E-Content

On

Polarisation:Part-1

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Polarisation

Polarisation is a property applying to transverse waves that specifies the geometrical orientation of the oscillations.

A simple example of a polarized transverse wave is vibrations traveling along a taut string, for example, in a musical instrument like a guitar string. Depending on how the string is plucked, the vibrations can be in a vertical direction, horizontal direction, or at any angle perpendicular to the string. In contrast, in longitudinal waves, such as sound waves in a liquid or gas, the displacement of the particles in the oscillation is always in the direction of propagation, so these waves do not exhibit polarization. Transverse waves that exhibit polarization include electromagnetic waves such as light and radio waves, gravitational waves,[6] and transverse sound waves (shear waves) in solids.

An electromagnetic wave such as light consists of a coupled oscillating electric field and magnetic field which are always perpendicular to each other; by convention, the "polarization" of electromagnetic waves refers to the direction of the electric field. In linear polarization, the fields oscillate in a single direction. In circular or elliptical polarization, the fields rotate at a constant rate in a plane as the wave travels. The rotation can have two possible directions; if the fields rotate in a right hand sense with respect to the direction of wave travel, it is called right circular polarization, while if the fields rotate in a left hand sense, it is called left circular polarization.

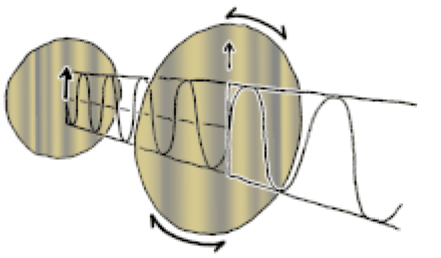
Light or other electromagnetic radiation from many sources, such as the sun, flames, and incandescent lamps, consists of short wave trains with an equal mixture of polarizations; this is called *unpolarized light*. Polarized light can be produced by passing unpolarized light through a polarizer, which allows waves of only one polarization to pass through. The most common optical materials (such as glass) are isotropic and do not affect the polarization of light passing through them; however, some materials—those that exhibit birefringence, dichroism, or optical activity—can change the polarization of light. Some of these are used to make polarizing filters. Light is also partially polarized when it reflects from a surface.

Quantum Mechanical Point of View

According to quantum mechanics, electromagnetic waves can also be viewed as streams of particles called photons. When viewed in this way, the polarization of an electromagnetic wave is determined by a quantum mechanical property of photons called their spin. A photon has one of two possible spins: it can either spin in a right hand sense or a left hand sense about its direction of travel. Circularly polarized electromagnetic waves are composed of photons with only one type of spin, either right- or left-hand. Linearly polarized waves consist of photons that are in a superposition of right and left circularly polarized states, with equal amplitude and phases synchronized to give oscillation in a plane.

Polarization is an important parameter in areas of science dealing with transverse waves, such as optics, seismology, radio, and microwaves. Especially impacted are technologies such as lasers, wireless and optical fiber telecommunications, display technology and radar.

