DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
IB PHYSICS

TSOKOS LESSON 4-3
WAVE CHARACTERISTICS

Reading Activity Questions?

Essential Idea:

- All waves can be described by the same sets of mathematical ideas. Detailed knowledge of one area leads to the possibility of prediction in another.

Nature Of Science:

- **Imagination:** It is speculated that polarization had been utilized by the Vikings through their use of Iceland Spar over 1300 years ago for navigation (prior to the introduction of the magnetic compass). Scientists across Europe in the 17th–19th centuries continued to contribute to wave theory by building on the theories and models proposed as our understanding developed.

Theory Of Knowledge:

- Wavefronts and rays are visualizations that help our understanding of reality, characteristic of modeling in the physical sciences.
- How does the methodology used in the natural sciences differ from the methodology used in the human sciences?
- How much detail does a model need to contain to accurately represent reality?

Understandings:

- Wavefronts and rays
- Amplitude and intensity
- Superposition
- Polarization

Applications And Skills:

- Sketching and interpreting diagrams involving wavefronts and rays
- Solving problems involving amplitude, intensity and the inverse square law
- Sketching and interpreting the superposition of pulses and waves

Applications And Skills:

- Describing methods of polarization
- Sketching and interpreting diagrams illustrating polarized, reflected and transmitted beams
- Solving problems involving Malus's law

Guidance:

- Students will be expected to calculate the resultant of two waves or pulses both graphically and algebraically
- Methods of polarization will be restricted to the use of polarizing filters and reflection from a non-metallic plane surface

Data Booklet Reference:

$$I \propto A^2$$

$$I \propto x^{-2}$$

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

Utilization:

- A number of modern technologies, such as LCD displays, rely on polarization for their operation

Aims:

- Aim 3: these universal behaviours of waves are applied in later sections of the course in more advanced topics, allowing students to generalize the various types of waves

Aims:

- Aim 6: experiments could include (but are not limited to): observation of polarization under different conditions, including the use of microwaves; superposition of waves; representation of wave types using physical models (eg slinky demonstrations)

Aims:

- Aim 7: use of computer modelling enables students to observe wave motion in three dimensions as well as being able to more accurately adjust wave characteristics in superposition demonstrations

Introductory Video:
Polarization of Light

Wavefronts and Rays

- If you consider a wave to be moving horizontally, a ***wavefront*** is a plane perpendicular to the wave and perpendicular to the direction the wave is travelling

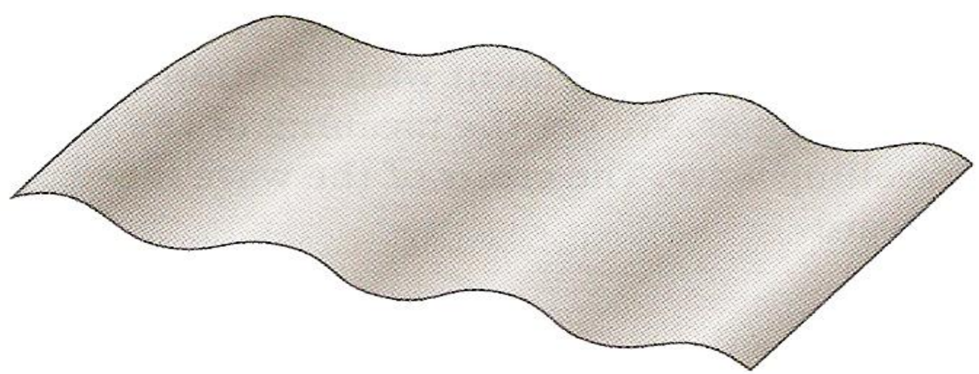
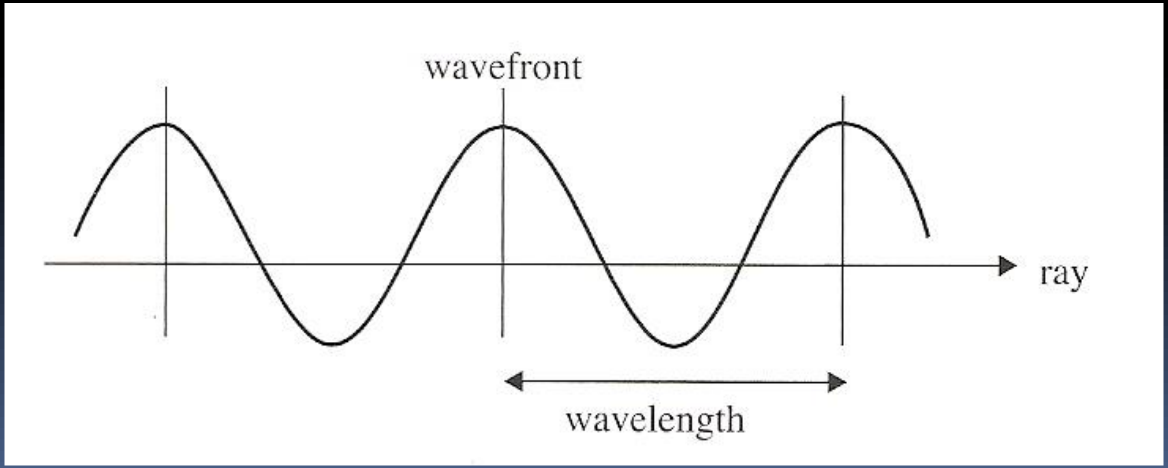


Figure 2.17 A two-dimensional wave.

Wavefronts and Rays

- Rays are a pretty good baseball team
- They are also lines perpendicular to the wavefronts in the direction the wave is travelling



Wavefronts and Rays

- Examples:
  - The waves on the beach would have a rectangular wavefront
  - If you drop a stone in the water, the wavefront would be cylindrical
  - Light waves from a point source would have spherical wavefronts

Amplitude and Intensity

- Force is in Newtons
- Work /Energy is force times distance = N·m or Joules
- Power is Work/Energy per unit time = J/s or Watts
- Intensity is Power per square area = W/m^2

Amplitude and Intensity

- If power is radiated spherically from a point source (old light bulb),

$$I = \frac{P}{4\pi x^2}$$

Amplitude and Intensity

- Inverse square law: Intensity is proportional to the inverse of the square of the distance

$$I = \frac{P}{4\pi x^2}$$

$$I \propto x^{-2}$$

Amplitude and Intensity

- Since intensity is a function of energy and energy of a wave is proportional to the square of the amplitude,

$$I = \frac{P}{4\pi x^2}$$

$$I \propto x^{-1}$$

$$I \propto A^2$$

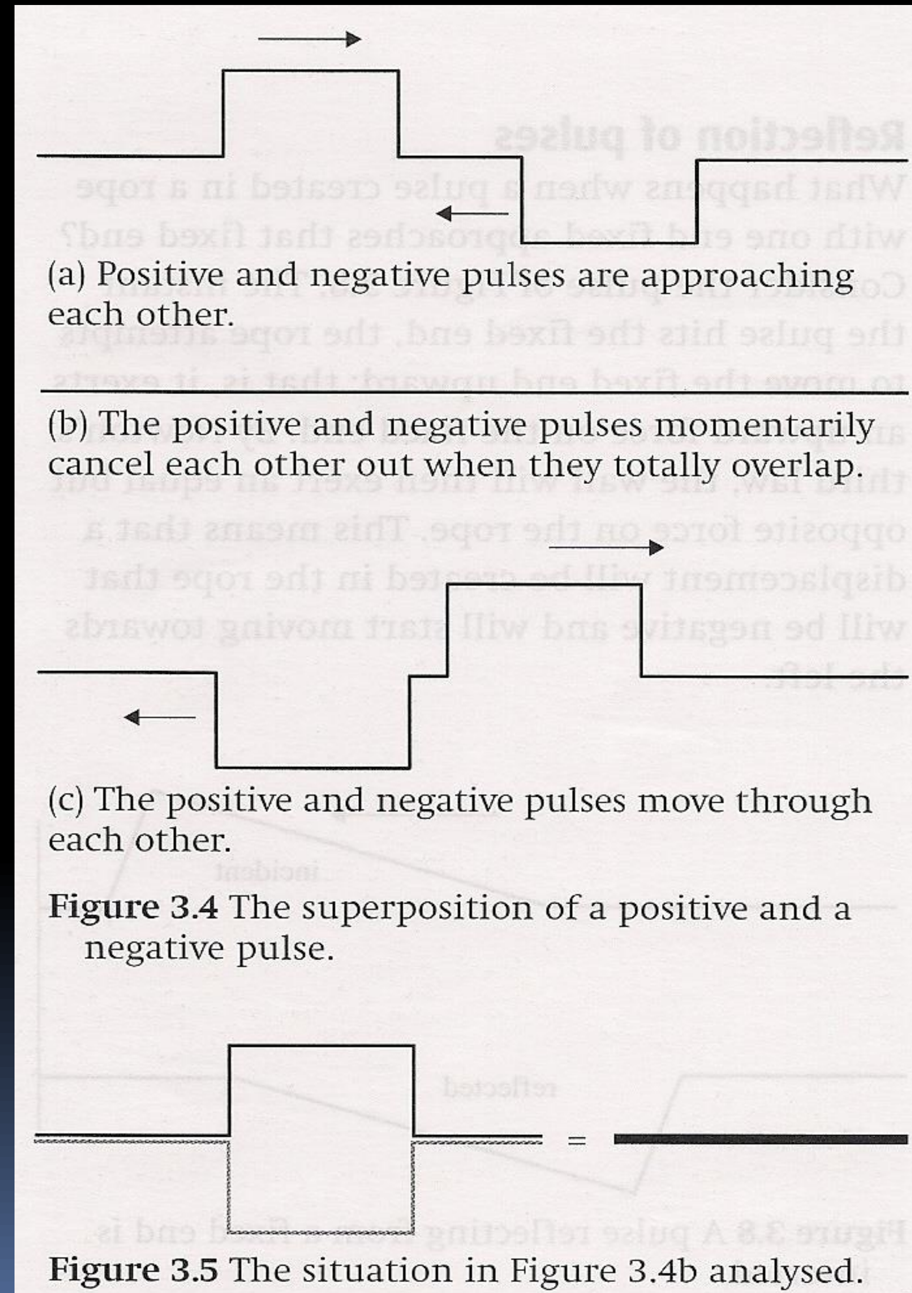
Superposition
Not Super Position

Superposition

- **When two or more pulses meet, the displacement at that point is the algebraic sum of the individual displacements**
- ***Review of Reflection and Superposition***

Superposition

- **Superposition of two opposite, but equal pulses**



(a) Positive and negative pulses are approaching each other.

(b) The positive and negative pulses momentarily cancel each other out when they totally overlap.

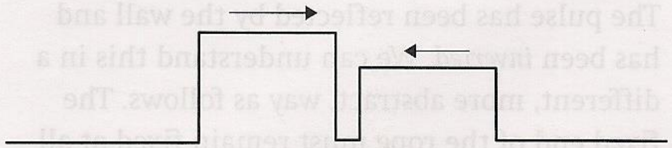
(c) The positive and negative pulses move through each other.

