverging rays.
- **Laws of reflection**: Laws followed by light rays whenever reflection takes place
  - ❖ The incident ray, reflected ray and the normal at the point of incidence all lie in the same plane
  - ❖ The angle of reflection is equal to the angle of incidence
- **Snell's law**: For oblique incidence of light on a transparent medium surface

$$refractive\ index = \frac{\sin i}{\sin r}$$

  - ❖ The incident ray, refracted ray and the normal at the point of incidence all lie in the same plane
  - ❖ The angle of refraction is not equal to the angle of incidence.
  - ❖ A ray of light propagating from a rarer to a denser medium moves towards the normal. This can be observed for obliquely incident rays.
- **Plane mirror**: a polished surface with infinite radius of curvature
- **Spherical mirror- concave and convex**: spherical mirrors are part of spherical surfaces. The polished surface makes them concave or convex.
- **Spherical lens-convex and concave**: transparent medium bounded by spherical surfaces, if a thin block of medium has two surfaces bulge out, they form a convex lens
- **Prism**: a rectangular block cut along its diagonal gives two prisms. Each piece has two refracting surfaces, a base and the angle between the refracting surfaces (in this case $=90^0$) is called angle of prism.
- **Light Waves**: Light is part of the electromagnetic spectrum. They are transverse waves; the origin of light is from electromagnetic transitions of electrons inside the atoms giving

out the radiation. The frequency depends upon the source. Wavelength depends upon the medium in which light is travelling

- **Wavefront**: defined as a surface of constant phase.

- **Huygens's principle**
  - ❖ Each point of the wavefront is a source of a secondary disturbance and the wavelets emanating from these points spread out in all directions with the speed of the wave. These wavelets emanating from the wavefront are usually referred to as secondary wavelets
  - ❖ If we draw a common tangent (in the forward direction) to all these spheres, we obtain the new position of the wavefront at a later time.

- **Huygens's construction**: Wavefronts drawn on the basis of Huygens principle
- **Superposition of waves**: if two (or more) waves travelling through the same medium at the same time meet, the net displacement of the medium at any time becomes equal to the algebraic sum of the individual displacements.
- **Coherent sources of light**

  Two sources are said to be coherent if they obey the following properties:

  (a) Two sources must be emitting waves of the same wavelength or frequency.

  (b) The amplitude of the waves produced by the two sources must be either equal or approximately equal.

  (c) The waves produced by the two sources must have either the same phase or a constant phase difference.

- **Incoherent sources of light**

  Two sources are said to be incoherent if they obey the following properties:

  (a) Two sources may be emitting waves of the same wavelength or frequency.

  (b) The amplitude of the waves produced by the two sources may not be either equal or approximately equal.

  (c) The waves produced by the two sources do not have either the same phase or constant phase difference

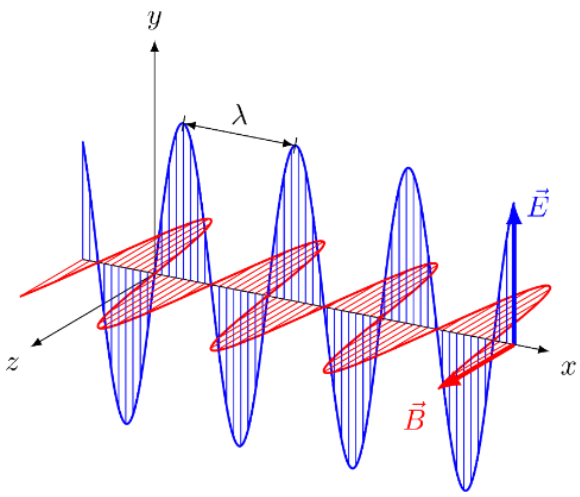
- **Fringes**: the bright and dark line pattern obtained due to interference of light
- **Fringe width**: the separation between two consecutive bright or dark fringes. It depends upon the wavelength of light

- **Diffraction**: the shadow cast by an opaque object, close to the region of geometrical shadow, there are alternate dark and bright regions. Due to bending of light waves at corners. Diffraction is a general characteristic exhibited by all types of waves, be it sound waves, light waves, water waves or matter waves. Since the wavelength of light is much smaller than the dimensions of most obstacles; we do not encounter diffraction effects of light in everyday observations.
- **Diffraction fringes**: Alternate dark and bright regions just like in interference.

Introduction

We have learnt about electromagnetic waves. The key features are

- They originate from regularly oscillating electric and magnetic fields.
- Waves consist of mutually perpendicular and oscillating electric and magnetic field vectors.
- The waves are transverse as the electric and magnetic field vectors are perpendicular to the direction of propagation. -you are familiar with the following diagram from your lesson on electromagnetic waves.