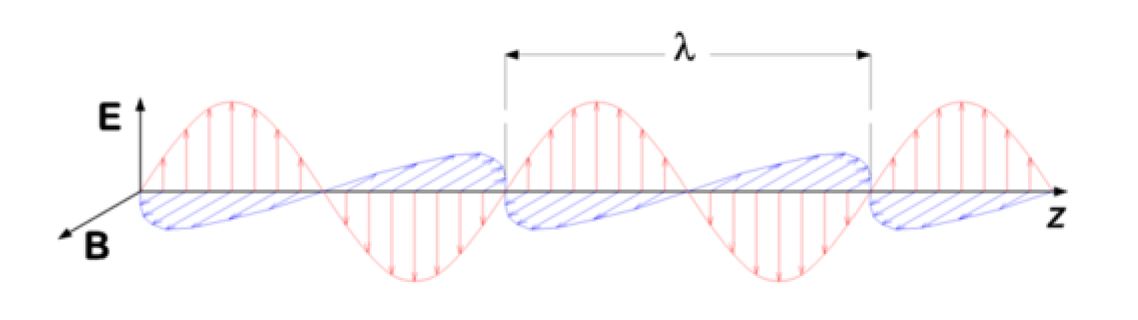
Wave propagation and polarization



cross linear polarized

Most sources of light are classified as incoherent and unpolarized (or only "partially polarized") because they consist of a random mixture of waves having different spatial characteristics, frequencies (wavelengths), phases, and polarization states. However, for understanding electromagnetic waves and polarization in particular, it is easier to just consider coherent plane waves; these are sinusoidal waves of one particular direction (or wavevector), frequency, phase, and polarization state. Characterizing an optical system in relation to a plane wave with those given parameters can then be used to predict its response to a more general case, since a wave with any specified spatial structure can be decomposed into a combination of plane waves (its so-called angular spectrum). Incoherent states can be modeled stochastically as a weighted combination of such uncorrelated waves with some distribution of frequencies (its *spectrum*), phases, and polarizations.

Transverse electromagnetic waves



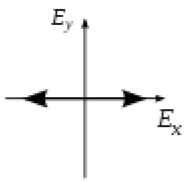
A "vertically polarized" electromagnetic wave of wavelength λ has its electric field vector **E** (red) oscillating in the vertical direction. The magnetic field **B** (or **H**) is always at right angles to it (blue), and both are perpendicular to the direction of propagation (**z**).

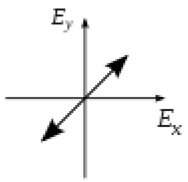
Electromagnetic waves (such as light), traveling in free space or another homogeneous isotropic non-attenuating medium, are properly described as transverse waves, meaning that a plane wave's electric field vector **E** and magnetic field **H** are in directions perpendicular to (or "transverse" to) the direction of wave propagation; **E** and **H** are also perpendicular to each other.

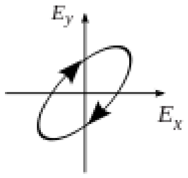
By convention, the "polarization" direction of an electromagnetic wave is given by its electric field vector. Electric field vector is also called as optical vector.

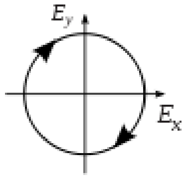
Electric field oscillation

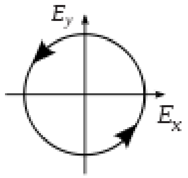
Polarization is best understood by initially considering only pure polarization states, and only a coherent sinusoidal wave at some optical frequency. The vector in the adjacent diagram might describe the oscillation of the electric field emitted by a single-mode laser (whose oscillation frequency would be typically 10^{15} times faster). The field oscillates in the *x*-*y* plane, along the page, with the wave propagating in the *z* direction, perpendicular to the page. The first two diagrams below trace the electric field vector over a complete cycle for linear polarization at two different orientations; these are each considered a distinct *state of polarization* (SOP). Note that the linear polarization at 45° can also be viewed as the addition of a horizontally linearly polarized wave (as in the leftmost figure) and a vertically polarized wave of the same amplitude *in the same phase*.

