

# Nature of Light and Laws of Geometric Optics

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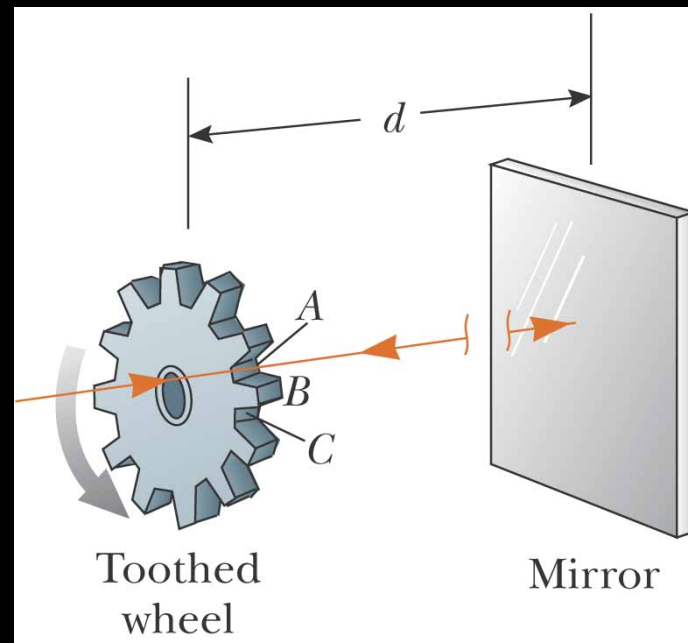
- The nature of light
- Reflection
- Refraction
  - Index of refraction
- Huygens' Principle
- Dispersion and Prisms
- Total Internal Reflection

# The Nature of Light

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- 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



$$\omega = 27.5 \text{ rev} / \text{s}$$

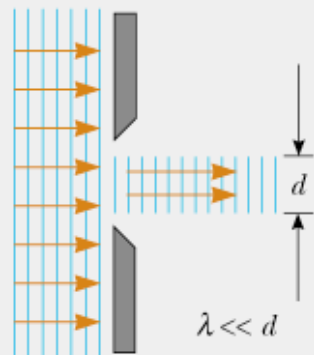
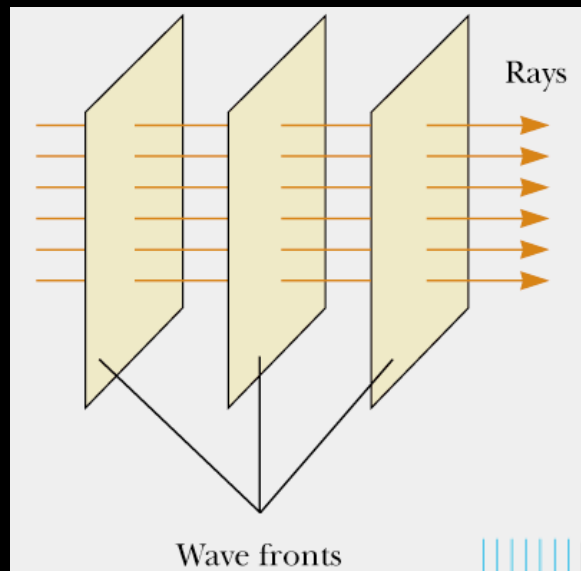
$$N_{\text{teeth}} = 360$$

$$d = 7500 \text{ m}$$

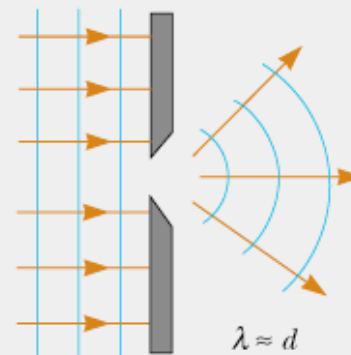
$$t = \frac{\theta}{\omega} = \frac{1/720}{27.5} = 5.05 \times 10^{-5} \text{ s}$$

$$c = \frac{2d}{t} = \frac{2(7500 \text{ m})}{5.05 \times 10^{-5} \text{ s}} = 2.97 \times 10^8 \text{ m} / \text{s}$$