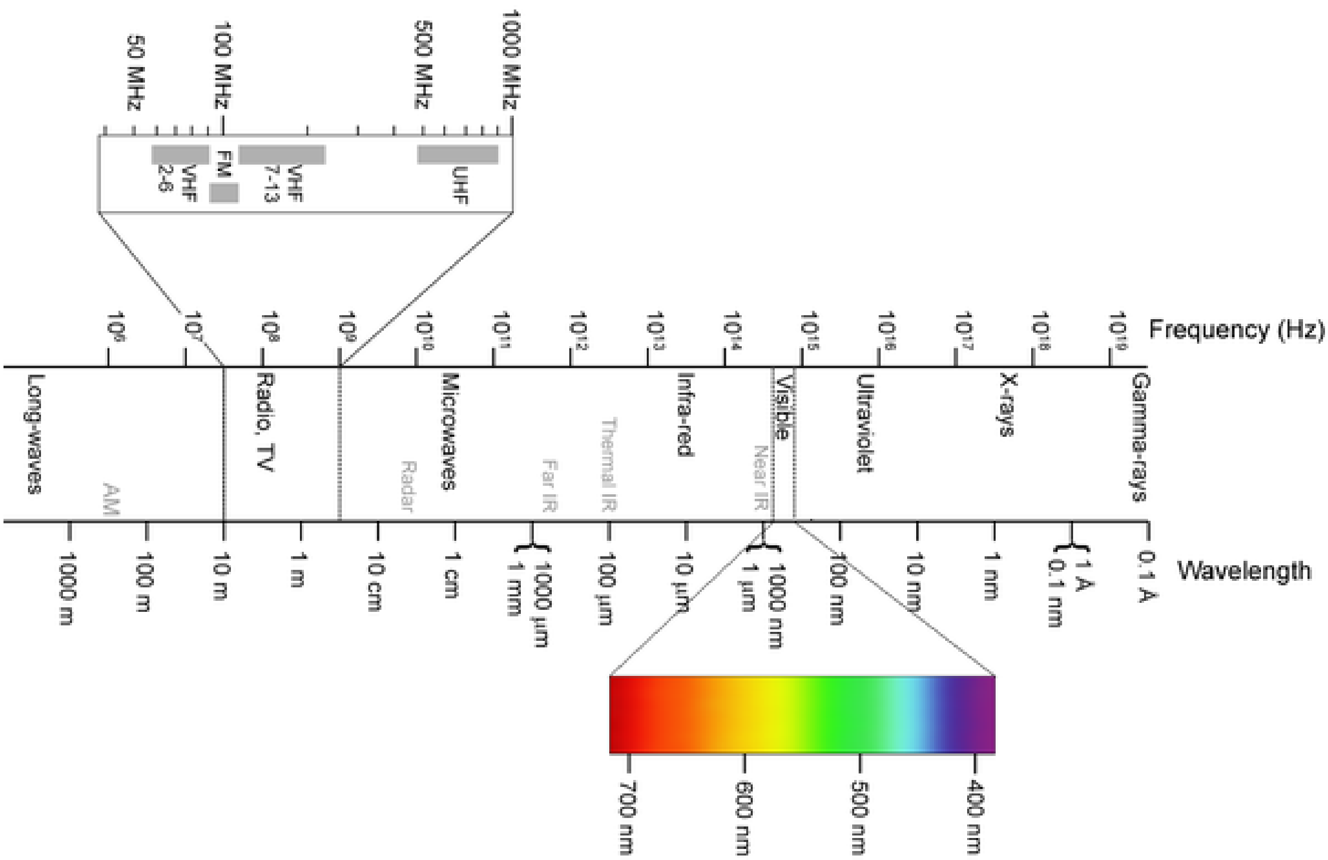
https://upload.wikimedia.org/wikipedia/commons/thumb/4/40/EM-Wave_noGIF.svg/2000px-EM-Wave_noGIF.svg.png

Also see the gif file given below. The E and B vectors are perpendicular, move with same periodicity or frequency. E and B vectors are not to scale

https://commons.wikimedia.org/wiki/File:Electromagneticwave3D.gif

- **Electromagnetic waves travel through vacuum as well as material medium**
- **The waves are associated with distinct frequency, dependent upon the frequency of the source.**