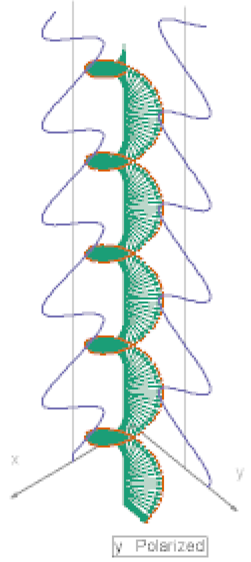


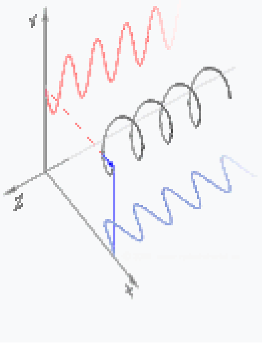



E_y
E_x


E_y
E_x


E_y
E_x


x
y
y Polarized


y

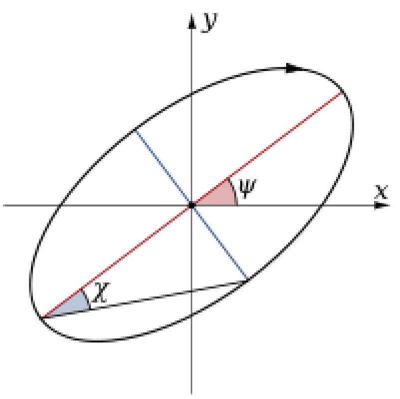
A circularly polarized wave as a sum of two linearly polarized components 90° out of phase

Now if one were to introduce a phase shift in between those horizontal and vertical polarization components, one would generally obtain elliptical polarization[12] as is shown in the third figure. When the phase shift is exactly ±90°, then *circular polarization* is produced (fourth and fifth figures). Thus is circular polarization created in practice, starting with linearly polarized light and employing a quarter-wave plate to introduce such a phase shift. The result of two such phase-shifted components in causing a rotating electric field vector is depicted in the animation on the right.

Note that circular or elliptical polarization can involve either a clockwise or counterclockwise rotation of the field. These correspond to distinct polarization states, such as the two circular polarizations shown above.

Polarization ellipse[edit]

Main article: Polarization ellipse



Consider a purely polarized monochromatic wave. If one were to plot the electric field vector over one cycle of oscillation, an ellipse would generally be obtained, as is shown in the figure, corresponding to a particular state of elliptical polarization. Note that linear polarization and circular polarization can be seen as special cases of elliptical polarization.

Unpolarized and partially polarized light

Natural light, like most other common sources of visible light, is incoherent: radiation is produced independently by a large number of atoms or molecules whose emissions are uncorrelated and generally of random polarizations. In this case the light is said to be *unpolarized*. This term is somewhat inexact, since at any instant of time at one location there is a definite direction to the electric and magnetic fields, however it implies that the polarization changes so quickly in time that it will not be measured or relevant to the outcome of an experiment. A so-called depolarizer acts on a polarized beam to create one which is actually *fully* polarized at every point, but in which the polarization varies so rapidly across the beam that it may be ignored in the intended applications.

Unpolarized light can be described as a mixture of two independent oppositely polarized streams, each with half the intensity.

Light is said to be *partially polarized* when there is more power in one of these streams than the other. At any particular wavelength, partially polarized light can be statistically described as the superposition of a completely unpolarized component and a completely polarized one.

Polarized sunglasses[edit]

Effect of a polarizer on reflection from mud flats. In the picture on the left, the horizontally oriented polarizer preferentially transmits those reflections; rotating the polarizer by 90° (right) as one would view using polarized sunglasses blocks almost all specularly reflected sunlight.

One can test whether sunglasses are polarized by looking through two pairs, with one perpendicular to the other. If both are polarized, all light will be blocked.

Unpolarized light, after being reflected by a specular (shiny) surface, generally obtains a degree of polarization. This phenomenon was observed in 1808 by the mathematician Étienne-Louis Malus, after whom Malus's law is named. Polarizing sunglasses exploit this effect to reduce glare from reflections by horizontal surfaces, notably the road ahead viewed at a grazing angle.

Wearers of polarized sunglasses will occasionally observe inadvertent polarization effects such as color-dependent birefringent effects, for example in toughened glass (e.g., car windows) or items made from transparent plastics, in conjunction with natural polarization by reflection or scattering. The polarized light from LCD monitors (see below) is very conspicuous when these are worn.

Sky polarization and photography

The effects of a polarizing filter (right image) on the sky in a photograph.