Figure 3.4 The superposition of a positive and a negative pulse.

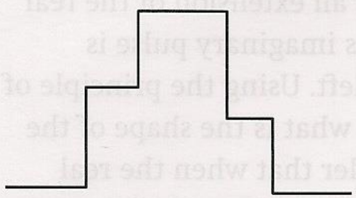
Figure 3.5 The situation in Figure 3.4b analysed.

Superposition

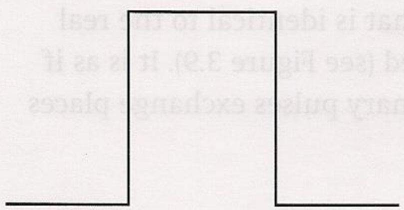
- **Superposition of two positive and unequal pulses**



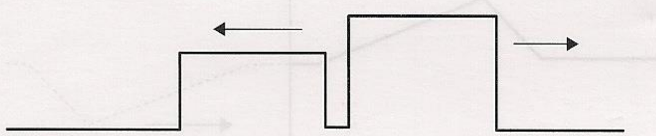
(a) The pulses are approaching each other.



(b) The pulses are beginning to overlap.



(c) The overlap is complete; the pulses are on top of each other.



(d) The pulses move through each other.

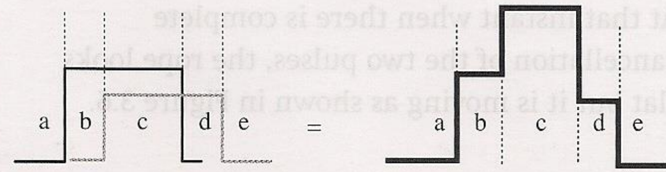


Figure 3.2 The situation in Figure 3.1b analysed.

so the resulting pulse is also zero. In region b, both are non-zero and the resulting pulse is the sum of the individual pulse heights.

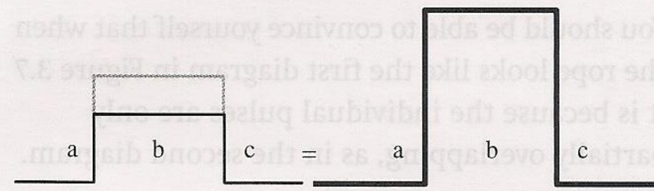
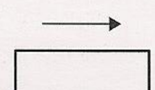


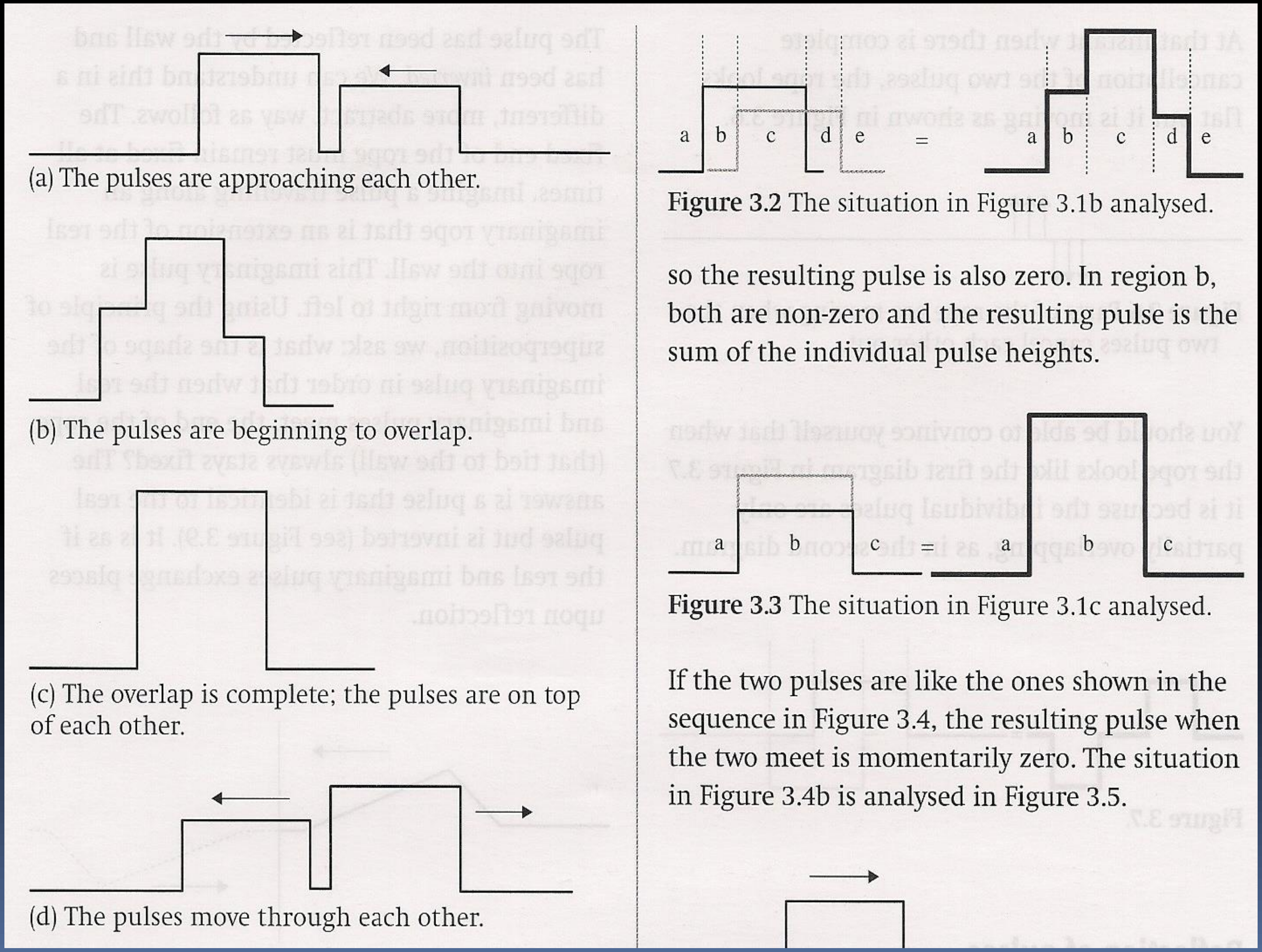
Figure 3.3 The situation in Figure 3.1c analysed.

If the two pulses are like the ones shown in the sequence in Figure 3.4, the resulting pulse when the two meet is momentarily zero. The situation in Figure 3.4b is analysed in Figure 3.5.



Superposition

- **After superposition, the waves continue as if nothing ever happened**



(a) The pulses are approaching each other.

(b) The pulses are beginning to overlap.

(c) The overlap is complete; the pulses are on top of each other.

(d) The pulses move through each other.

Figure 3.2 The situation in Figure 3.1b analysed.

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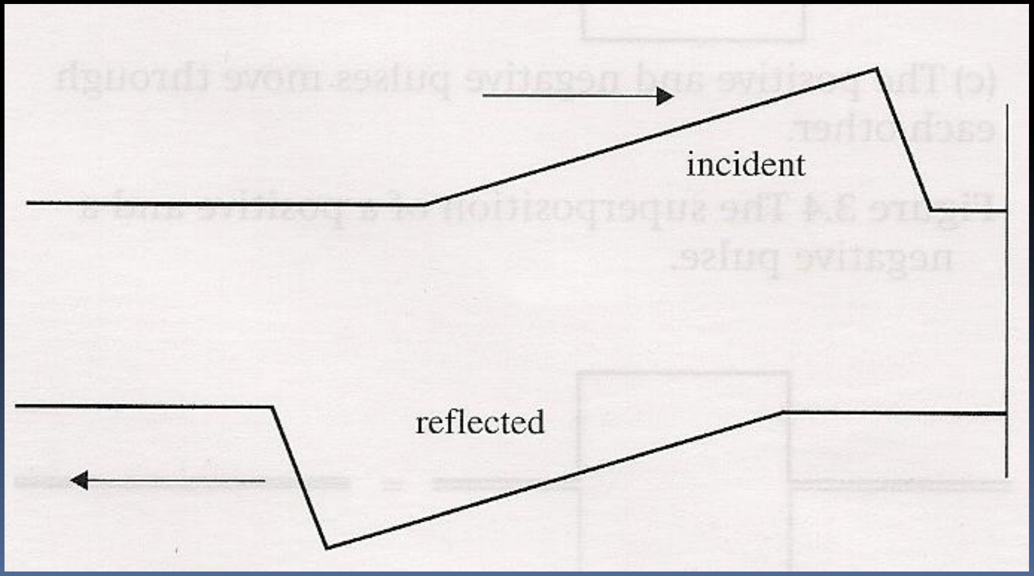
Law of Reflection