- **Electromagnetic waves have a range of frequencies.**
- **Associated with the frequency and the nature of medium through which the wave travels is the wavelength related by $v = f\lambda$**
- **The entire electromagnetic spectrum, arranged in order of their frequencies or wavelength is called the electromagnetic spectrum in increasing order of frequency (decreasing order of wavelengths,) the spectrum includes radio waves, infrared radiation, visible light, ultraviolet radiation, x rays and gamma rays.**
- **Visible light has frequencies between about 4×10^{14} and 7.9×10^{14} Hz**
- **The human eye and brain perceive different frequencies or wavelengths as different colors.**
- **All electromagnetic waves irrespective of the wavelength band travel with the same speed in vacuum.**
- **The ratio of E/B = c the velocity of light in vacuum**
- **Light originates from atoms, due to electron jumps from higher energy states to lower energy states. As changes in electrical and hence magnetic fields are involved, the emanating light wave is electromagnetic and possesses all the features of electromagnetic waves in general.**



We have learnt in previous modules that light behaves like a wave. The phenomenon of interference and diffraction, which we can only explain using wave theory.

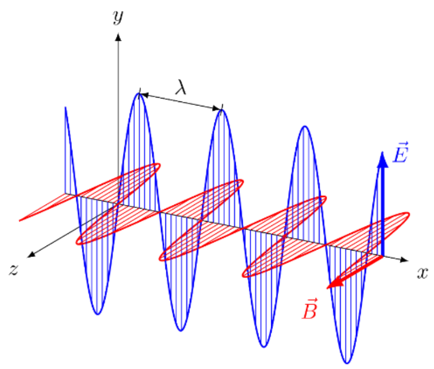
Electromagnetic Waves and hence light waves are transverse in nature. We will now learn a special phenomenon called polarisation.

This phenomenon in turn establishes the transverse nature of light waves.

The dictionary meaning of polarisation is anything thoughts, actions, behaviour conforming to a certain way.

Polarisation Of Light

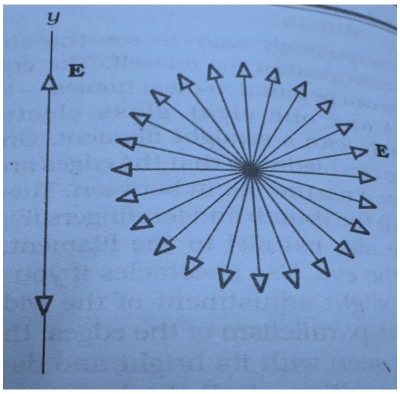
Light waves are transverse in nature; we have learnt that light is an electromagnetic wave. In



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

The illustrated wave has **the electric vector** confined to the **-y direction**. This is said to be **linearly polarised light.** The word polarisation here means **all electric vectors to lie in the x-y plane.**

Light from any source, say sun, bulbs etc. has an electric vector in any random plane at any instant which means the electric vector is perpendicular to the x axis but not restricted or confined to any particular plane.

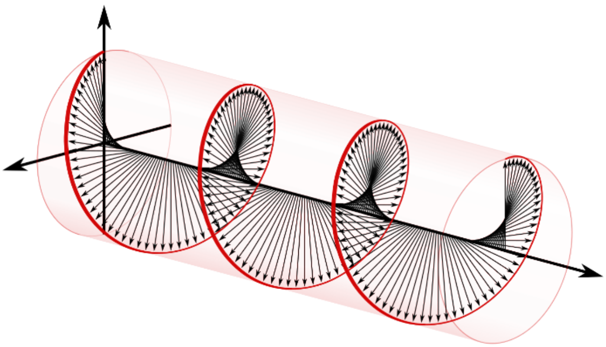


In the figure only the electric field vectors are drawn, this can help you to imagine Polarised light where the E vector is along the y axis or **unpolarised** light where the E vector could be in any direction perpendicular to the direction of propagation.

A light wave is **transverse** but **unpolarised, that** is, there is no preferred plane of polarisation.

Other than **plane polarised light, can we have other restrictions on the electric vector?**

Look at the following figure, the electric vector executes circles and is called **circularly** polarised light.



https://upload.wikimedia.org/wikipedia/commons/thumb/8/82/Circular.Polarization.Circularly.Polarized.Light_Without.Components_Right.Handed.svg/2000px-Circular.Polarization.Circularly.Polarized.Light_Without.Components_Right.Handed.svg.png

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

But in the present course we shall restrict ourselves to only plane polarised light.

DO YOU THINK

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

Yes But we talk about polarisation referring only to the electric vector.

The electric field vector is much larger as E/B = 3 $\times 10^8$ m/s

Watch

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

POLAROIDS OR POLARISERS

A transparent crystal which is such that: when unpolarised light is incident on it, the emergent light is polarised.

In the early 17th century, sailors travelling to Iceland brought back crystals now known as calcite. These crystals were natural polarizers.