Polarization is observed in the light of the sky, as this is due to sunlight scattered by aerosols as it passes through the earth's atmosphere. The scattered light produces the brightness and color in clear skies. This partial polarization of scattered light can be used to darken the sky in photographs, increasing the contrast. This effect is most strongly observed at points on the sky making a 90° angle to the sun. Polarizing filters use these effects to optimize the results of photographing scenes in which reflection or scattering by the sky is involved.[19]:346–347[32]:495–499

Plane of polarisation

Plane of polarization being the one that contains the propagation direction and the electric vector.

Malus law

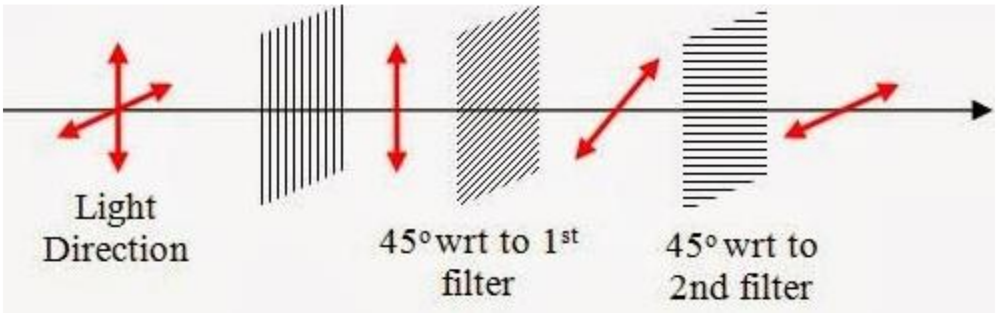
Malus' law states that the intensity of plane-polarized light that passes through an analyzer varies as the square of the cosine of the angle between the plane of the polarizer and the transmission axes of the analyzer.

Malus Law Formula

The law helps us quantitatively verify the nature of polarized light. Let us understand the expression for Malus' law.

Point 1 – When Unpolarized light is incident on an ideal polarizer the intensity of the transmitted light is exactly half that of the incident unpolarized light no matter how the polarizing axis is oriented.

Point 2 – An ideal polarizing filter passes 100% of incident unpolarized light, that is polarized in the direction of filter's (Polarizer) Polarizing axis.



Solved Problems and Questions

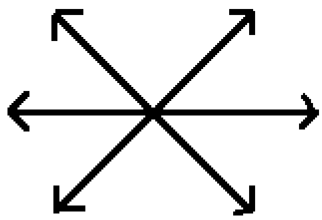
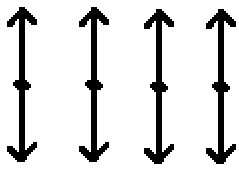
1. Which wave can be polarized?

Solution:

Lightwave gets polarised. The phenomenon of polarization takes place only in the transverse nature of waves. So sound waves cannot be polarised.

2. What is the difference between unpolarized light and plane-polarized light?

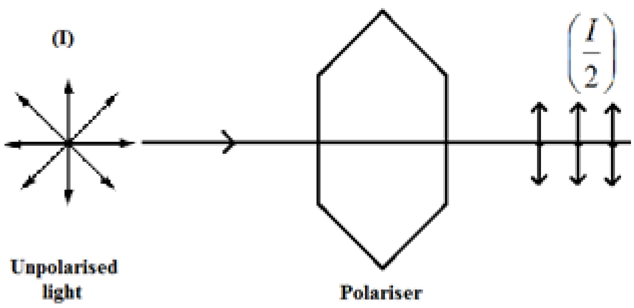
Solution:

Unpolarised light	**Plane polarised light**
	

3. An Unpolarised light with intensity (I) is passing through a polarizer. What happens to the intensity of incident light?

