Today’s Topics

- Polarization of Light
  - Polarization by Absorption
  - Polarization by Reflection
  - Polarization by Scattering
  - Polarization by Birefringence
  - Circular versus Linear Polarization

- Derivation of Laws of Reflection and Refraction Using Principles of Light Propagation
  - Huygen’s Principle
  - Fermat’s Principle
Polarization of Light

- Recall: for a given direction of light propagation, there are two different (transverse) polarizations.

One linear polarization of light

Polarization by absorption

- Some materials absorb light of one linear polarization and not the other (e.g., polarizing film). The linear polarization along the transmission axis is transmitted, while the other polarization is absorbed.

For light of intensity $I$ linearly polarized at an angle $\theta$ with the polarizing axis, the transmitted intensity is $I \cos^2 \theta$. "polaroid"
Polarization by absorption (2)

- Amount of light that goes through two crossed polarizers depends on whether or not there is a polarizer in between!

no light gets through

1/4 of light intensity that makes it through first polarizer gets through all 3 polarizers

http://www.colorado.edu/physics/2000/applets/lens.html
Polarization by reflection

- There is a special angle at which the reflected light is completely polarized (electric field perpendicular to the plane of incidence). (Note the refracted ray is only partially polarized.) This angle is called the polarizing angle, or Brewster’s angle. It is given by:

\[ \tan \theta_p = \frac{n_2}{n_1} \]

At this angle, the angle between the reflected and refracted rays is 90°.
Polarization by scattering

- Molecules that scatter light behave like dipole radiators – no energy is scattered along dipole axis.

![Diagram showing polarization by scattering](image)

- Electric dipole excited by incident light.
- Light is preferentially emitted by this dipole perpendicular to dipole axis, so it is polarized.
Polarization by birefringence

- Some crystals have different indices of refraction for different light polarizations
  - different velocities for the different light polarizations
  - can design prism to use total internal reflection to eliminate one of the polarizations

isotropic crystal (sodium chloride)  dichroic crystal (calcite)
Circular Polarization

- Circularly polarized light consists of two perpendicular electromagnetic plane waves with equal amplitude and 90° difference in phase.

Right-circularly polarized light

http://www.optics.arizona.edu/jcwyant/JoseDiaz/AnimatedGifs/polarization.gif
Derivation of laws of reflection and refraction

- Ultimately, derivation follows from Maxwell’s equations

- Laws were understood before Maxwell’s equations were discovered in terms of:
  - Huygens principle
  - Fermat’s principle
Huygen’s Principle

- All points on a given wave front are taken as point sources for the production of spherical secondary waves, called wavelets, that propagate outward through a medium with speeds characteristic of waves in that medium. After some time interval has passed, the new position of the wave front is the surface tangent to the wavelets.
Animation of Huygens’ Principle

Law of Reflection from Huygens’ Principle

Consider two representative rays AA’ and BB’

- The lengths A’A” and B’B” are equal, A’B” is shared by the triangles A’A”B” and B”B’A’, and (by construction) angles A’A”B” and A’B’B” are right angles

=> angles B’A’B” and A”B”A’ are equal.
Snell’s Law from Huygens’ Principle

- Ray A hits interface at point A’ when ray B is at point B’
- Ray B hits interface at point B” when ray A is at point A”

Light speed in media 1 and 2 are $c/n_1$ and $c/n_2$. So $n_2r_2 = n_1r_1$.

Triangles $A’A”B”$ and $B”A’A’$ share edge $A’B”$, and angles $A’A”B”$ and $B’A”A’$ are both 90°

$\Rightarrow \sin(A’B”A”') = (n_1/n_2)\sin(A’B”B’)
Fermat’s Principle

The path taken by light traveling from one point to another is such that the time of travel is a minimum. That is, light travels along the path of least time.

1) Derive law of reflection from Fermat’s principle:

Light ray goes from A to mirror to B, and travels along straight line before and after reflection. Time = c(length of path), so minimize path length.

Path length = \( \sqrt{X^2 + y^2} + \sqrt{X^2 + (Y - y)^2} \)

Minimize with respect to y: \( y = \frac{Y}{2} \)

\( \Rightarrow \) angle of incidence = angle of reflection
Fermat’s Principle

1) Derive law of refraction using Fermat’s Principle:

Light ray goes from A to B, and travels along straight line before and after refraction.

Time = \((c/n_1)\)(length of path 1)+(c/n_2)(length of path 2)

Minimize \(\sqrt{X_1^2 + y^2} / n_1 + \sqrt{X_2^2 + (Y - y)^2} / n_2\) with respect to \(y\)

\[\Rightarrow \frac{n_1 y}{\sqrt{X_1^2 + y^2}} = \frac{n_2 (Y - y)}{\sqrt{X_2^2 + (Y - y)^2}}\]

\[\Rightarrow n_1 \sin \theta_1 = n_2 \sin \theta_2\]
A plane wavefront of light (AA') approaches an air–water interface as shown. \( n < n' \). Which diagram best shows the refracted wave?
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The rays in the figure are reflected and refracted at the front and back surfaces of the glass. Which of the following is true of the angles of these rays relative to normal?

A. $1 = 2 = 3 = 4$
B. $1 = 2; \ 3 = 4; \ 	ext{but } 1 \neq 3$
C. $1 = 2 = 3; \ 	ext{but } 4 \neq 1$
D. $1 = 4; \ 	ext{but } 2 \neq 4$
E. $1 \neq 2 \neq 3 \neq 4$
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Two polarizers have their transmission axes at an angle $\theta$. Unpolarized light of intensity $I$ is incident on the first polarizer. What is the intensity of the light transmitted by the second polarizer?

A. $I \cos^2 \theta$
B. $0.5I \cos^2 \theta$
C. $0.25I \cos^2 \theta$
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A. the beams from both images are polarized.
B. calcite has different indices of refraction for the two beams.
C. there is interference between the two beams.
D. the calcite has increased the resolving power of your eye.
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