Nowadays synthetic substances can be used as polaroids.

You must have seen **thin plastic** sheets, called polaroids o**r 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 polarised, 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 polarisation.

Methods Of Polarisation

It is possible to transform unpolarised light into **polarised light**. We will now, consider methods to get plane or linearly polarised light waves, in which the transverse vibrations occur in a single plane or in one direction.The process of transforming unpolarised light into polarised light is known as **polarisation**.

There are three methods of polarizing light:

- **(i) Polarisation by Transmission**
- **(ii) Polarisation by Reflection**
- **(iii)Polarisation by Scattering**

(i) Polarisation By Transmission

Use of a Polaroid Filter

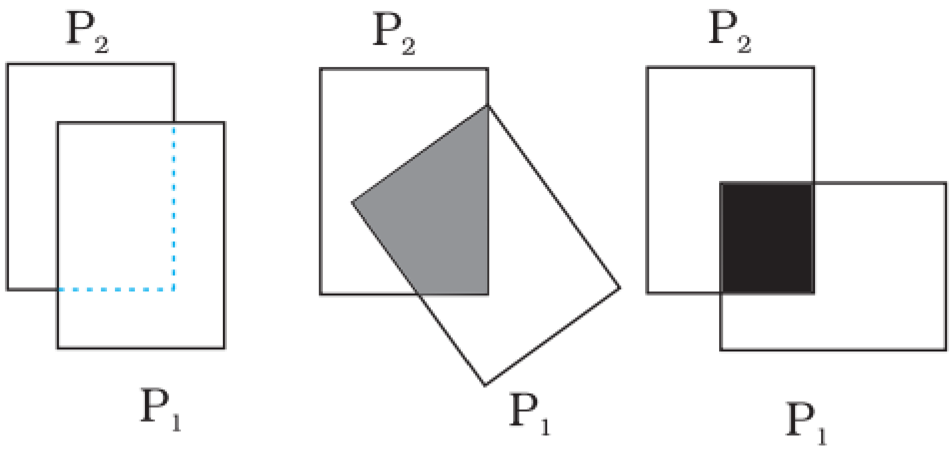
The most common method of polarisation involves the use of Polaroids.

Remember, the notion of two planes or directions of vibration is merely a simplification that helps us to visualize the wavelike nature of the electromagnetic wave. In this sense, a Polaroid serves as a device that filters out one-half of the vibrations upon transmission of the light through the filter.

When unpolarised light is transmitted through a Polaroid, it emerges with one-half the intensity and with vibrations in a single plane; it emerges as polarised light.

Thus, if an **unpolarised light** wave is incident on such a polaroid then the light wave will get **linearly polarised or plane polarised** with the electric vector oscillating along a direction perpendicular to the aligned molecules; this direction is known as the **pass-axis of the polaroid**.

If the light from an ordinary source (like a sodium lamp) passes through a polaroid sheet P_1, 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.

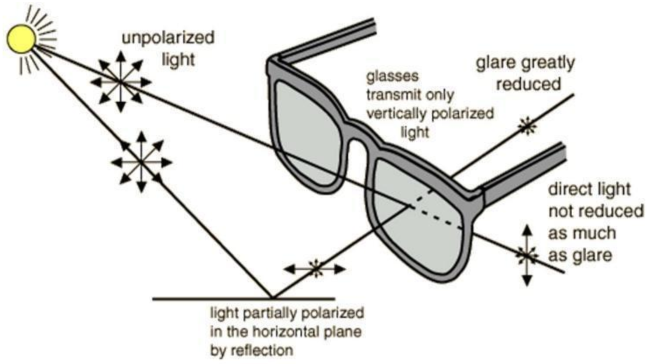
But now rotating P_1 has a dramatic effect on the light coming from P_2.

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

When turned by 90º from this position, P_1 transmits nearly the full intensity emerging from P_2

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 180^0 to 360^0

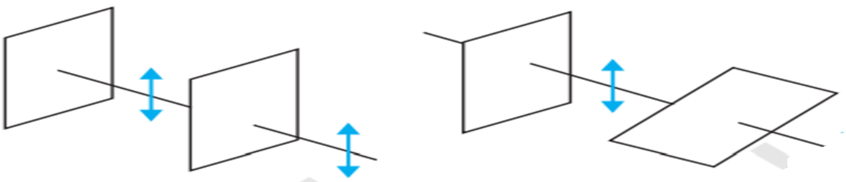
Notice that the light seen through a single polaroid P_1 does not vary with angle.



http://www.theuptightsuburbanite.com/wp-content/uploads/2016/08/howsunworks-1300x722.jpg

The transmitted polarisation 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.