Solution:

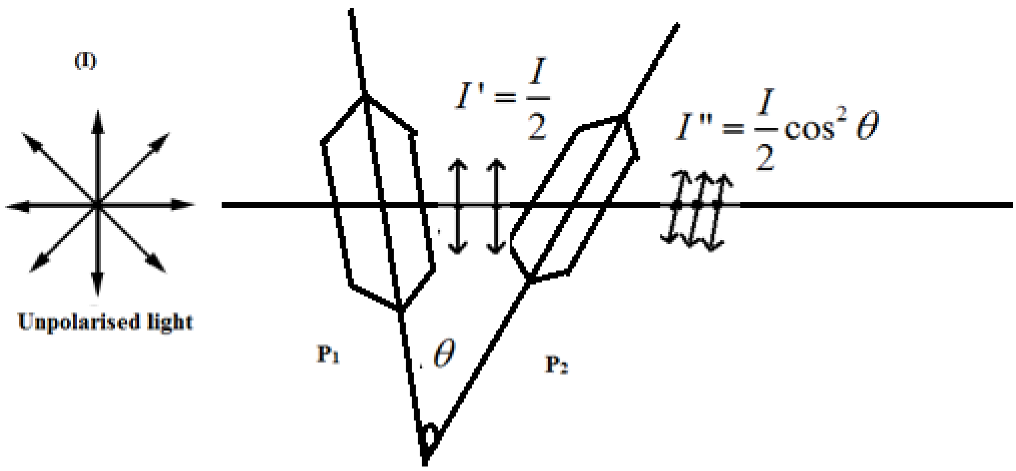
An unpolarized light of intensity (I) passes through a polariser, outcoming light intensity becomes half of its initial value\left(\frac{I}{2} \right)(2*I*).



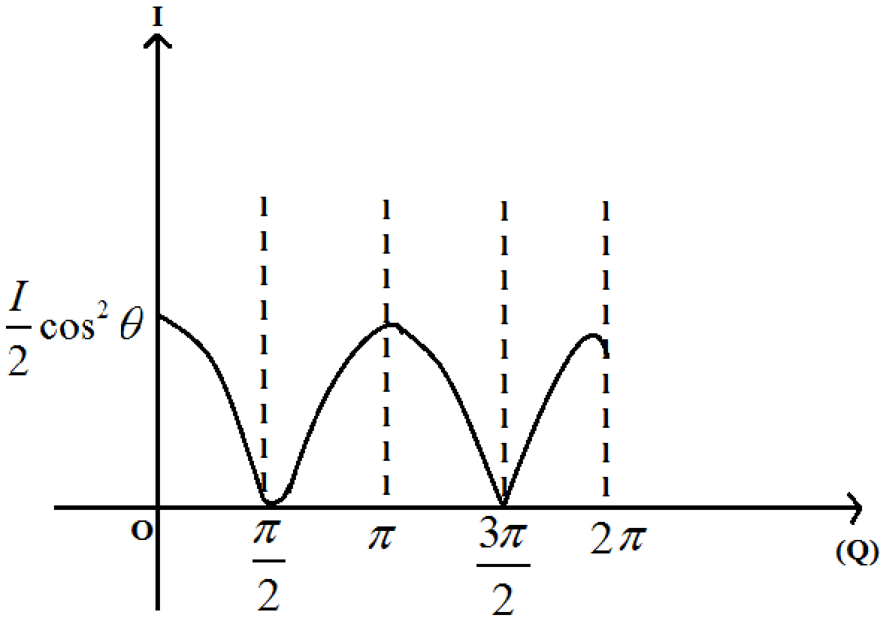
4. An unpolarised light passes through two successive polaroids (P_1 and P_2) the polaroid P_1 makes angle θ with the axis of the polaroid P_2. Find out the intensity final out coming light? And if θ is varied from 0 to 27. Plot the intensity variation graph?

Solution:

An unpolarised light passes through two successive polaroids.