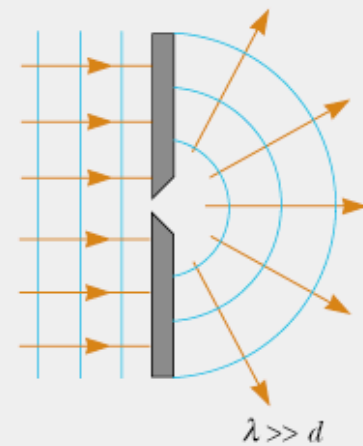
# Ray Approximation in Geometric Optics



(a)

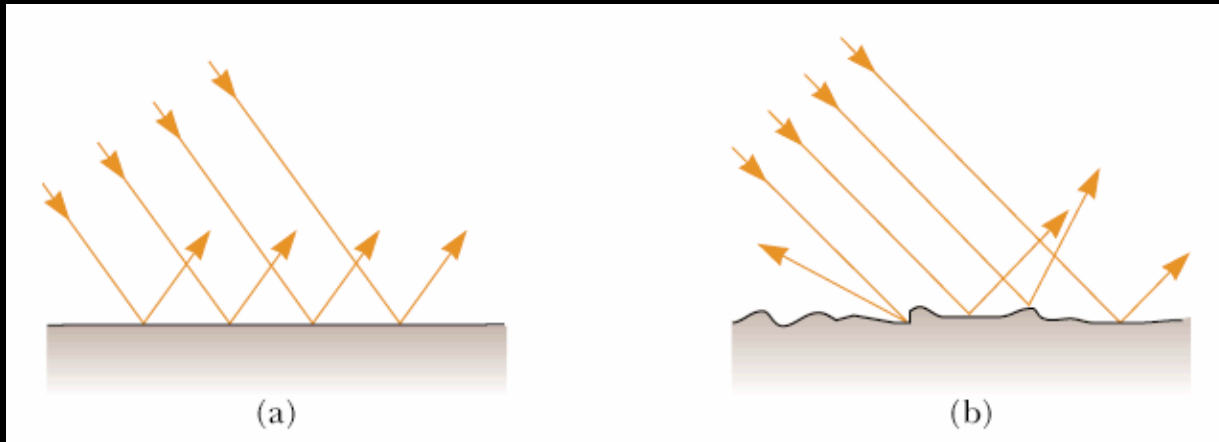


(b)



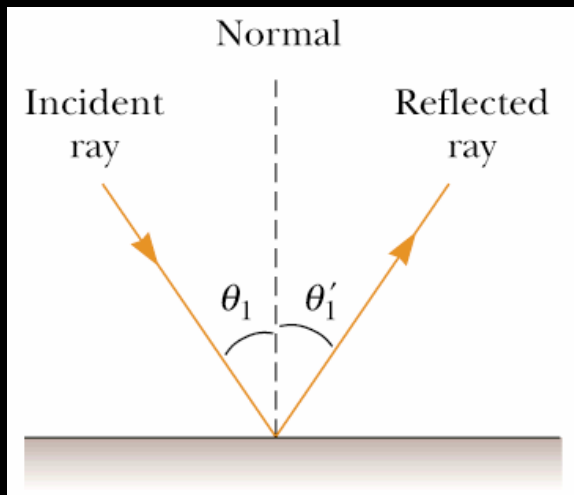
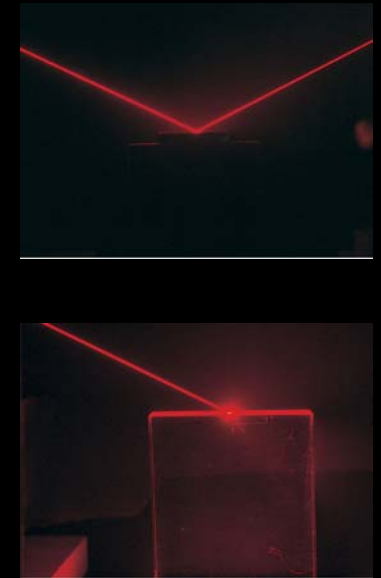
(c)