- *Light Reflection and Refraction*

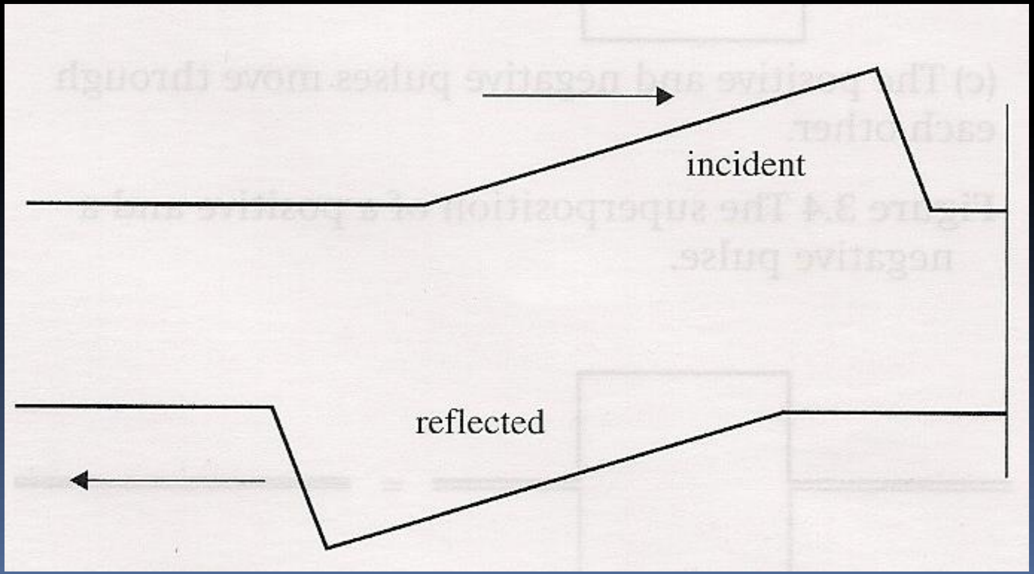
Law of Reflection

- ***What happens to a pulse on a rope tied to a wall?***



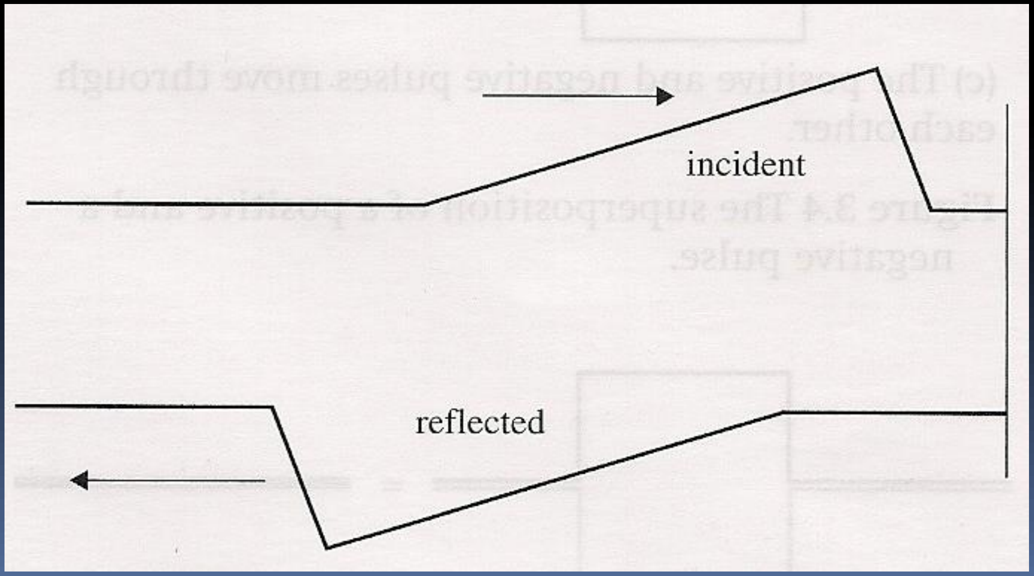
Law of Reflection

- *What happens to a pulse on a rope tied to a wall?*
- *The pulse reflects inverted and traveling in the opposite direction:*



Law of Reflection

- *What when a series of pulses travels on a rope tied to a wall?*
- *The pulses reflect inverted, they travel through one another, and they cancel one another when they meet – superposition.*



Law of Reflection

- ***Law of Reflection***: The ***angle of incidence, i*** (angle between the ray and the normal to the reflecting surface at the point of incidence) is equal to the ***angle of reflection, r*** (angle between the normal and the reflected ray).

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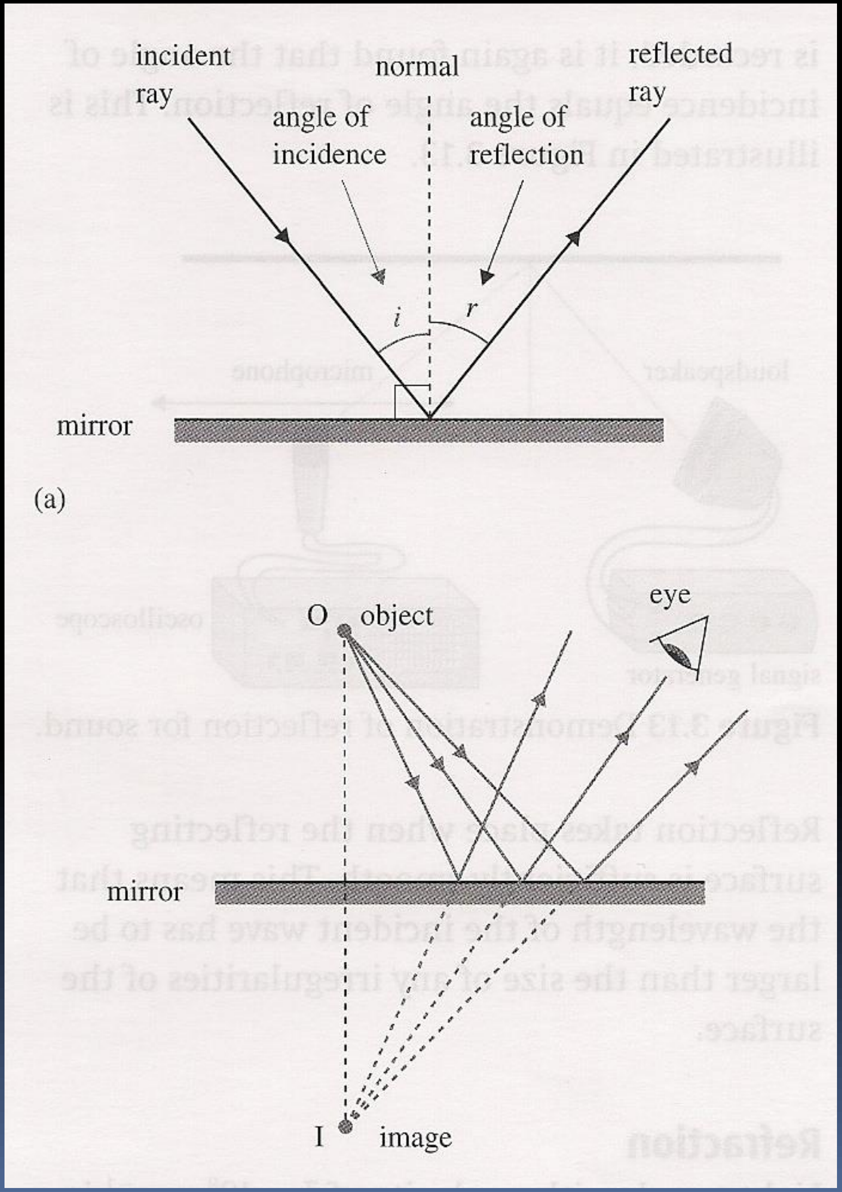
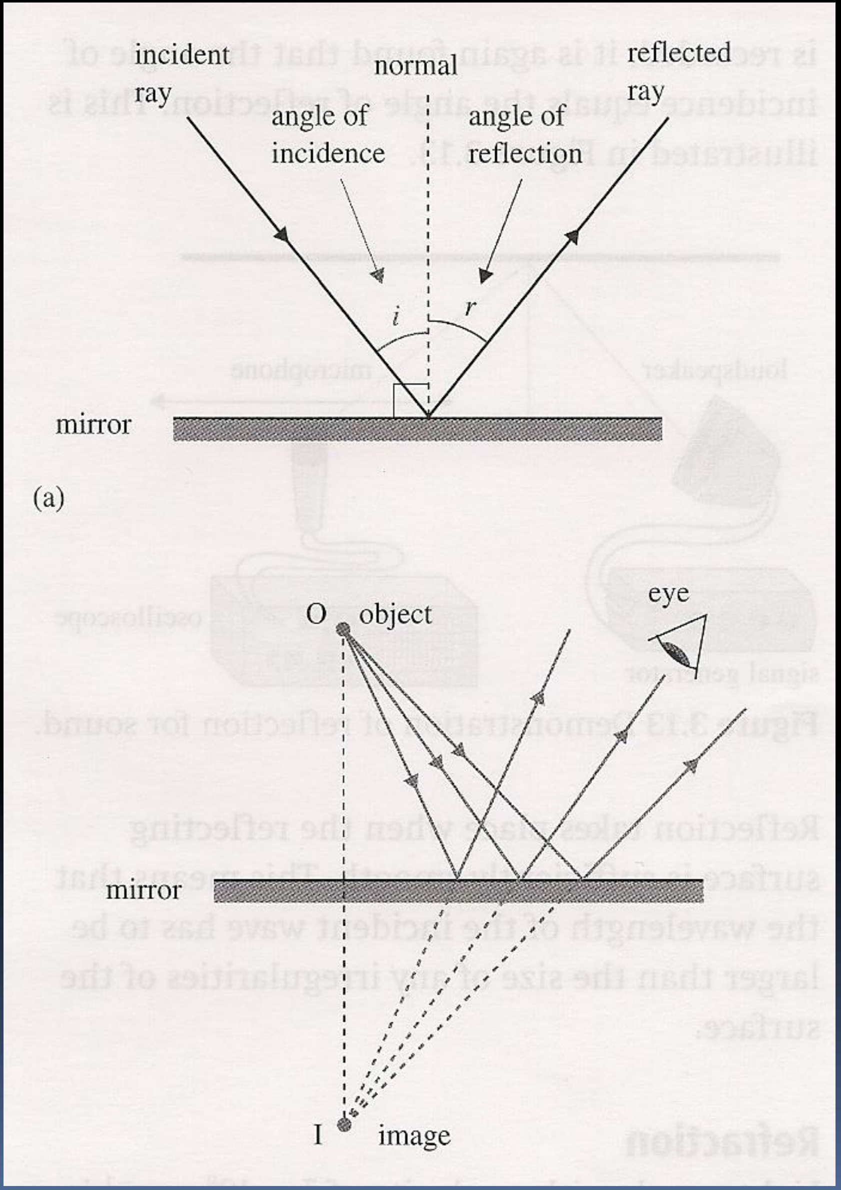


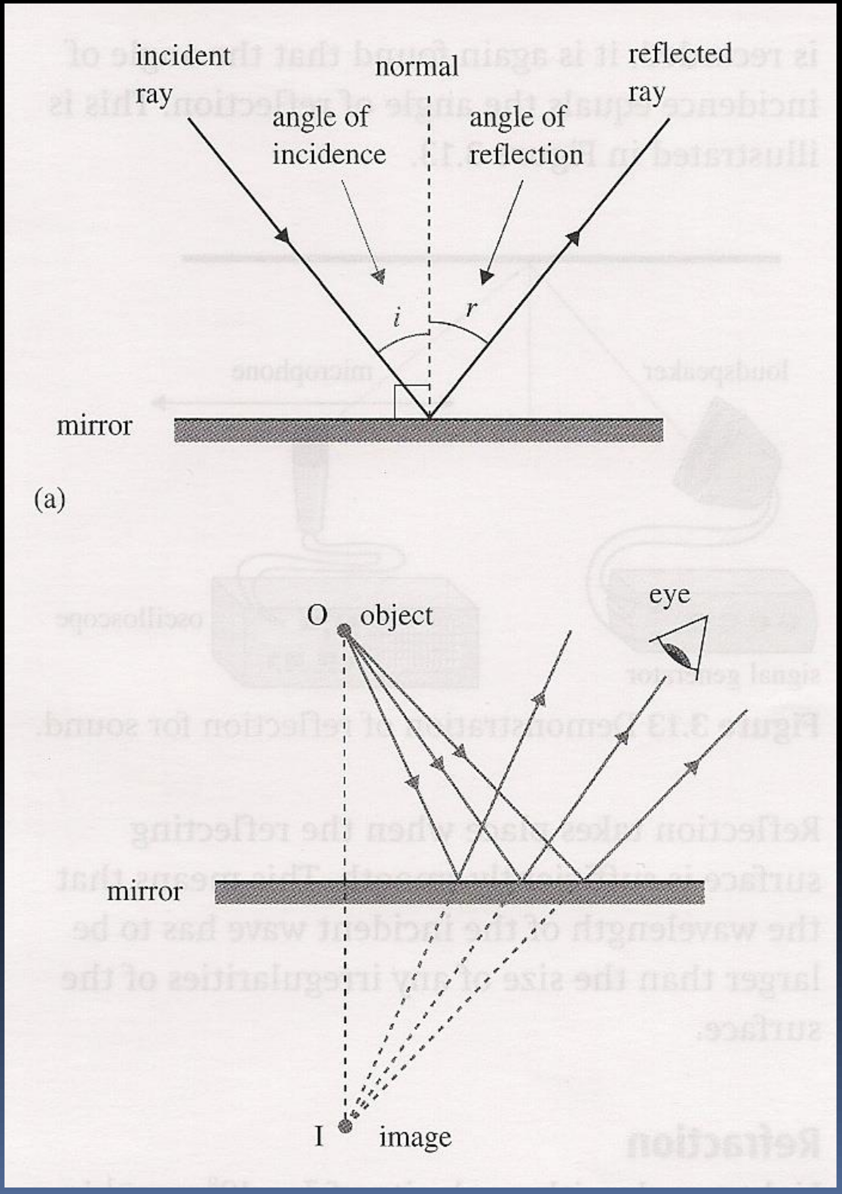
Law of Reflection

- **The reflected and incident rays and the normal to the surface lie on the same plane, called the plane of incidence.**