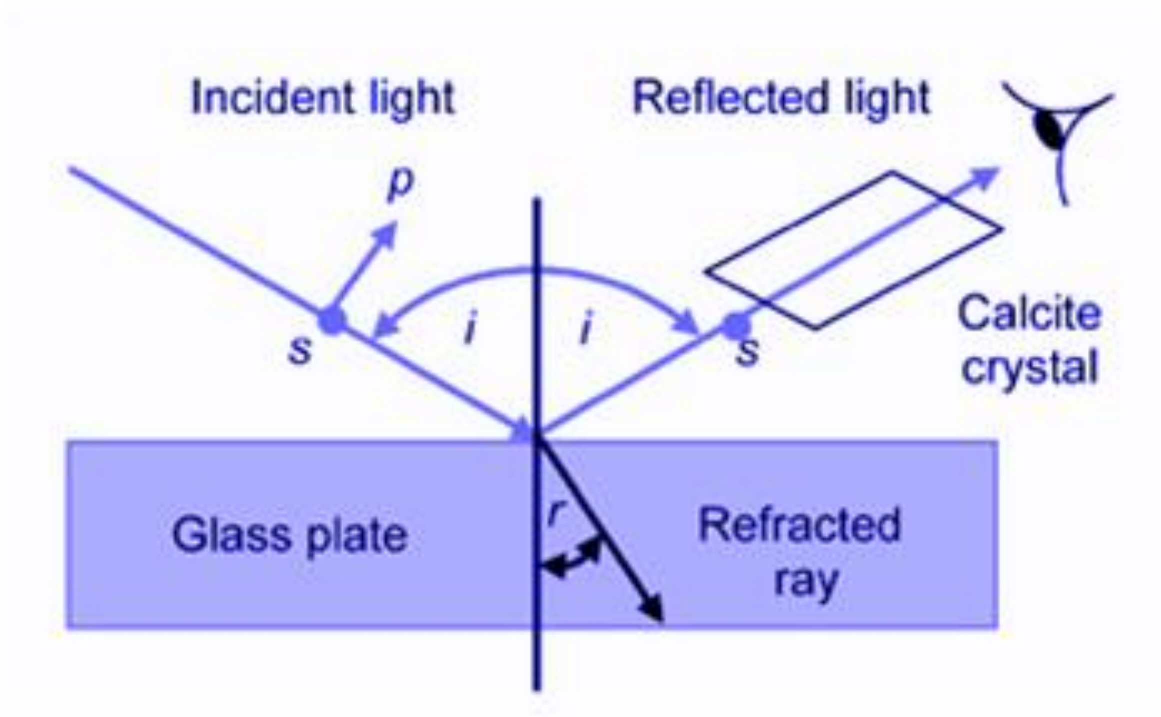
θ – is the angle between the axis of the polaroids intensity variation with respect to 0 to 2π. It is nothing ($\cos^2$ θ) curve.



Brewster's law

Brewster's law is a relationship of light waves at the maximum polarization angle of light. This law is named after Sir David Brewster, a Scottish physicist, who proposed the law in the year 1811. The law states that the p-polarized rays vanish completely on different glasses at a particular angle.

Further, the polarization angle is also called as Brewster's angle. It is an angle of incidence where the ray of light having a p-polarization transmitted through a dielectric surface that is transparent without any reflection. While, the unpolarized light at this angle is transmitted, the light is reflected from the surface.



Brewster was able to determine that the refractive index of the medium is numerically equal to the tangent angle of polarization.

$$\mu = \tan i$$

To show that reflected and refracted rays are perpendicular

From the Brewster's Law Formula.

$\mu = \tan i$

Where,

μ = Refractive index of the medium.

i = Polarization angle.

From Snell's Law:

$\mu = \sin i / \sin r$……..1

From Brewster's Law:

$\mu = \tan i = \sin i / \cos i$……..2

Comparing both formulas: 1 and 2

$\cos i = \sin r = \cos(\pi/2 - r)$

$i = \pi/2 - r$,

or $i + r = \pi/2$

Therefore, the reflected and the refracted rays are at right angles to each other.

Application of Brewster's Law

One general example for the application of Brewster's law is polarized sunglasses. These glasses uses the principle of Brewster's angle. The polarized glasses reduce glare that is reflecting directly from the sun and also from horizontal surface like road and water. Photographers also use the same law to reduce the reflection from reflective surfaces by using polarizing filter for the lens.

