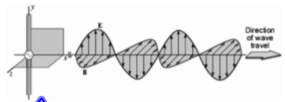
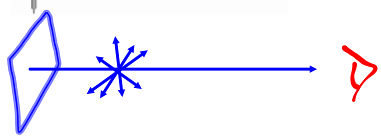
Polarization of Light

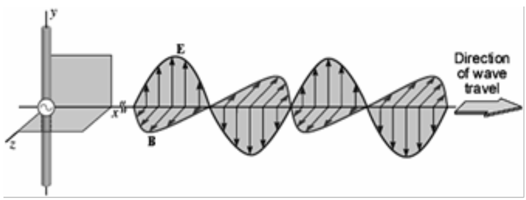
Production of EM waves: oscillating electric charge produces varying electric and magnetic fields

Transverse: vibration is perpendicular to direction of motion of energy

Speed: all EM waves travel at 3.00×10^{8} m/s in a vacuum



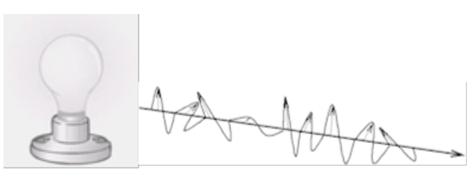


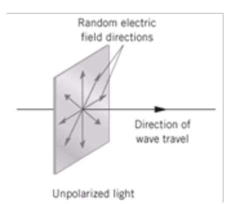


Polarization of Light

Unpolarized Light –

light in which the electric field vector vibrates in random directions



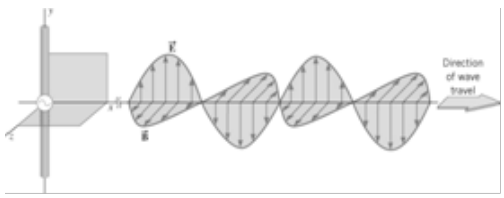


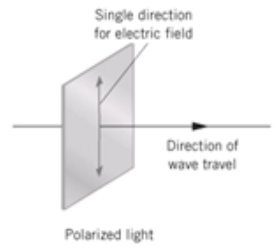
Examples: light bulb, the sun, us

Polarization of Light

Polarized Light –

light in which the electric field vector vibrates in ..one plane only





Plane of Polarization:

plane in which the electric field vector vibrates

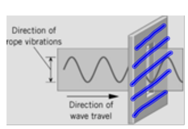
Methods of Polarization

a) Polarizing filter

Polarizer-material that produces...Plane polarized light from an unpolarized beam

Transmission axis-direction of polarization that...a polarizer allows through

Simple model of a polarizer using a wave on a rope



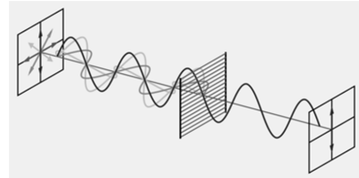
Transmission axis of polarizer is parallel to the plane of polarization of the wave

Transmission axis of polarizer is perpendicular to the plane of polarization of the wave.

Note: only transverse waves can be polarized-not longitudinal waves

Note: light can be polarized but not sound

How is a polarizing filter made?



A Polaroid polarizing filter was in its original form an arrangement of many microscopic crystals.
Its later form is made from polyvinyl alcohol (PVA) plastic with an iodine doping. Stretching of the sheet during manufacture particular direction. Electrons from the iodine dopant are able to travel along the chains, ensuring that light polarized parallel to the chains is absorbed by the sheet (resonance); light polarized perpendicularly to the chains is transmitted.

Therefore: The transmission axis is . . . perpendicular to the direction of the long chain molecules

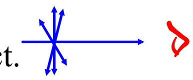
APPLICATION - IMAX 3-D films - The movies are recorded on two separate rolls of film, using a camera that provides images from the two different perspectives that correspond to what is observed by human eyes and allow us to see in three dimensions. The camera has two apertures located at roughly the spacing between our eyes. The films are projected using a projector with two lenses. Each lens has its own polarizer and the two polarizers are perpendicular.