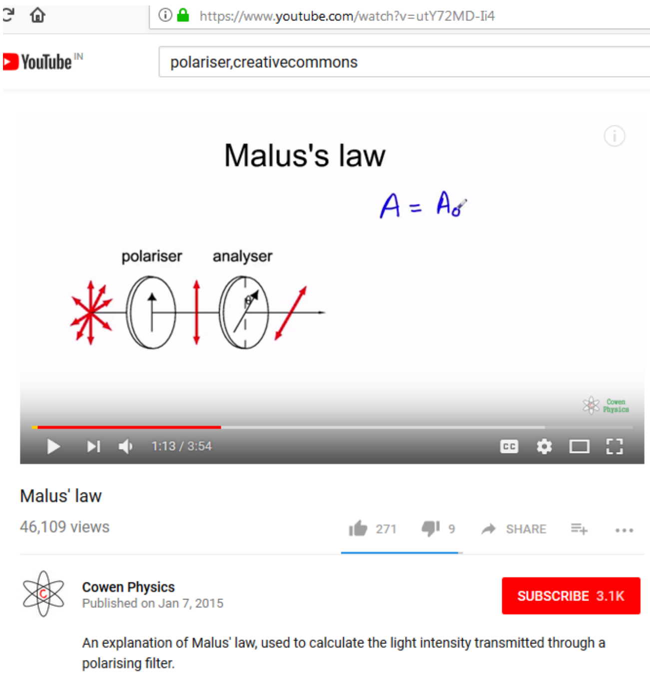
If the pass-axis of P_2 makes an angle θ with the pass-axis of P_1, then when the polarised beam passes through the polaroid P_2, the component E cos θ (along the pass-axis of P_2) will pass through P_2.

Thus, as we rotate the polaroid P_1 (or P_2), the intensity will vary as:

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

where I_0 is the intensity of the polarised light after passing through P_1 .

This is known as **Malus' law**.



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

Let Us Sum It Up

- **The above discussion shows that the intensity coming out of a single polaroid is half of the incident intensity.**
- By putting a second polaroid, the intensity can be further controlled from 50% to zero of the incident intensity by adjusting the angle between the pass-axes of two polaroids.
- **If we were to see any object through a polaroid. The polaroid does not distort the shape or dimensions of the object; it merely serves to produce a dimmer image of the object since one-half of the light is blocked**
- Polaroids can be used to control the intensity, in sunglasses, windowpanes, etc.
- **Polaroids are also used in photographic cameras and 3D movie cameras.**

Example

Discuss the intensity of transmitted light when a polaroid sheet is rotated between two crossed polaroids?

Solution:

Let I_0 be the intensity of polarised light after passing through the first polariser P_1.

Then the intensity of light after passing through second polariser P_2 will be

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

where θ is the angle between pass axes of P_1 and P_2.

Since P_1 and P_3 are crossed the angle between the pass axes of P_2 and P_3 will be $(\pi/2 - \theta)$. Hence the intensity of light emerging from P_3 will be

$$I = I_0 \cos^2\theta . \cos^2\left(\frac{\pi}{2} - \theta\right)$$

$$= I_0 \cos^2\theta \sin^2\theta = \left(\frac{I_0}{4}\right)\sin^2 2\theta$$

Hence the transmitted intensity will be maximum when $\theta = \frac{\pi}{4}$

Example:

What is the intensity of emergent light when the pass axis of polarizer and analyser are

a. 0^0

b. 180^0

Solution:

When the pass axis of the polarizer and analyzer are parallel or anti parallel to each other, the maximum intensity of plane polarised light is transmitted by the analyser and is equal to the intensity emerging from the Polariser.

Example:

Two polarizing sheets have their polarizing directions parallel so that the intensity of the transmitted light is maximum. Through what angle must the either sheet be turned if the intensity is to drop by one half?

Solution:

Here, $I = \frac{I_0}{2}$

Using Malus law,

$I = I_{0\ \cos^2\theta}$

Therefore, $\frac{I_0}{4} = I_0 \cos\theta$ or $\cos\theta = \pm\frac{1}{\sqrt{2}}$

Hence, $\theta = \pm 45^0, \pm 135^0$

The same effect occurs no matter which sheet is rotated or in which direction it is rotated.

Example:

Two polaroids are crossed to each other. If one of them is rotated through 60^0, then what percentage of the incident unpolarised light will be transmitted by the polaroids?