Birefringence or Double Refraction

When an unpolarized light beam enters an anisotropic medium such as calcite, it usually splits into two linearly polarized beams. One of the beams obeys Snell's law of refraction and is known as the *ordinary ray* (o ray). The second beam, which, in general, does not obey Snell's law, is known as the *extraordinary ray* (e ray). These two waves are linearly polarized and, in general, propagate with different wave and ray velocities (wave velocity is also referred to as phase velocity), and hence are characterized by different refractive indices. This phenomenon is known as *double refraction*, or *birefringence*, which is of great importance and is used to realize several polarization-based devices. In this chapter, we will discuss plane wave propagation in an anisotropic medium and some applications.

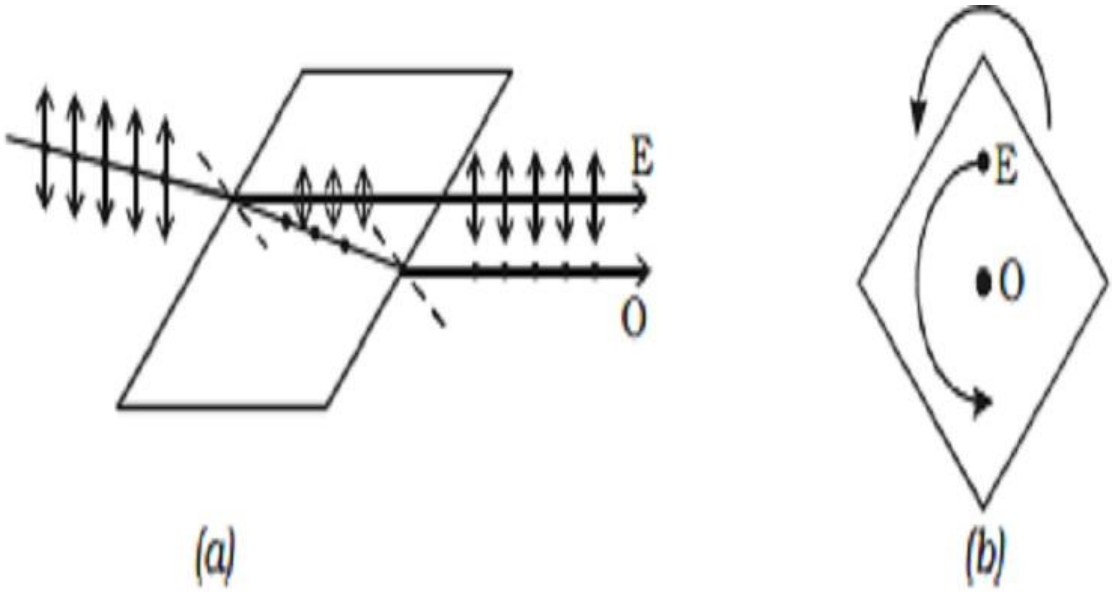
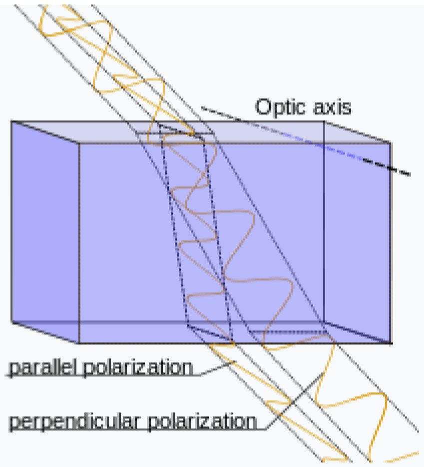


Fig Double refraction



Incoming light in the parallel (*p*) polarization sees a different effective index of refraction than light in the perpendicular (*s*) polarization, and is thus refracted at a different angle.

Doubly refracted image as seen through a calcite crystal, seen through a rotating polarizing filter illustrating the opposite polarization states of the two images.

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