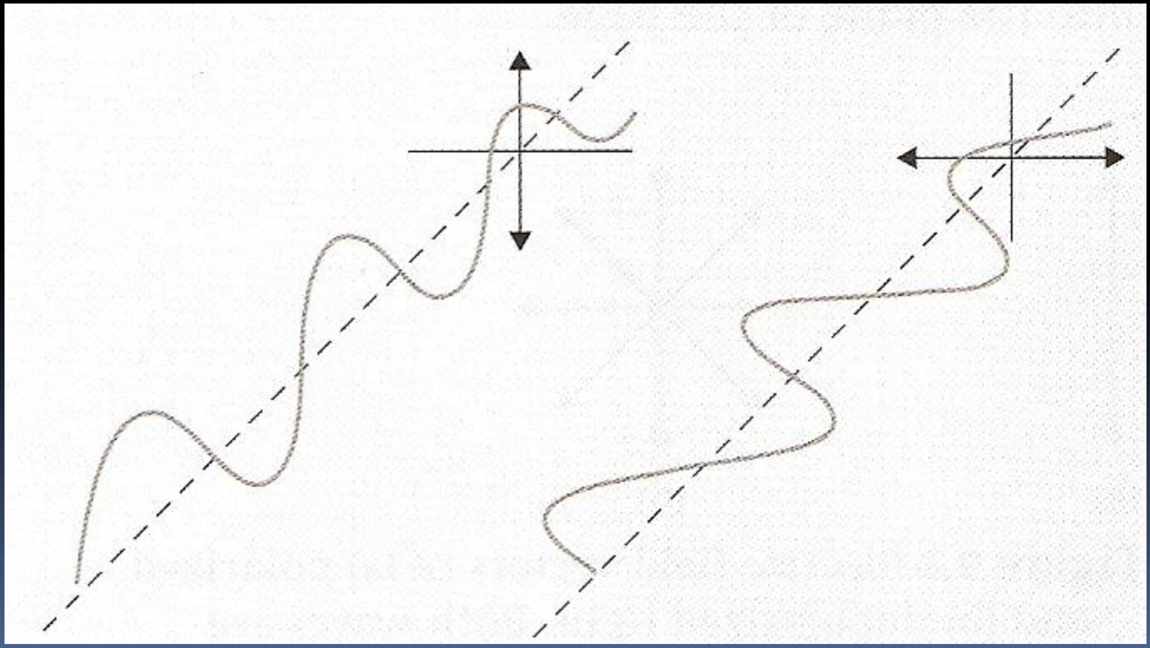
Law of Reflection

- **Reflection takes place when the reflecting surface is sufficiently smooth i.e., the wavelength of the incident wave is larger than any irregularities in the surface**



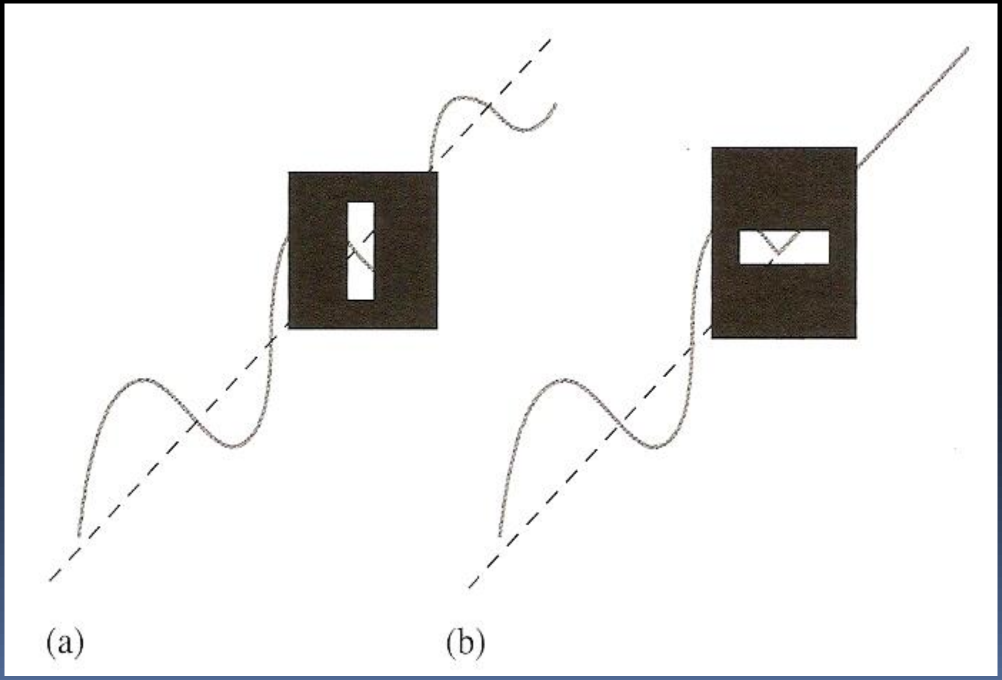
Polarization

- Property of all transverse waves
- Changes in electron energy levels release plane-polarized photons



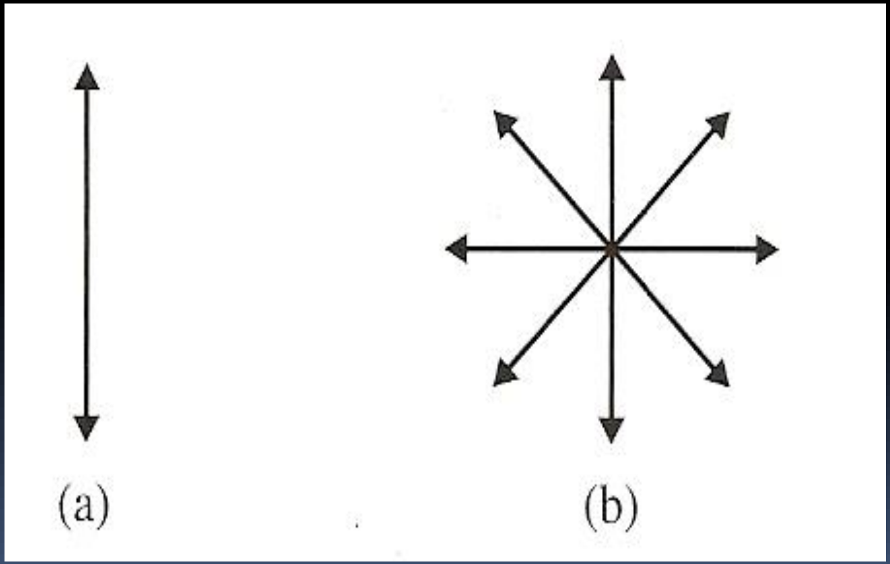
Polarization

- A light wave polarized in the vertical direction will pass through a vertical slit, but is stopped by a horizontal slit



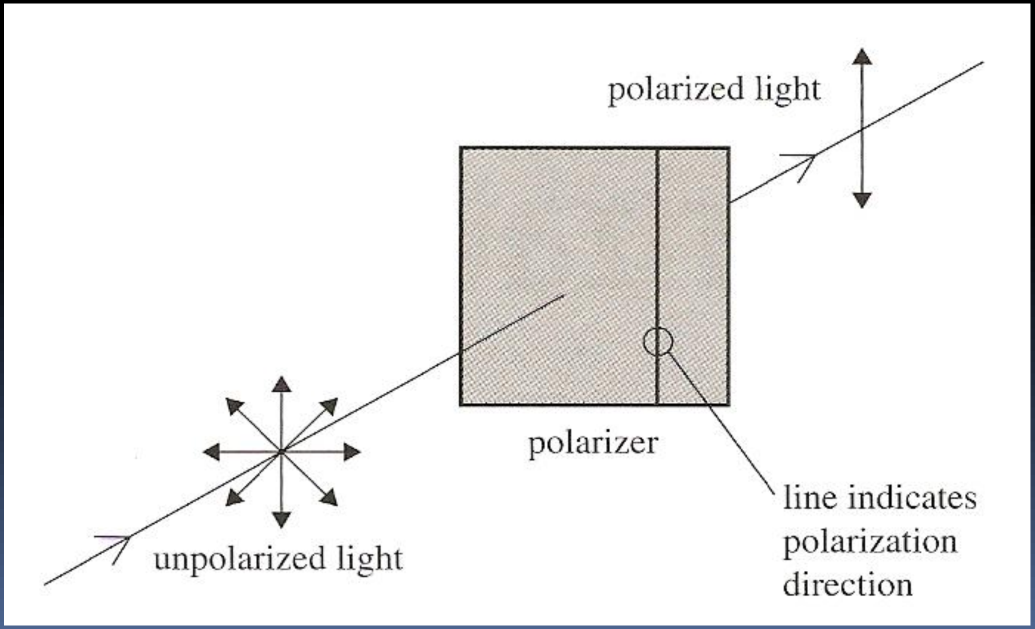
Polarization

- The light wave in (a) is polarized to the vertical plane
- The light wave in (b) is unpolarized