Solution:

Intensity of light emerging from the first polaroid, $I_1 = \frac{I_0}{2}$

Intensity of light emerging from the second polaroid, $I_2 = I_{1cos^2\theta} = \frac{I_0}{2}cos^2\theta$

$\theta = 90^0$ (initially the two polaroids are crossed to each other) and when $\theta = 60^0$

Then the angle between their polarizing directions will:

$\theta = 90^0 - 60^0 = 30^0$

Therefore,

$I_2 = \frac{I_0}{2}cos^2 30^0 = 3/8\ I_0$

Or

$\frac{I_2}{I_0} = 0.375$

Therefore, transmitted light percentage is $= \frac{I_2}{I_0} \times 100 = 37.5\%$

(ii) Polarisation By Scattering

Polarisation also occurs when light is scattered while traveling through a medium.

The light from a clear blue portion of the sky shows a rise and fall of intensity when viewed through a polaroid which is rotated.

This is nothing but sunlight, which has changed its direction (having been scattered) on encountering the molecules of the earth's atmosphere. As Figure shows, the incident sunlight is unpolarised. The dots stand for polarisation perpendicular to the plane of the figure.

The double arrows show polarisation in the plane of the figure. (There is no phase relation between these two in unpolarised light). Under the influence of the electric field of the incident wave the electrons in the molecules acquire components of motion in both these directions. We have drawn an observer looking at 90° to the direction of the sun. Clearly, charges accelerating parallel to the double arrows do not radiate energy towards this observer since their acceleration has no transverse component.

The radiation scattered by the molecule is therefore represented by dots. It is polarised perpendicular to the plane of the figure.

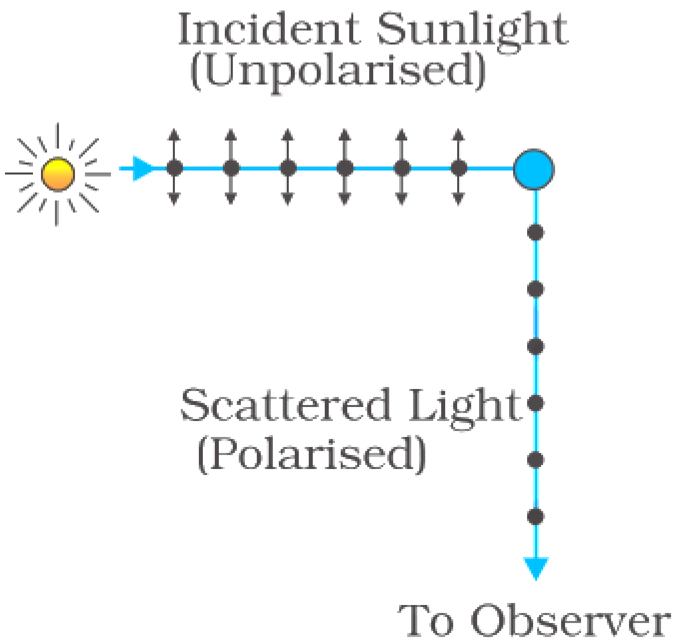
This explains the polarisation of scattered light from the sky.

This will clarify why scattering produces polarisation

When light strikes the atoms of a material, it will often set the electrons of those atoms into vibration. The vibrating electrons then produce their own electromagnetic wave that is radiated outward in all directions.

This newly generated wave strikes neighboring atoms, forcing their electrons into vibrations at the same original frequency. These vibrating electrons produce another electromagnetic wave that is once more radiated outward in all directions.

This absorption and reemission of light waves causes the light to be scattered about the medium.



Polarisation of the blue scattered light from the sky. The incident sunlight is unpolarised (dots and arrows). A typical molecule is shown. It scatters light by 90º polarised normal to the plane of the paper (dots only).

The light from a clear blue portion of the sky shows a rise and fall of intensity when viewed through a polaroid which is rotated (used as an analyser).**This process of scattering contributes to the blueness of our sky**.

This scattered light is partially polarised. Polarisation by scattering is observed as light passes through our atmosphere. The scattered light often produces a glare in the skiy. Photographers know that this partial polarisation of scattered light leads to photographs characterized by a **washed-out** sky.

The problem can easily be corrected by the use of a Polaroid filter. As the filter is rotated, the partially polarised light is blocked and the glare is reduced. The photographic secret of capturing a vivid blue sky as the backdrop of a beautiful foreground lies in the physics of polarisation and polaroid filters. The sky is blue, neat and gives good contrast.