# Reflection



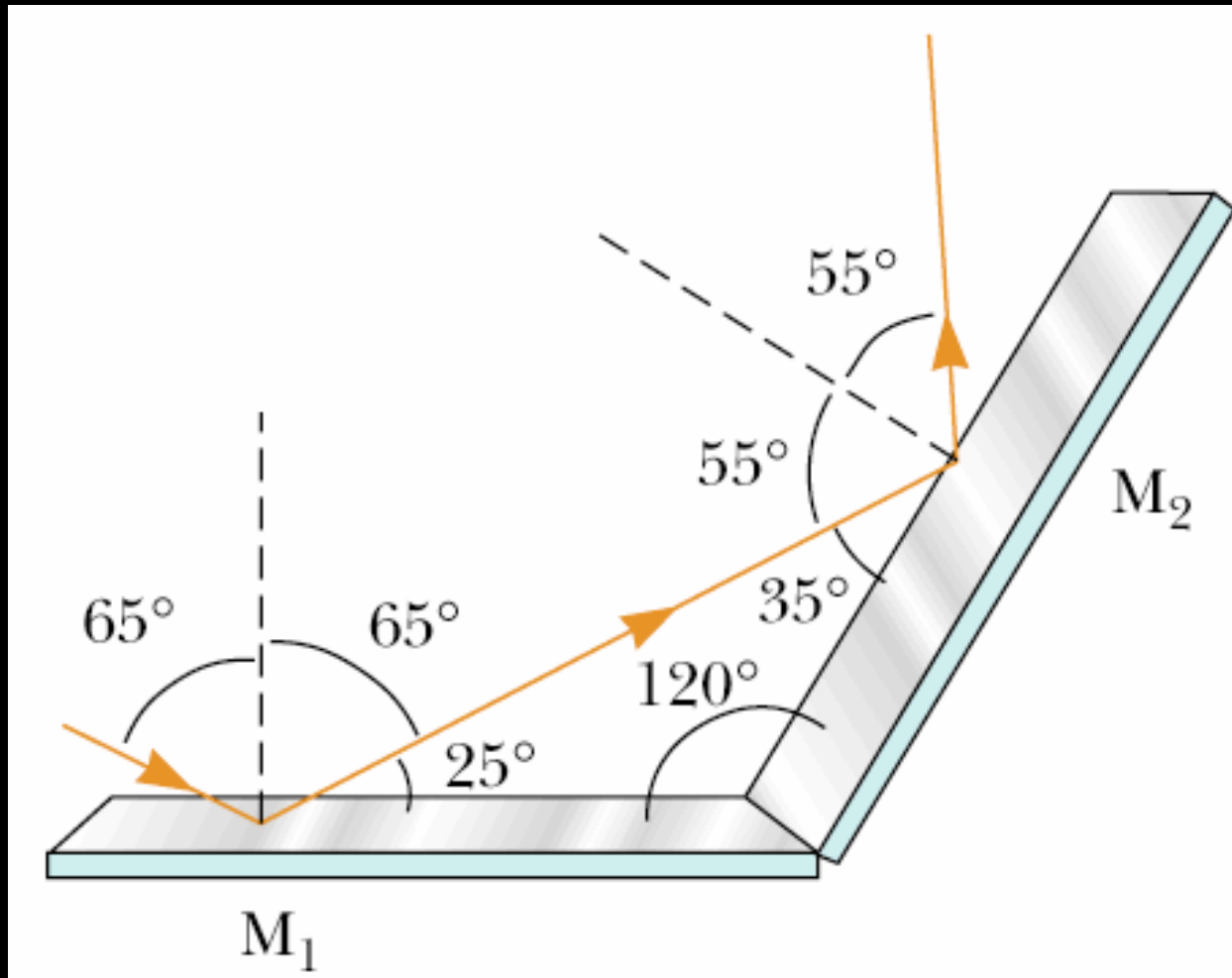
Specular Reflection

Diffuse Reflection

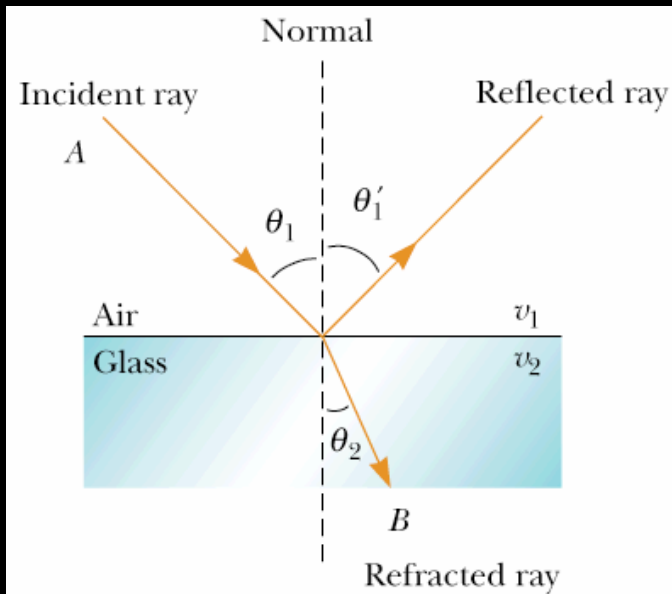


$$\theta_1' = \theta_1$$

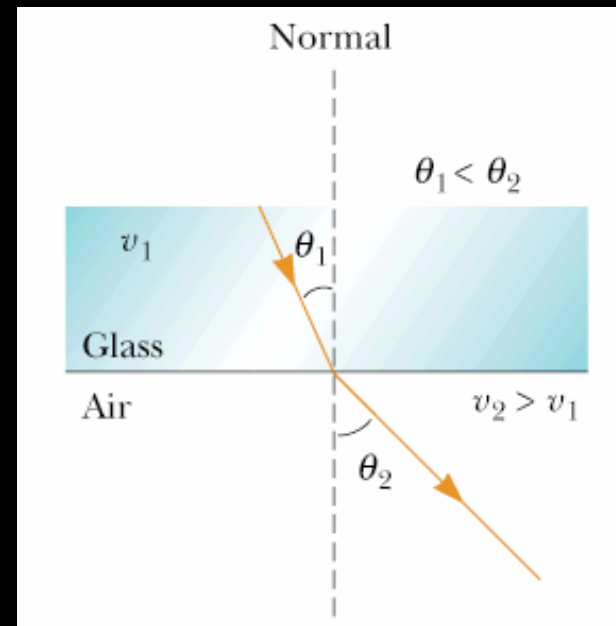
# Double Reflection



# Refraction



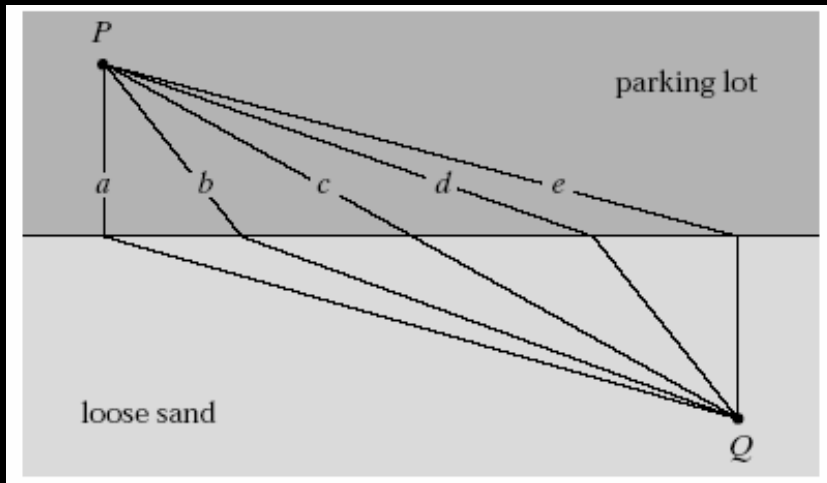
$$\frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{v_1} = \text{constant}$$



# Concept Question

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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