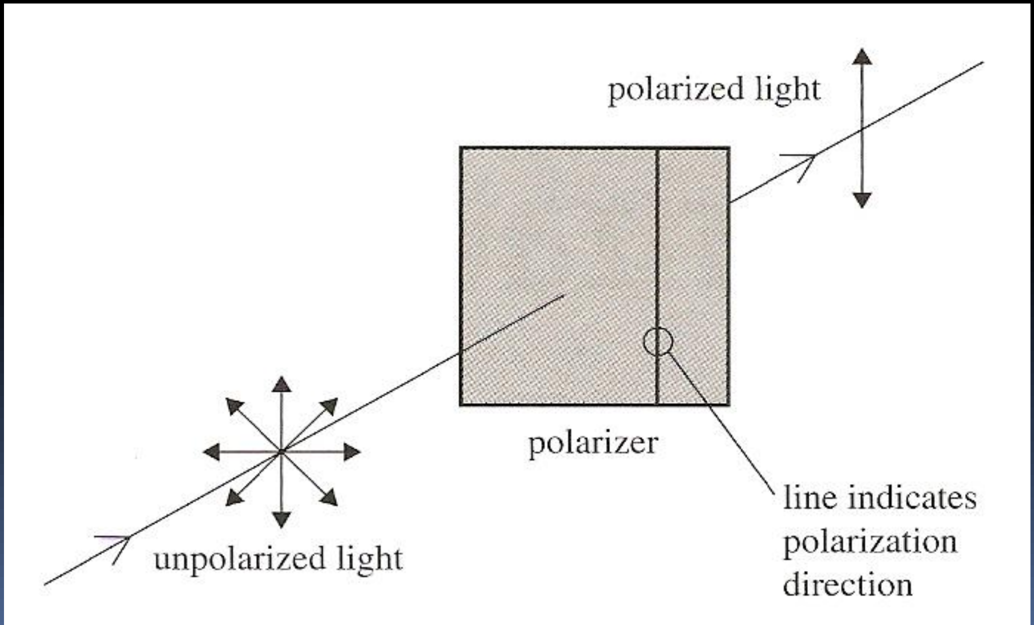
Polarization

- The most common polarizer of light is Polaroid, a plastic invented by 19-year old Harvard undergrad, Edwin Land, in 1928
- You may have heard of his Polaroid camera



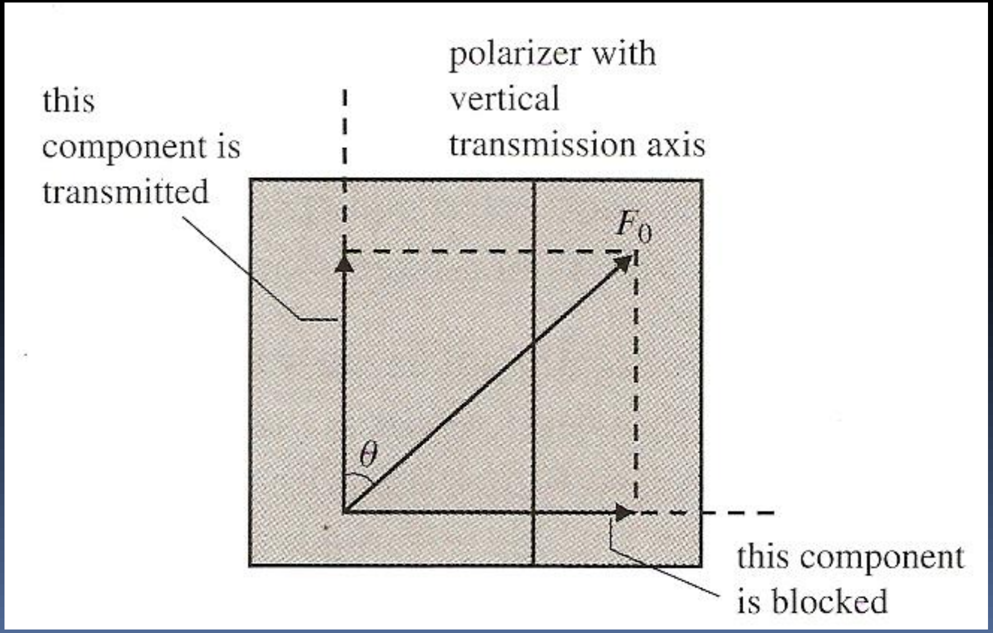
Polarization

- Polarizers have a molecular structure that only allows light of a certain orientation to pass thru
- The direction of polarization is usually shown by a line on the film

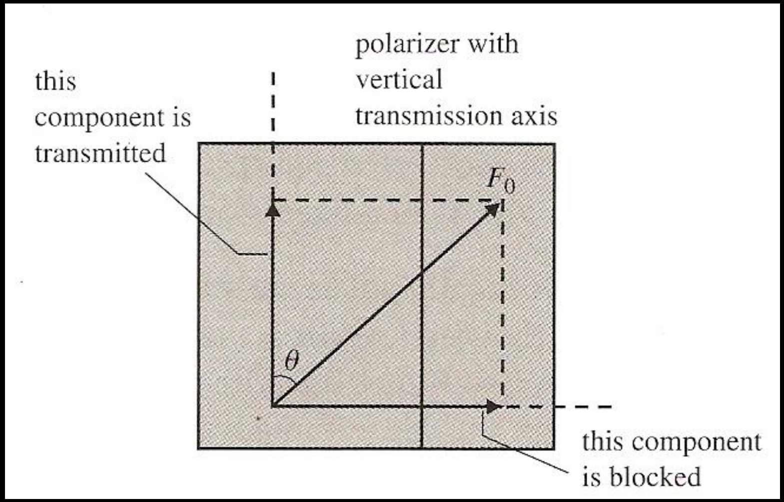


Malus's Law

- Vertically polarized film will let 100% of vertical waves through and 0% of horizontal waves
- ***But what about those aligned at angles in between?***



Malus's Law

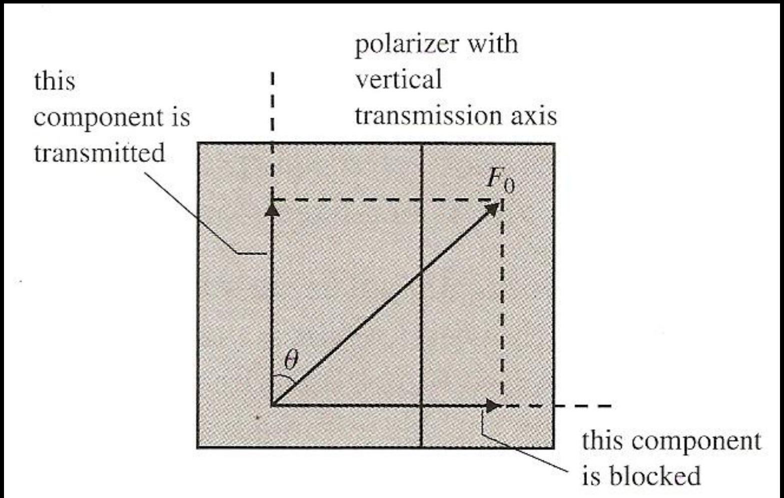


- ***But what about those aligned at angles in between?***
- ***For an electric field, E_o , only the vertical <u>component</u> of the field will pass through***

$$E = E_0 \cos\theta$$

Malus's Law

$$E = E_0 \cos\theta$$



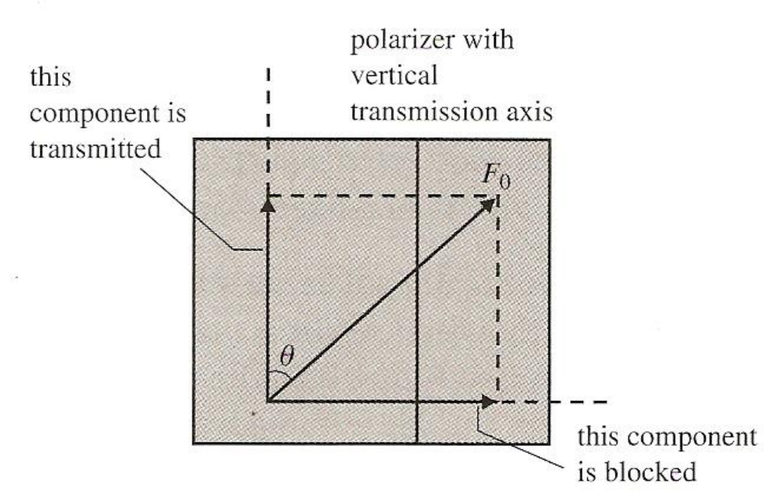
- The intensity of the light that passes through is proportional to the square of the field strength, so,

