Nature of Light and Laws of Geometric Optics

- The nature of light
- Reflection
- Refraction
  - Index of refraction
- Huygens’ Principle
- Dispersion and Prisms
- Total Internal Reflection
The Nature of Light

- Light as Particles
  - Tactile Theory (Ancient Greeks)
  - Emission Theory (al-Haitham)
  - Newton
- Light as Waves ($\omega, k$)
  - Huygens
  - Maxwell
- Quantum Theory ($E = hf$)
  - Photons
Fizeau’s Method for Speed of Light Measurement

\[ \omega = 27.5 \text{rev/s} \]
\[ N_{\text{teeth}} = 360 \]
\[ d = 7500 m \]

\[ t = \frac{\theta}{\omega} = \frac{1/720}{27.5} = 5.05 \times 10^{-5} s \]

\[ c = \frac{2d}{t} = \frac{2(7500 m)}{5.05 \times 10^{-5} s} = 2.97 \times 10^8 m/s \]
Ray Approximation in Geometric Optics

(a) \( \lambda << d \)

(b) \( \lambda \approx d \)

(c) \( \lambda >> d \)
Reflection

Specular Reflection

Diffuse Reflection

\[ \theta'_1 = \theta_1 \]
Double Reflection
Refraction

\[
\frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{v_1} = \text{constant}
\]
Suppose the sprinters wish to get from point $Q$ on the beach to point $P$ on the parking lot as quickly as possible. Which path takes the least time?

1. a
2. b
3. c
4. d
5. e
6. All paths take the same amount of time.
Index of Refraction

\[ n \equiv \frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}} = \frac{c}{v} \]

Going from one medium to another, the frequency of light does not change but its wavelength does.

\[ \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{c/n_1}{c/n_2} = \frac{n_2}{n_1} \]

If one of the medium’s is vacuum (n=1),

\[ n = \frac{\lambda}{\lambda_n} \]

Snell’s Law of Refraction

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
Light Propagation Through a Slab

\[
\sin \theta_2 = \frac{n_1}{n_2} \sin \theta_1
\]

\[
\sin \theta_3 = \frac{n_2}{n_1} \sin \theta_2
\]

\[
\sin \theta_3 = \frac{n_2}{n_1} \frac{n_1}{n_2} \sin \theta_1 = \sin \theta_1
\]

\[
x = \frac{h}{\cos \theta_2}
\]

\[
d = x \sin \alpha
\]

\[
\alpha = \theta_1 - \theta_2
\]

\[
d = \frac{h}{\cos \theta_2} \sin(\theta_1 - \theta_2)
\]
Huygens’ Principle
Huygens’ Principle Applied to Reflection and Refraction

\[ \sin \theta = \frac{A'C}{AC} \quad \text{and} \quad \sin \theta' = \frac{AD}{AC} \]

\[ A'C = AD \]

\[ \theta_1 = \theta'_1 \]

\[ \sin \theta_1 = \frac{v_1 \Delta t}{AC} \quad \text{and} \quad \sin \theta_2 = \frac{v_2 \Delta t}{AC} \]

\[ \frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{c}{n_1} \]

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
Dispersion and Prisms

\[ n = n(\lambda) \]

angle of deviation

- Crown glass
- Acrylic
- Fused quartz

\[ \lambda, \text{ nm} \]

\[ 400 \quad 500 \quad 600 \quad 700 \]
Measuring $n$ Using a Prism

\[ \theta_2 = \frac{\Phi}{2} \]

\[ \theta_1 = \theta_2 + \alpha = \frac{\Phi}{2} + \frac{\delta_{\text{min}}}{2} \]

\[ \sin \theta_1 = n \sin \theta_2 \]

\[ \sin \left( \frac{\Phi + \delta_{\text{min}}}{2} \right) = n \sin \left( \frac{\Phi}{2} \right) \]

\[ n = \frac{\sin \left( \frac{\Phi + \delta_{\text{min}}}{2} \right)}{\sin \left( \Phi/2 \right)} \]
Angle of Deviation

\[ \delta = \theta_1 + \theta_4 - \alpha \]
Total Internal Reflection

Critical Angle, $\theta_c$

$n_1 \sin \theta_c = n_2 \sin 90^\circ$

$$\sin \theta_c = \frac{n_2}{n_1}$$

Only for $n_1 > n_2$
View From a Fish Eye

\[
\sin \theta_c = \frac{n_2}{n_1} = \frac{1}{1.33} = 0.752
\]

\[
\theta_c = 48.8^\circ
\]

For \( \theta < \theta_c \): The fish sees above the water.

For \( \theta = \theta_c \): The fish sees the shoreline.

For \( \theta > \theta_c \): The fish sees the pond bottom.
Applications of TIR

- Retroreflector
- Periscope
- Fiber Optic Cable
For Next Class

- Reading Assignment
  - Chapter 36: Image Formation
- WebAssign: Assignment 13