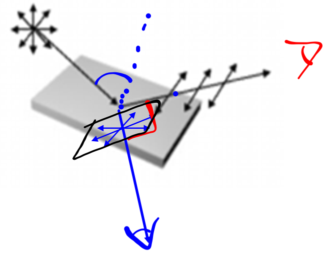
In one type of theater, viewers watch the action on-screen using glasses with corresponding polarizers for the left and right eyes.
Because of the crossed polarizers the left eye only sees the image from the left lens of the projector and the right eye sees only the image from the right lens. Since the two images have the approximate perspectives that the left and right eyes would see in reality, the brain combines the images to produce a realistic 3-D effect.

b) Reflection from a non-metallic plane surface

Sunlight is unpolarized. When sunlight is incident on an object, part of the light will be absorbed by the object (or refracted inside the object) while the rest of the light will be reflected by the object. This reflected light is partially to completely polarized, depending on the angle of incidence.

The polarization direction will be in the same direction as the surface of the object, that is, the plane of polarization for the reflected light is parallel to the surface of the object. Sunlight striking the surface of water or a road are examples where reflected light will be polarized. This is often called *glare*.





What is glare?

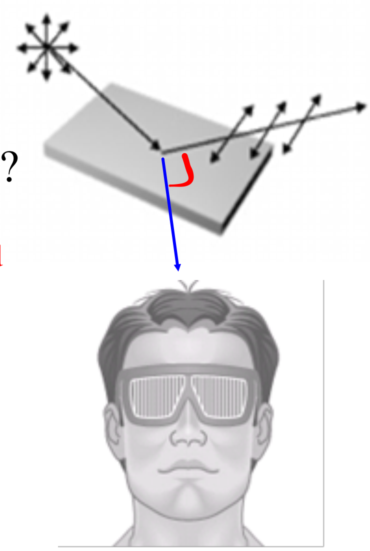
Reflected light that is polarized

What is the direction of polarization of glare?

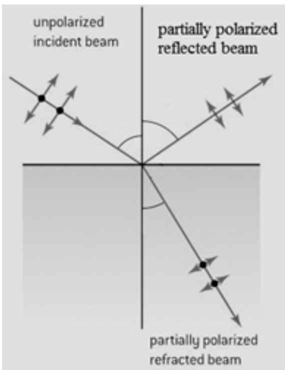
Parallel to surface (horizontal)

How do polarized sunglasses reduce glare?

Transmission axis is vertical – does not allow glare to pass through since glare is light that has been horizontally polarized by reflection from non-metallic surface

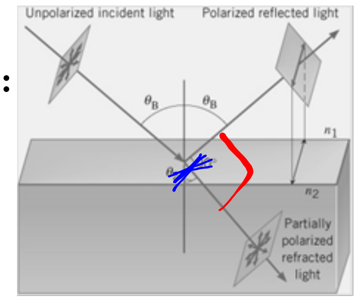


In 1809 the French experimenter Etienne-Louis Malus showed that when unpolarized light reflected off a glass plate it could be polarized to a degree that depended on the angle of incidence (left). In 1812 the Scottish physicist Sir David Brewster showed that when unpolarized light incident on the surface of an optically denser material (such as glass or water), at an angle called the polarizing angle (or Brewster's angle), the reflected ray would be completely polarized. At this angle the reflected ray and the refracted ray are at right angles (right).

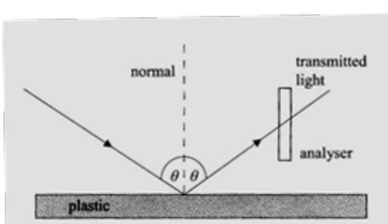


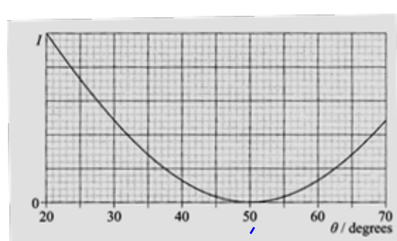
Brewster's Angle (θ_B):

$$\tan\theta_B = \frac{n_2}{n_1}$$



1. Unpolarized light is incident on the surface of a plastic. The angle of incidence is θ. The reflected light is viewed through a polarizing filter whose transmission axis is vertical. The variation with θ of the intensity *I* of the transmitted light is shown in the graph.





a) Explain why there is an angle of incidence for which the intensity of the reflected light transmitted through the polarizing filter is zero.