$$I \propto E^2$$

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

Malus's Law

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



$$\cos^2 45^\circ = 0.5$$

$$\cos^2 30^\circ = 0.75$$

$$\cos^2 60^\circ = 0.25$$

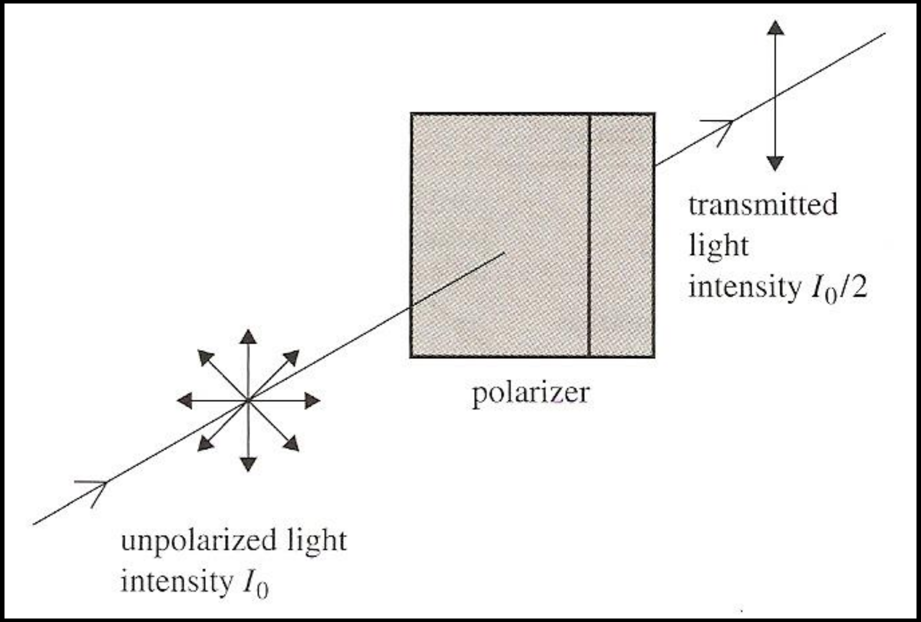
$$Avg = 0.5$$

- The intensity of the light that passes through is equal to ½

$$I = \frac{1}{2} I_0$$

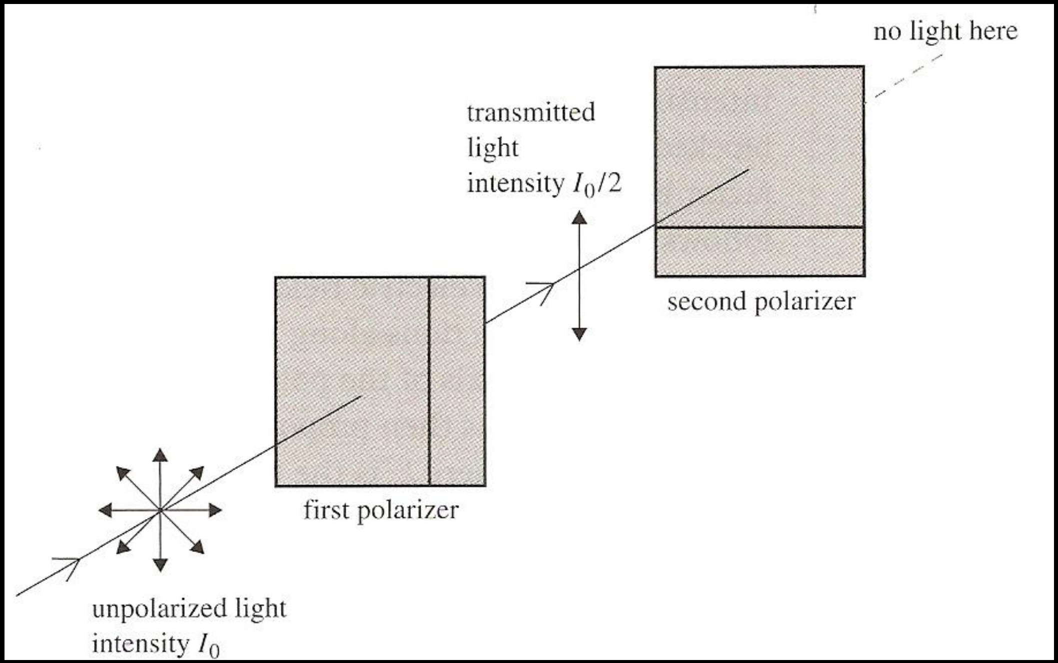
Polarizers and Analysers

- The intensity of ***unpolarized*** light passing through a polarizer is equal to ½ no matter what the orientation of the polarizing film



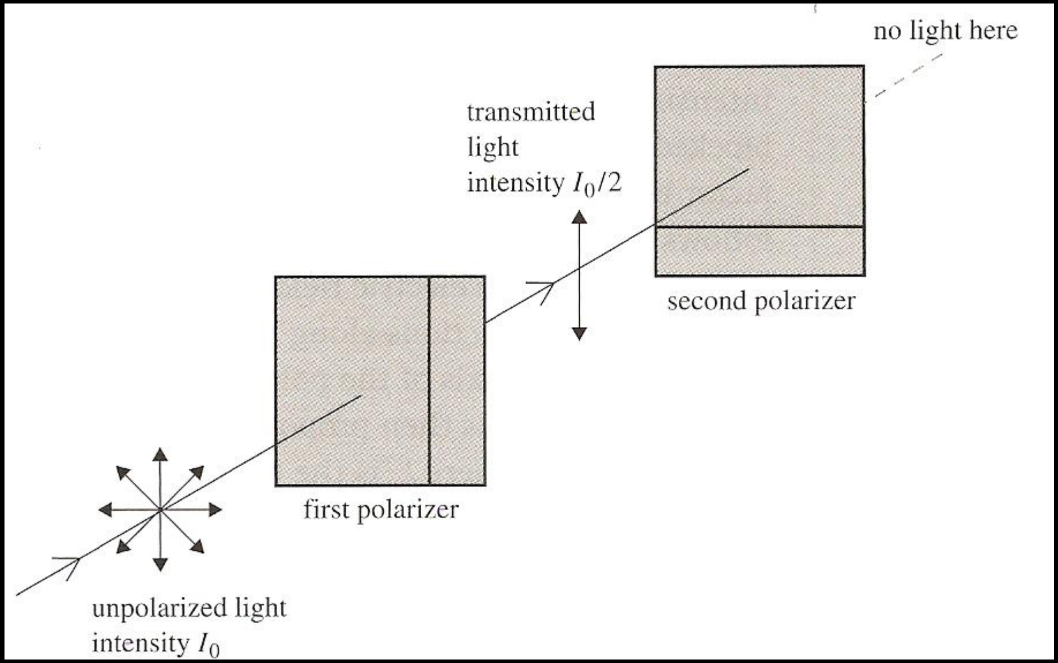
$$I = \frac{1}{2} I_0$$

Polarizers and Analysers



- If, however, the light is already polarized, the intensity of the ***polarized*** light passing through a polarizer will range from 100% (film axis aligned with light polarization axis) to 0% (film axis perpendicular to light polarization axis)

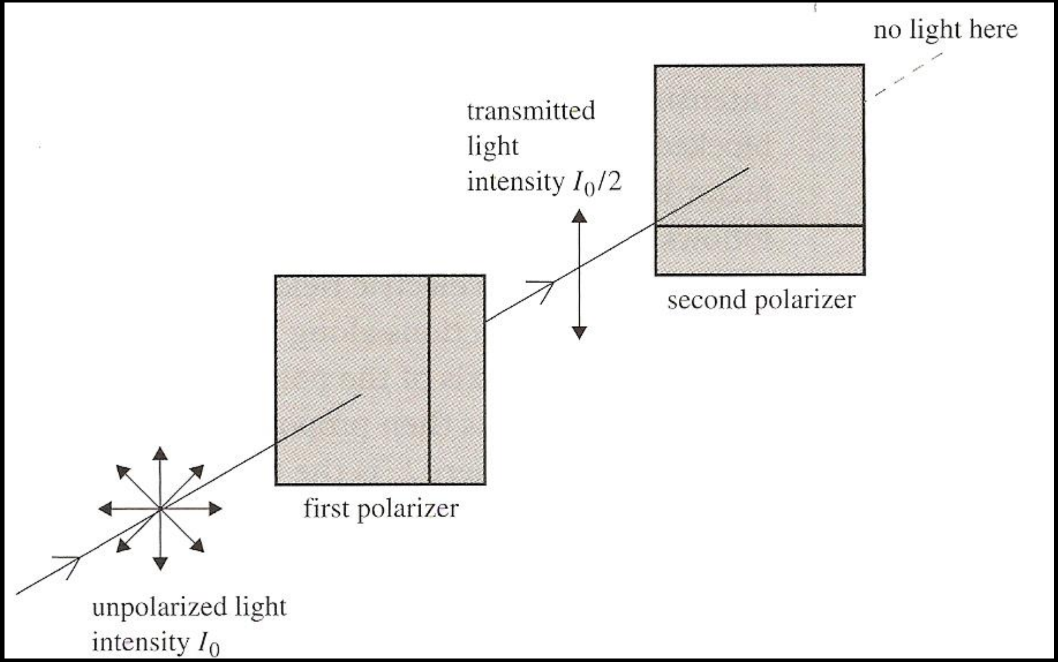
Polarizers and Analysers



- Typical Test Question:
  Unpolarized light of intensity **I_o** *light passes through two analyzers that at a 38° angle to each other. What is the intensity of the light at the other end?*

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

Polarizers and Analysers



- Typical Test Question:
  Unpolarized light of intensity **I_o** *light passes through two analyzers that at a 38° angle to each other. What is the intensity of the light at the other end?*

$$I = \frac{I_0}{2}\cos^2 38^\circ$$

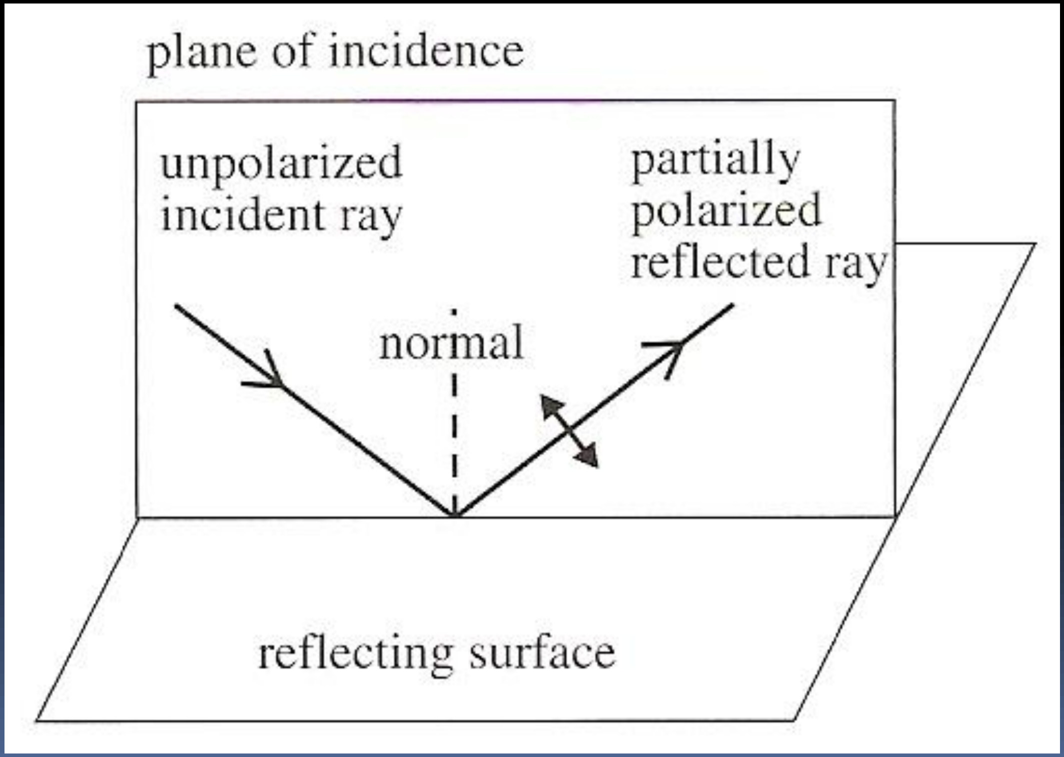
$$I = 0.31 I_0$$

Polarization by Reflection

- Light can be partially polarized through reflection
- When light is reflected off a non-metallic surface, not all planes of light are reflected equally