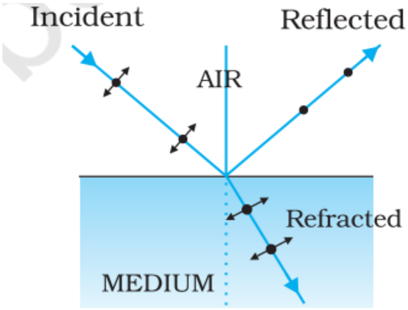
The scattering of light by molecules was intensively investigated by C.V. Raman and his collaborators in Kolkata in the 1920s.

Raman was awarded the Nobel Prize for Physics in 1930 for this work.

(iii) Polarisation By Reflection And Refraction

The figure shows light reflected from a transparent medium, say, water. As before, the dots and arrows indicate that both polarisations are present in the incident and refracted waves.

We have drawn a situation in which the reflected wave travels at right angles to the refracted wave. The oscillating electrons in the water produce the reflected wave.



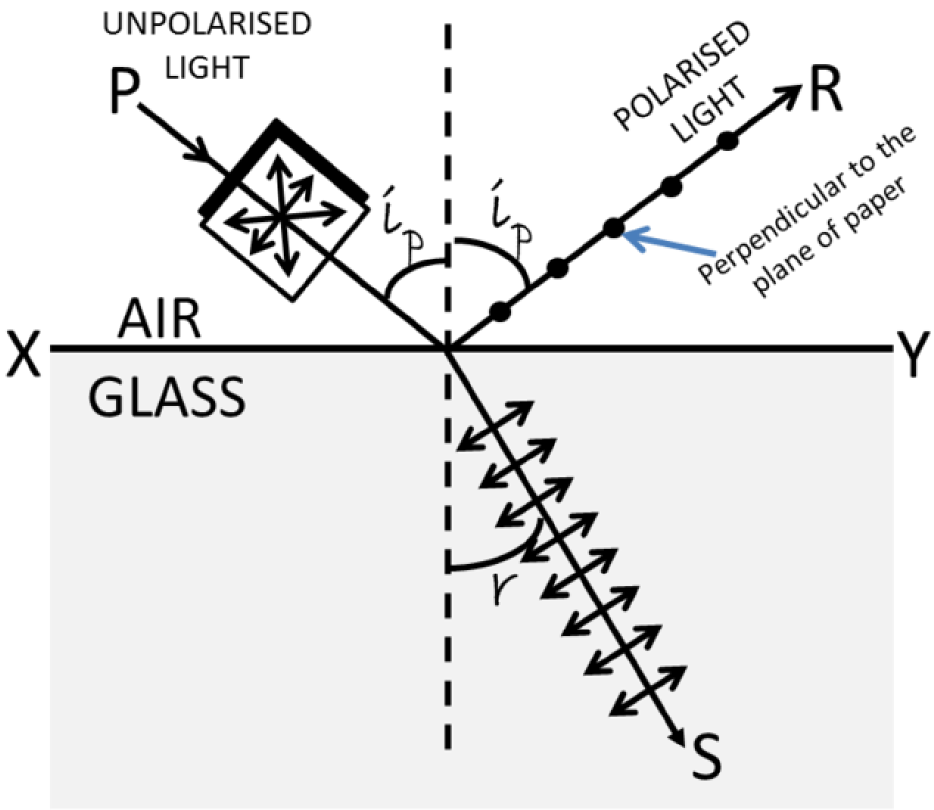
Polarisation of light reflected from a transparent medium at the Brewster angle (reflected ray perpendicular to refracted ray).

These move in the two directions transverse to the radiation from waves in the medium, i.e., the refracted wave. The arrows are parallel to the direction of the reflected wave Motion in this direction does not contribute to the reflected wave.

As the figure shows, the reflected light is therefore linearly polarised perpendicular to the plane of the figure (represented by dots). This can be checked by looking at the reflected light through an analyser. The transmitted intensity will be zero when the axis of the analyser is in the plane of the figure, i.e., the plane of incidence.

When unpolarised light is incident on the boundary between two transparent media, the reflected light is polarised with its electric vector perpendicular to the plane of incidence when the refracted and reflected rays make a right angle with each other.

Thus we have seen that **when a reflected wave is perpendicular to the refracted wave, the reflected wave is a totally polarised wave.**



https://upload.wikimedia.org/wikipedia/commons/thumb/9/92/Polarisation_of_light_by_reflection.png/694px-Polarisation_of_light_by_reflection.png

The angle of incidence in this case is called **Brewster's angle** and is denoted by i_p.

We can see that i_p is related to the refractive index of the denser medium.