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

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

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

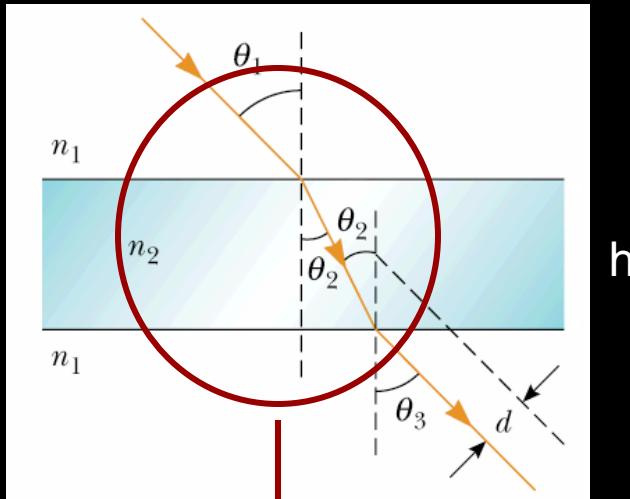
If one of the medium's is vacuum ( $n=1$ ),

$$n = \frac{\lambda}{\lambda_n}$$

**Snell's Law of Refraction**

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

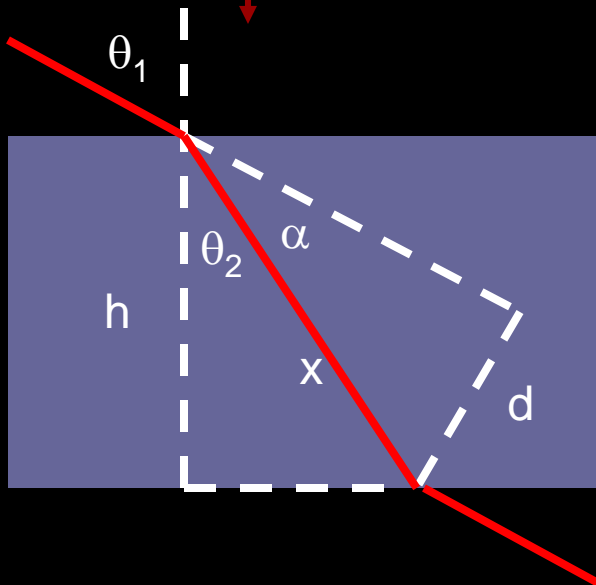
# Light Propagation Through a Slab



$$\sin \theta_2 = \frac{n_1}{n_2} \sin \theta_1$$

$$\sin \theta_3 = \frac{n_2}{n_1} \sin \theta_2$$

$$\sin \theta_3 = \frac{n_2}{n_1} \frac{n_1}{n_2} \sin \theta_1 = \sin \theta_1$$