Light reflected off plastic is partially polarized for other angles but completely polarized parallel to the surface (horizontal) at this angle ($\theta_B = 50^o$) and so cannot pass though a vertical polarizer

b) Determine the index of refraction of the plastic.

$$\tan 50^\circ = \frac{n_2}{n_{air}}$$

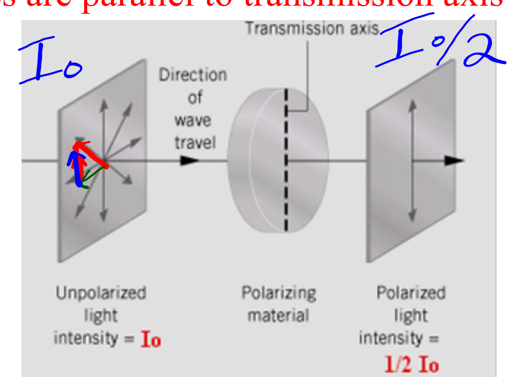
A more sophisticated model of a polarizer using light

I_0 = intensity of incident light

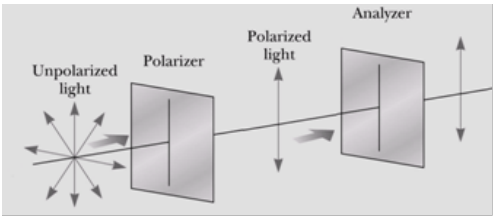
A polarizer allows the parallel component of any wave to pass through and blocks the perpendicular component of any wave.

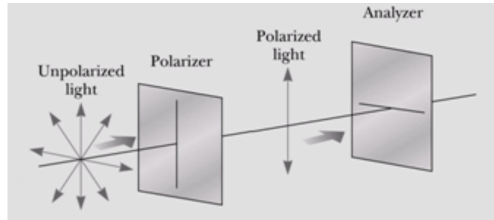
If unpolarized light is incident on a polarizer with intensity I_{-0}, what is the intensity of the transmitted polarized light? $\frac{1}{2} I_0$

Why? ½ of components of all waves are parallel to transmission axis



Analyzer – polarizer used to detect polarized light





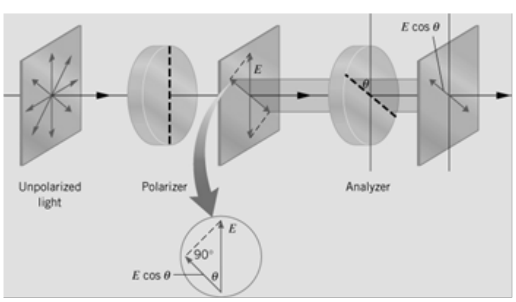
When the transmission axis of the analyzer is parallel to that of the polarizer . . . all polarized light passes through

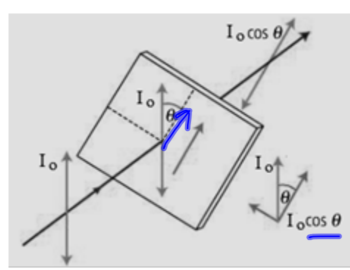
When the transmission axis of the analyzer is perpendicular to that of the polarizer . . . no light passes through

What happens when the analyzer is neither parallel nor perpendicular to the polarizer?

Only the component of the polarized light . . .

parallel to the transmission axis of the analyzer passes through





Malus' Law:

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

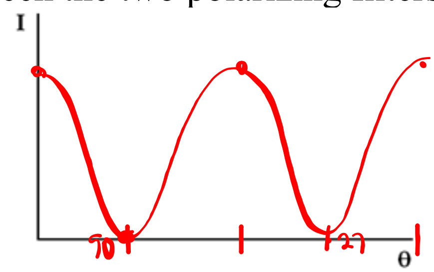
Where:

I = transmitted intensity

I_0 = intensity of light incident **on the analyzer**

θ = angle between transmission axis of polarizer and analyzer

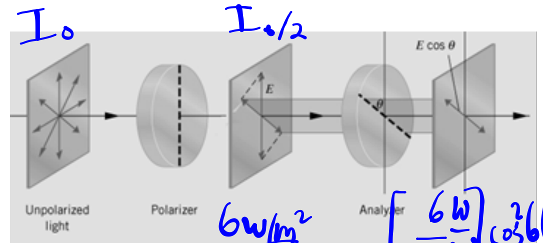
2. Sketch the relationship between the intensity of the transmitted light and the angle between the two polarizing filters.



3. Natural, unpolarized light of intensity 6.0 W m^{-2} is incident on two polarizing filters oriented at 60^0 to each other.
Find the intensity of the light transmitted through each of them.