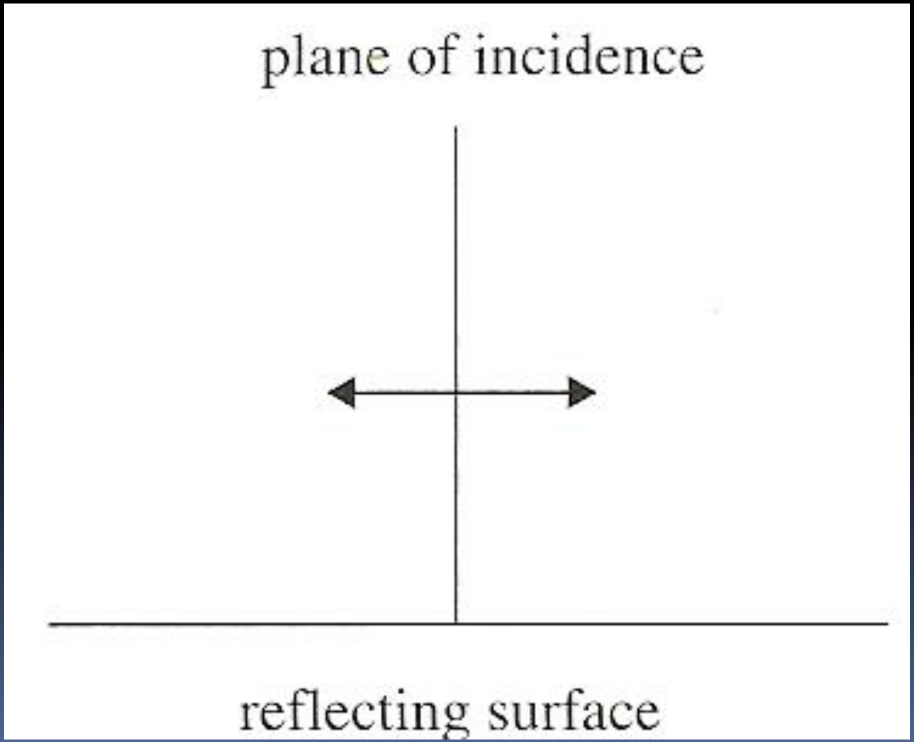
Polarization by Reflection

- Light in the plane of incidence has the least magnitude



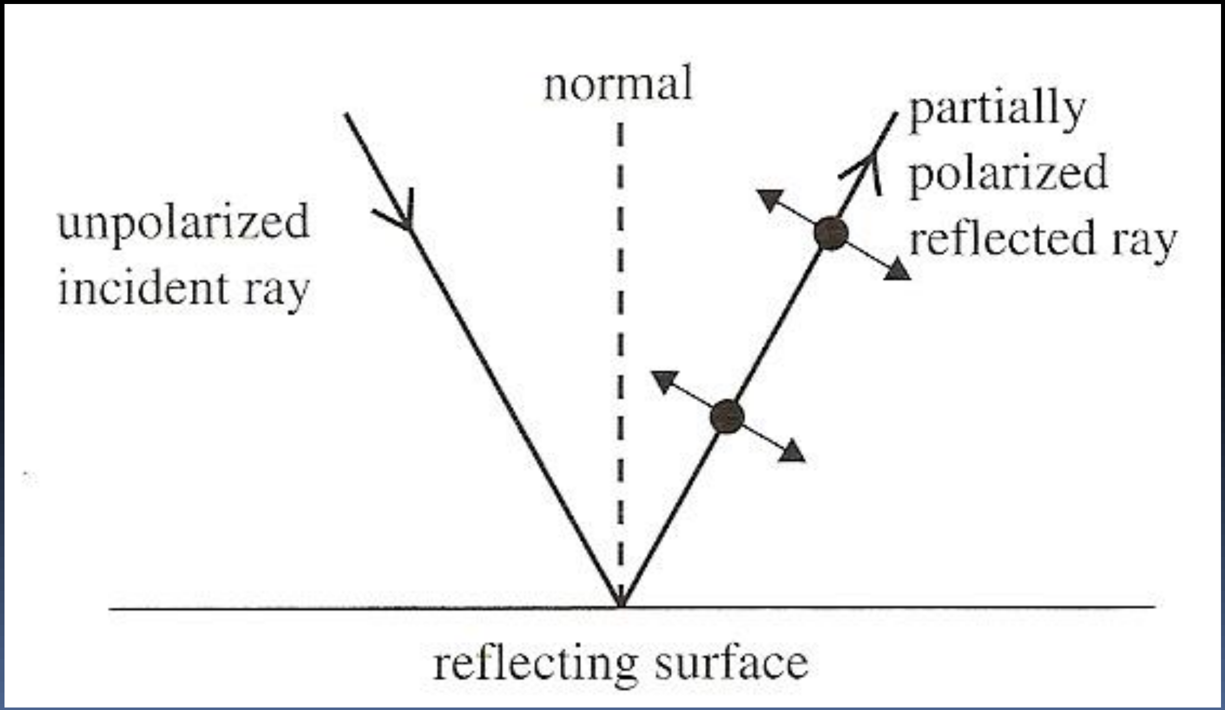
Polarization by Reflection

- Light in a plane perpendicular to the reflecting surface has the greatest magnitude



Polarization by Reflection

- The degree to which light is polarized parallel to the reflecting surface depends on the angle of incidence

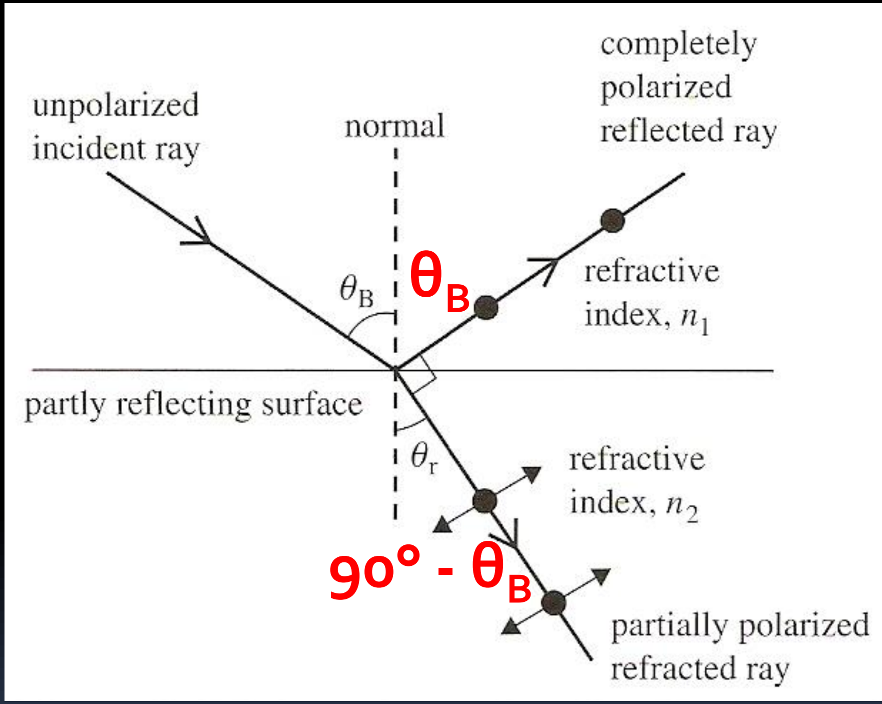


Brewster Angle

- Do not confuse with Brewster's Millions though Richard Pryor does seem to have an angle on everything
- Brewster found that the degree to which reflected light was polarized was dependent on the angle of ***incidence*** and angle of ***refraction***
- ***He also found that reflected light was 100% polarized when the angle between reflected light and refracted light was 90°***

Brewster Angle

- Brewster's Angle (θ_B) is defined as the angle of incidence which produces a 100% polarized reflected light
- If angle of incidence is θ_B, angle of reflection is also θ_B and the angle of refraction will be $90°-\theta_B$



Brewster Angle

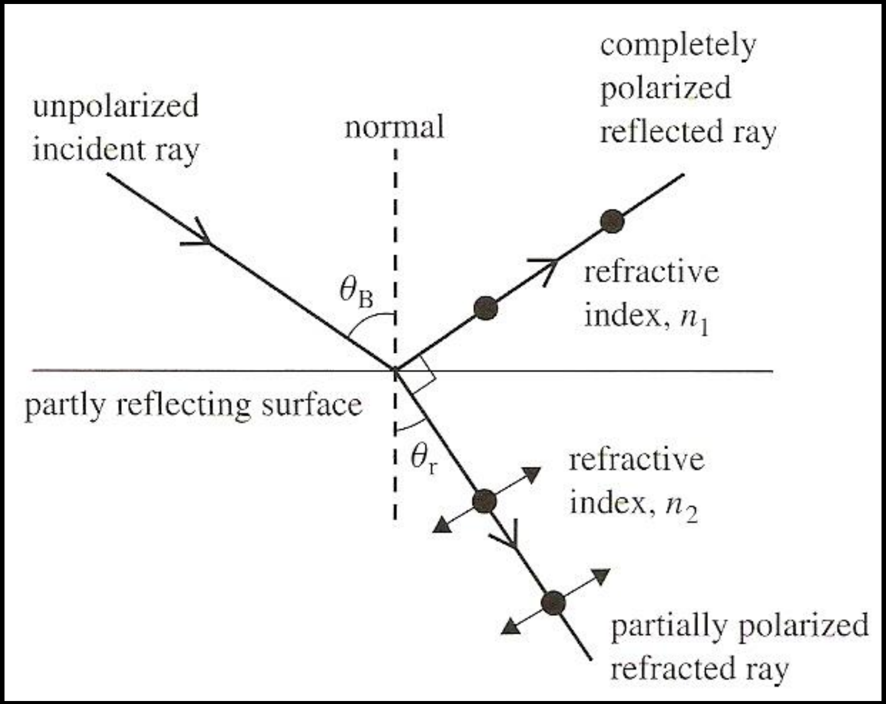
- Brewster's angle is dependent on the refractive indices of the two media

$$n_1 \sin\theta_B = n_2 \sin\left(90^\circ - \theta_B\right)$$

$$n_1 \sin\theta_B = n_2 \cos\left(\theta_B\right)$$

$$\frac{n_1}{n_2} = \frac{\cos\theta_B}{\sin\theta_B}$$

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



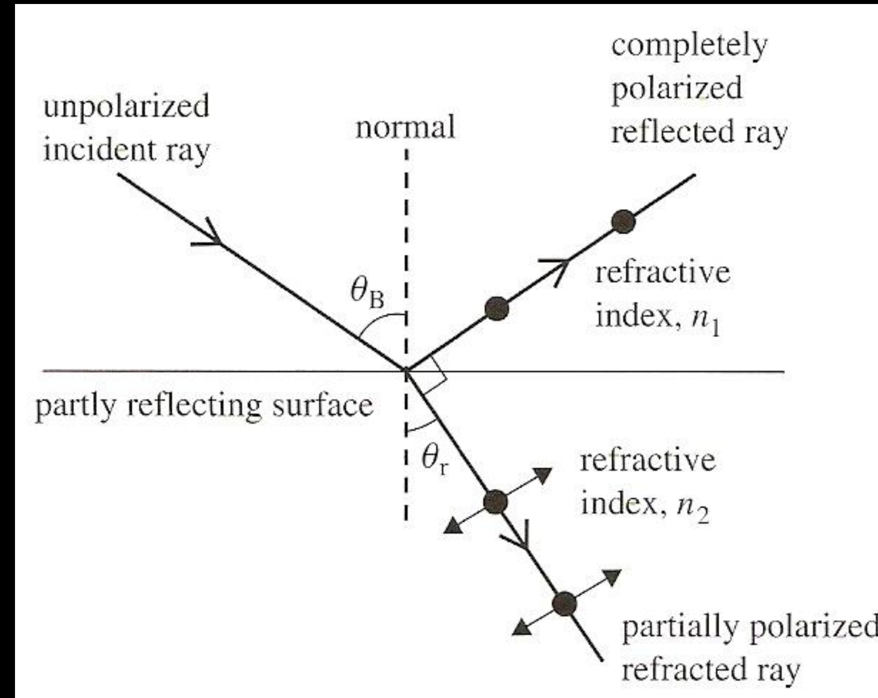
▶ Brewster's law states that

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

In particular, if the ray is incident from air ($n_1 = 1$), then $\tan\theta_B = n_2$.