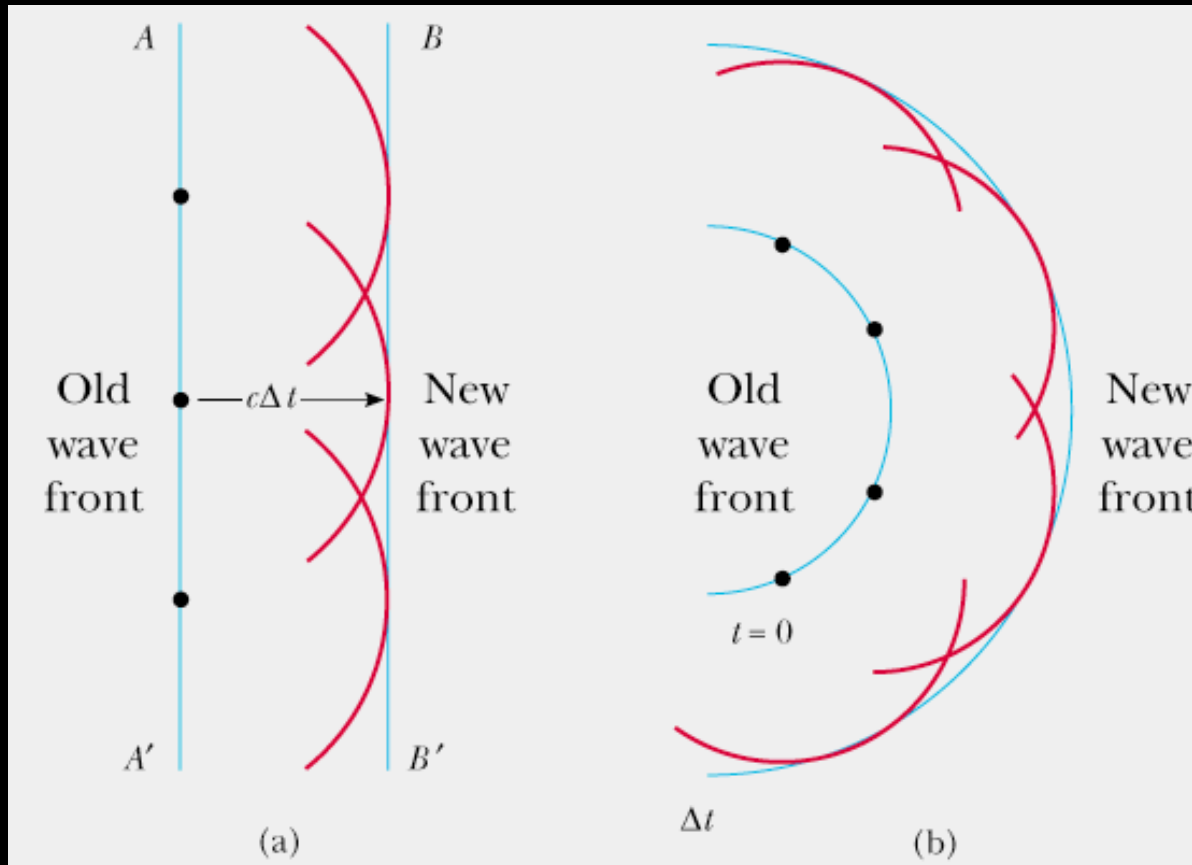
$$x = \frac{h}{\cos \theta_2}$$

$$d = x \sin \alpha$$

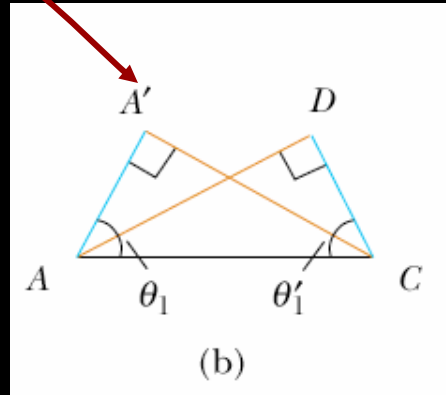
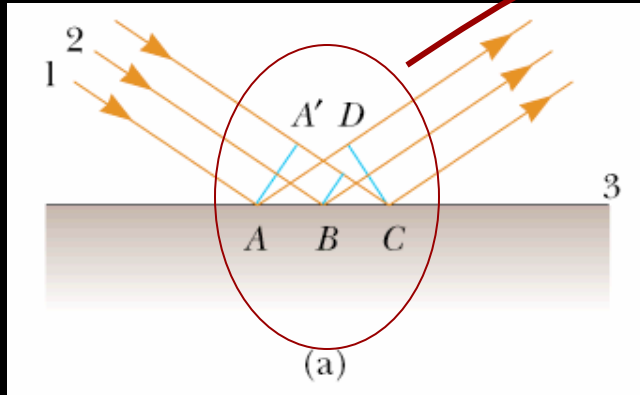
$$\alpha = \theta_1 - \theta_2$$