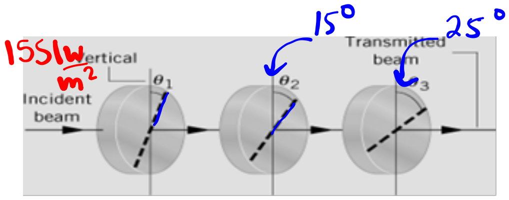
I_0 $\quad$ $I_0/2$

$6\,w/m^2$



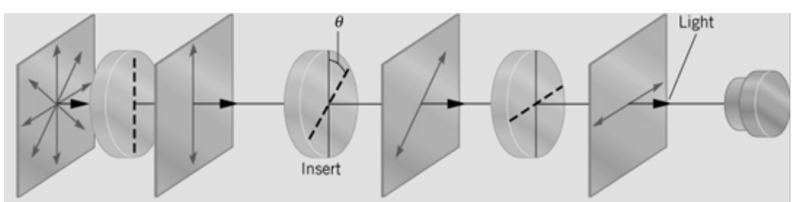
$\dfrac{6\,w/m^2}{2}$ $\quad$ $\left[\dfrac{6\,W/m^2}{2}\right]\cos^2 60^\circ$

4. A beam of unpolarized light, whose intensity is 1551 W/m^2, is incident on the first polarizing filter as shown. The three filters make angles of $\theta_1 = 30^o$, $\theta_2 = 45^o$, and $\theta_3 = 70^o$ with the vertical as shown. What is the final intensity of the beam transmitted through the three filters?



How can light be transmitted through "crossed polarizers?"

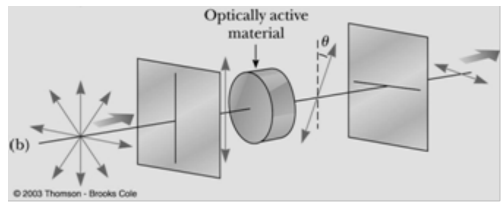
Insert an intermediate polarizer (or an optically active substance) between the original polarizer and the analyzer. Some component of light from the first polarizer will make it through this intermediate polarizer and then some component of this light will make it through the analyzer. The intermediate polarizer "rotates the plane of polarization" at the cost of lost intensity.



Optically Active Substance –

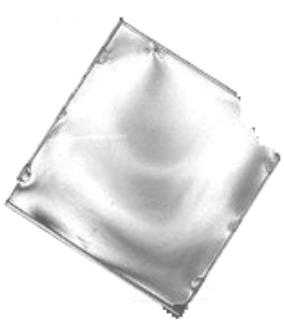
a) one that rotates the plane of polarization of the light that passes through it

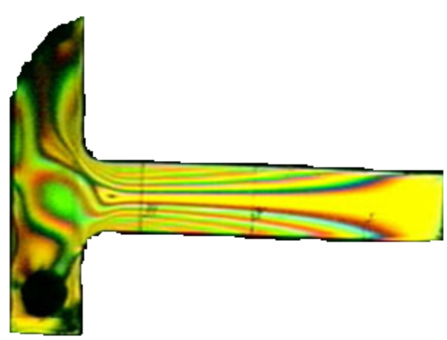
b) one that changes the plane in which the electric field vector of the light vibrates



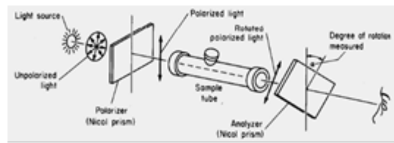
Applications of polarization

1. **Stress analysis**: Some materials are optically active under stress and allow different colors to pass through at different angles.
Engineers can build models out of plastic and subject them to stress. Then when they are placed between a polarizer and an analyzer and viewed, points of probable mechanical failure due to high stress can be determined.





2. **Determining the concentration of solutions**: Sugar solutions, such as glucose, are optically active. The angle by which polarized light is rotated when passing through the solution is related to the concentration of the solution. Therefore, if a container with a sugar solution is placed between a polarizer and an analyzer and the analyzer is rotated until the intensity of the light passing through it is maximum then from measuring the angle of rotation the concentration of the solution can be calculated.



3. **Liquid crystal displays (LCD):** Calculators, watches, computer screens and televisions have displays that are made up of thousands of small dots called pixels. In an LCD, each pixel is made of a tiny liquid crystal. Liquid crystals have a very useful property; normally they rotate the plane of polarization through 90^0, but when a voltage is applied across them, they don't. So if a liquid crystal is placed between two crossed polarizers the crystal goes dark when the voltage is applied.