Since we have Condition of polarisation by reflection from a transparent surface

$$(90 - i_P) + (90 - r) = 90$$

$$i_p + r = 90 = \pi/2,$$

we get from Snell's law

$$n = \frac{\sin i_p}{\sin r} = \frac{\sin i_p}{\sin\left(\frac{\pi}{2} - i_p\right)}$$

$$= \frac{\sin i_p}{\cos i_p} = \tan i_p$$

$$\mu \text{ or } n = \tan i_p$$

This is known as **Brewsters's law.**

Example:

Unpolarised light is incident on a plane glass surface. What should be the angle of incidence so that the reflected and refracted rays are perpendicular to each other?

Solution:

Here, $i + r = 90^0$

Therefore, $\tan i_p = \mu = 1.5$.

This gives, $i_p = 56.3°$.

Example:

Yellow light is incident on the smooth surface of a block of dense flint glass for which the refractive index is 1.6640. Find the polarizing angle. Also, find the angle of refraction.

Solution:

$\mu = 1.6640$

By Brewster's law, $\tan i_p = \mu$

Therefore, $\tan i_p = 1.6640$

$i_p = 59.0°$.

if r is the angle of refraction, then $i_p + r = 90^0$

$r = 90^0 - i_p = 31^0$

Example:

Unpolarised light is incident on a plane glass surface. What should be the angle of incidence so that the reflected and refracted rays are perpendicular to each other?

Solution:

For $i_p + r$ to be equal to $\pi/2$, we should have $\tan i_p = \mu = 1.5$.

This gives $i_p = 57°$. This is the Brewster's angle for air to glass interface

Example:

What is the Brewster angle for air to glass transition? (Refractive index of glass = 1.5.)

Solution:

$\tan i_p = \mu$

$i_p = tan^{-1} 1.5 \approx 56^0$

Our Reason To Study Wave Optics

We began wave optics by pointing out that there are some phenomena which can be explained only by the wave theory. In order to develop a proper understanding, we first described how some phenomena like reflection and refraction, which were studied on this basis of Ray Optics, can also be understood on the basis of Wave Optics.

Then we described Young's double slit experiment which was a turning point in the study of optics. Finally, we described some associated points such as diffraction, resolution, polarisation, and validity of ray optics.

Our model of the polarisation of light provides some substantial support for the wavelike nature of light. It would be extremely difficult to explain the polarisation phenomenon using a particle view of light. Polarisation would only occur with a **transverse wave**. For this reason, polarisation is one more reason why scientists believe that light exhibits wavelike behaviour.

Applications of Polaroids

Polarisation has a wealth of other applications besides their use in glare-reducing sunglasses.

In industry, Polaroid filters are used to perform stress analysis tests on transparent plastics. As light passes through a plastic, each colour of visible light is polarised with its own orientation. If such a plastic is placed between two polarizing plates, a colourful pattern is revealed. As the top plate is turned, the colour pattern changes as new colours become blocked and the formerly blocked colours are transmitted.

Polarisation is also used in the **entertainment i**ndustry to produce and show **3-D movies.** Three-dimensional movies are actually two movies being shown at the same time through two projectors. The two movies are filmed from two slightly different camera locations. Each individual movie is then projected from different sides of the audience onto a metal screen. The movies are projected through a polarizing filter. The polarizing filter used for the projector on the left may have its polarisation axis aligned horizontally while the polarizing filter used for the projector on the right would have its polarisation axis aligned vertically.

Consequently, there are two slightly different movies being projected onto a screen. Each movie is cast by light that is polarised with an orientation perpendicular to the other movie. The **audience then wears glasses that have two Polaroid filters**.

Each filter has a different polarisation axis - one is horizontal and the other is vertical.

The result of this arrangement of projectors and filters is that the left eye sees the movie that is projected from the right projector while the right eye sees the movie that is projected from the left projector. This gives the viewer a perception of depth.

Summary

- Natural light, e.g., from the sun is un-polarised. This means the electric vector takes all possible directions in the transverse plane, randomly.
- Light can be polarised, the electric vector may be restricted to move in a plane, circle or an ellipse.
- In this module we have studied only plane polarised light.
- Plane polarisation of light can be done by three methods. Passing light through a crystal -polaroids (eg calcite) scattering or reflection from a transparent surface
- A polaroid transmits only one component (parallel to a special axis). This axis is called the pass axis. The resulting light is called linearly polarised or plane polarised.
- When polarised light is viewed through a second polaroid whose axis turns through 2π, two maxima and minima of intensity are seen.
- The second polaroid which checks the polarisation produced by a polaroid is called an analyser
- Polarised light can also be produced by reflection at a special angle (called the Brewster angle)

  $\tan i_p = \mu$ or n * refractive index of the transparent medium
- Polarised light can also be produced by scattering through $\pi/2$ in the earth's atmosphere.