$$d = \frac{h}{\cos \theta_2} \sin(\theta_1 - \theta_2)$$

# Huygens' Principle



# Huygens' Principle Applied to Reflection and Refraction

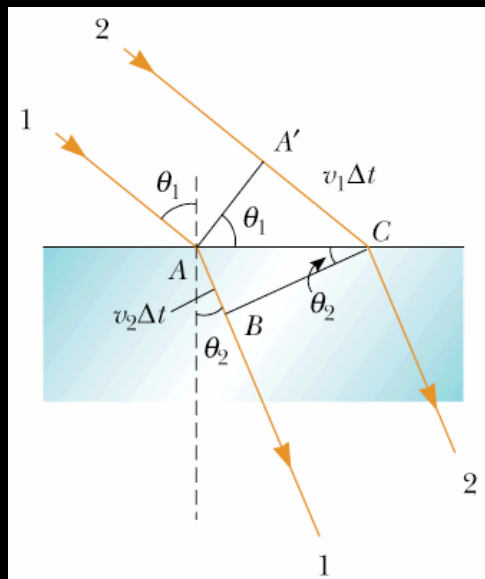


$$\sin \theta_1 = \frac{A'C}{AC}$$

$$\sin \theta'_1 = \frac{AD}{AC}$$

$$A'C = AD$$

$$\theta_1 = \theta'_1$$



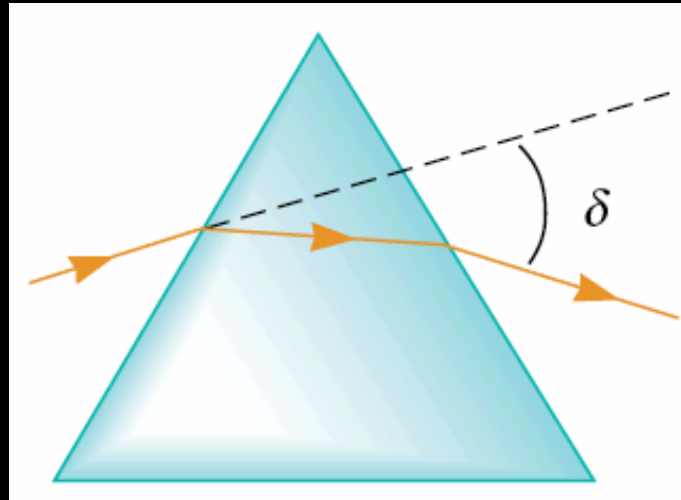
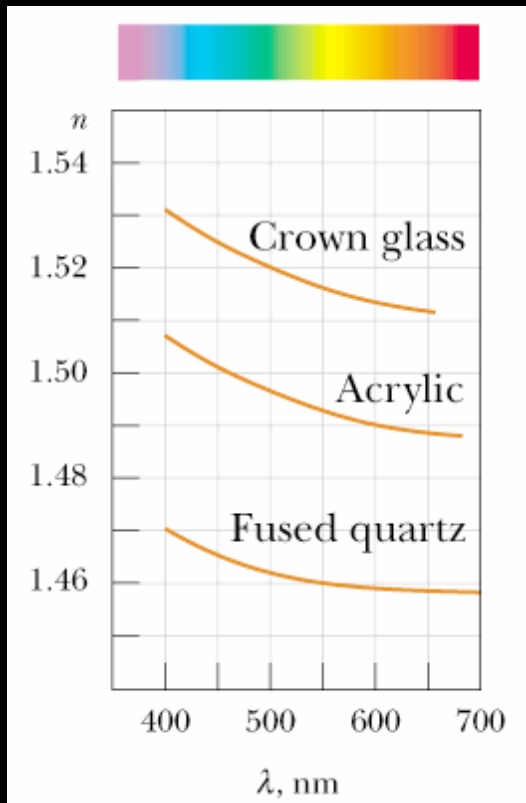
$$\sin \theta_1 = \frac{v_1 \Delta t}{AC}$$

$$\sin \theta_2 = \frac{v_2 \Delta t}{AC}$$

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{c/n_1}{c/n_2}$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