Brewster Angle

- If the incident ray is in air with $n_1 = 1$,



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

▶ Brewster's law states that

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

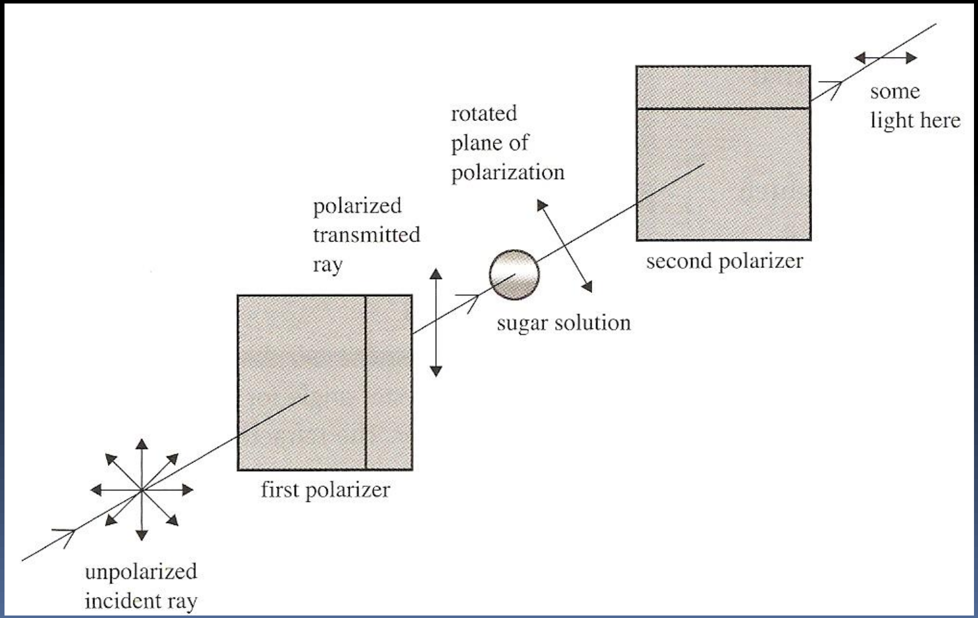
In particular, if the ray is incident from air ($n_1 = 1$), then $\tan\theta_B = n_2$.

Optical Activity

- Normally, two polarizers at right angles to each other would block all light passing thru
- If certain sugar solutions are placed between the polarizers, light passes through
- ***How come?***

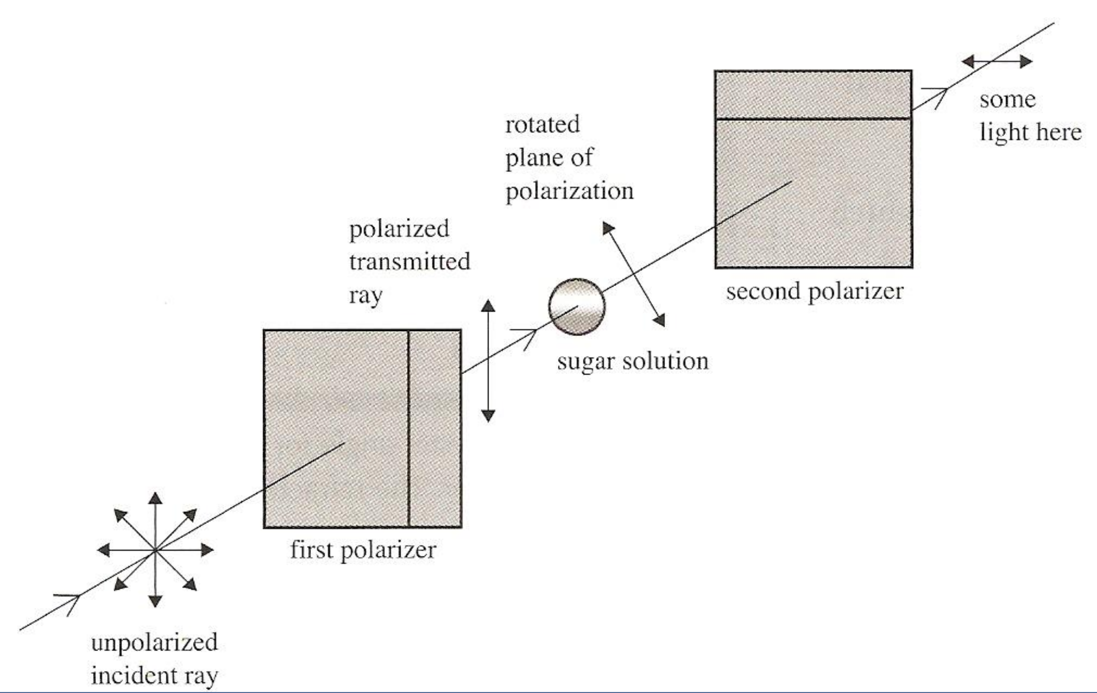
Optical Activity

- The sugar solution ***rotates*** the plane of polarization as the light passes through
- ***Rotation of the plane of polarization is called <u>optical activity</u>***
- ***Materials that show optical activity are called <u>optically active</u> materials***



Optical Activity

- Angle of change is dependent on distance travelled through the material and light wavelength
- Angle of change can be determined by the angle of the second polarizer from 90 degrees to the point where light disappears



Optical Activity

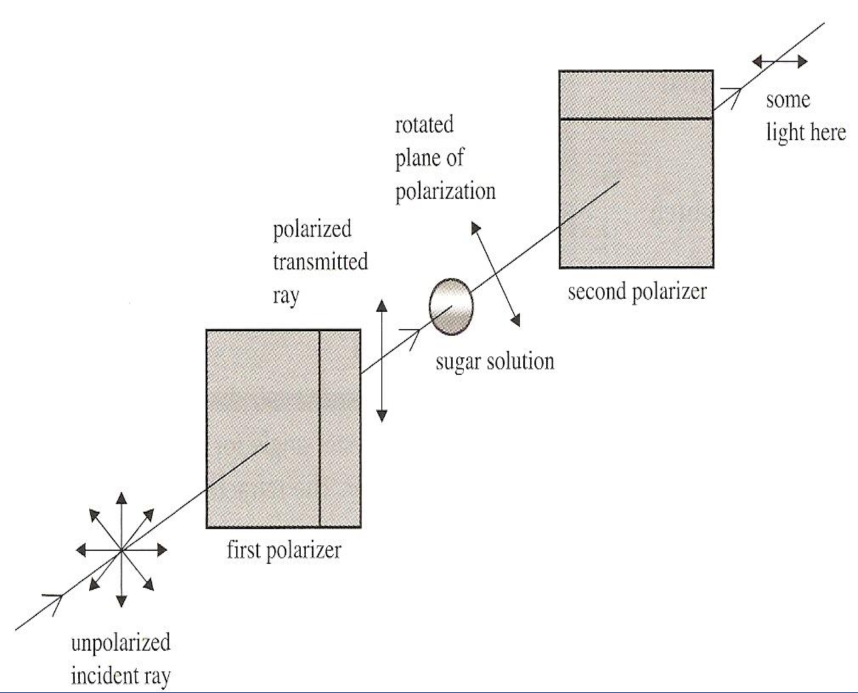
- Typical Test Question: *Unpolarized light of intensity* **I_o** *light passes through two analyzers at right angles to each other. A sugar solution is then placed between them. If the light on the other side is 0.12I_o, by what angle did the solution rotate the plane of polarization?*

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

$$0.12I_0 = \frac{I_0}{2}\cos^2\theta$$

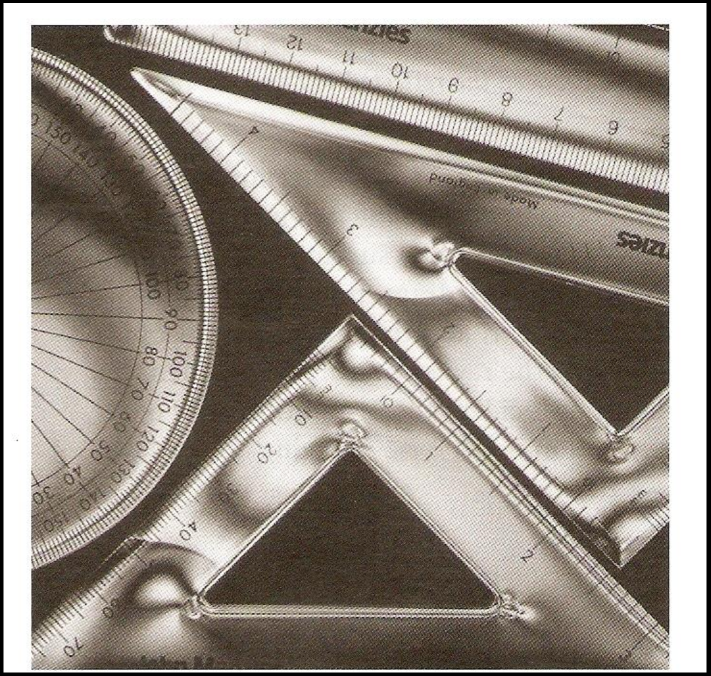
$$\cos^{-1}\sqrt{\frac{2(0.12I_0)}{I_0}} = \theta = 60°$$

Twist is 90 – 60 = 30°



Practical Applications

- ***Stress Analysis*** – certain materials will increase in their optical activity when subjected to stress
  - Degree of increase is proportional to force applied
- ***Measuring Solution Concentrations*** – the amount of a certain solution's optical activity will change based on concentration



Practical Applications

Practical Applications: Sunglasses

Practical Applications

- ***Liquid Crystal Displays***
  - Uses liquid crystals to make displays, hence the name
  - When an electric field is applied, the molecules align with the field to see the desired character
  - Apply the field to align molecules to polarizer so as to blank out the character
  - Color made by introducing green, red and blue filters

The Quick and Dirty of Polarization

Applications And Skills:

- Sketching and interpreting diagrams involving wavefronts and rays
- Solving problems involving amplitude, intensity and the inverse square law
- Sketching and interpreting the superposition of pulses and waves

Applications And Skills:

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- Amplitude and intensity
- Superposition
- Polarization

Essential Idea:

- All waves can be described by the same sets of mathematical ideas. Detailed knowledge of one area leads to the possibility of prediction in another.

QUESTIONS?

Homework

#15-24

STOPPED HERE ON MAY 7TH