# Dispersion and Prisms

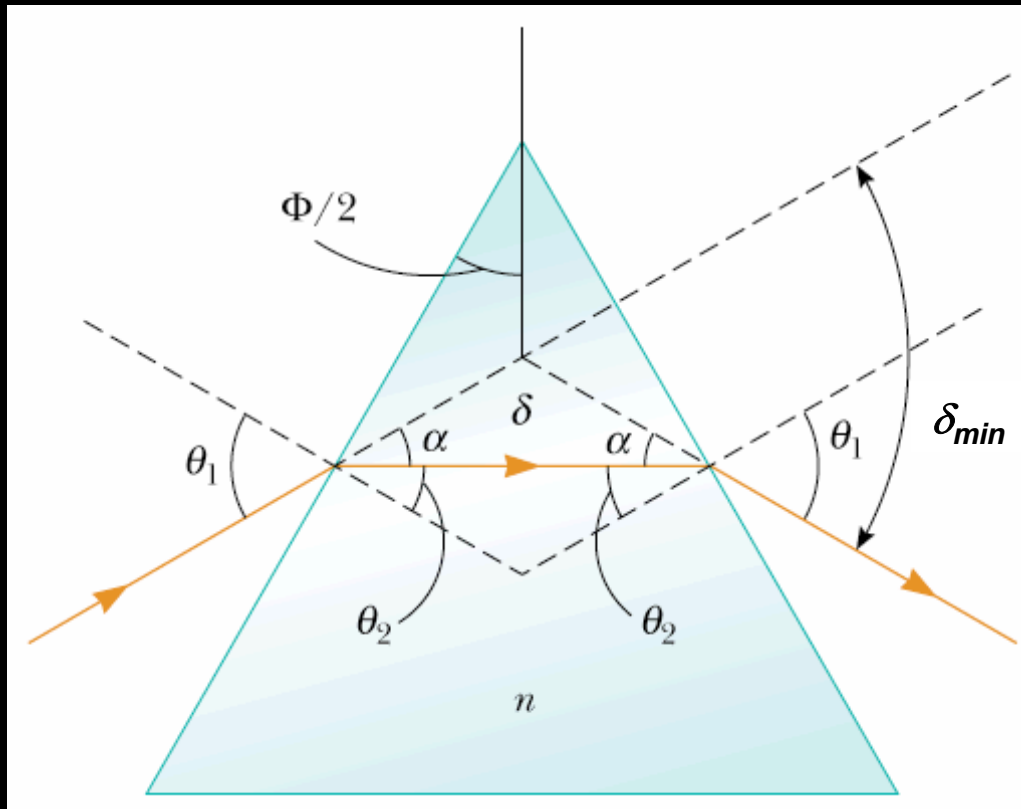


angle of deviation



$$n = n(\lambda)$$

# Measuring n Using a Prism



$$\theta_2 = \frac{\Phi}{2}$$

$$\theta_1 = \theta_2 + \alpha = \frac{\Phi}{2} + \frac{\delta_{min}}{2}$$

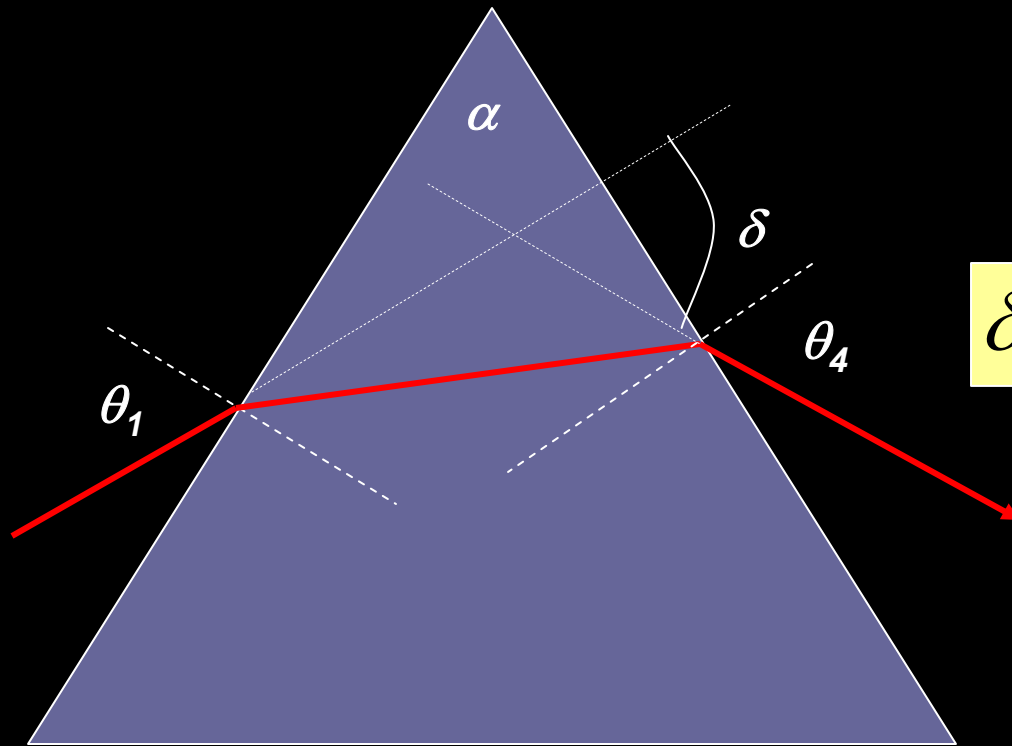
$$\sin \theta_1 = n \sin \theta_2$$

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

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

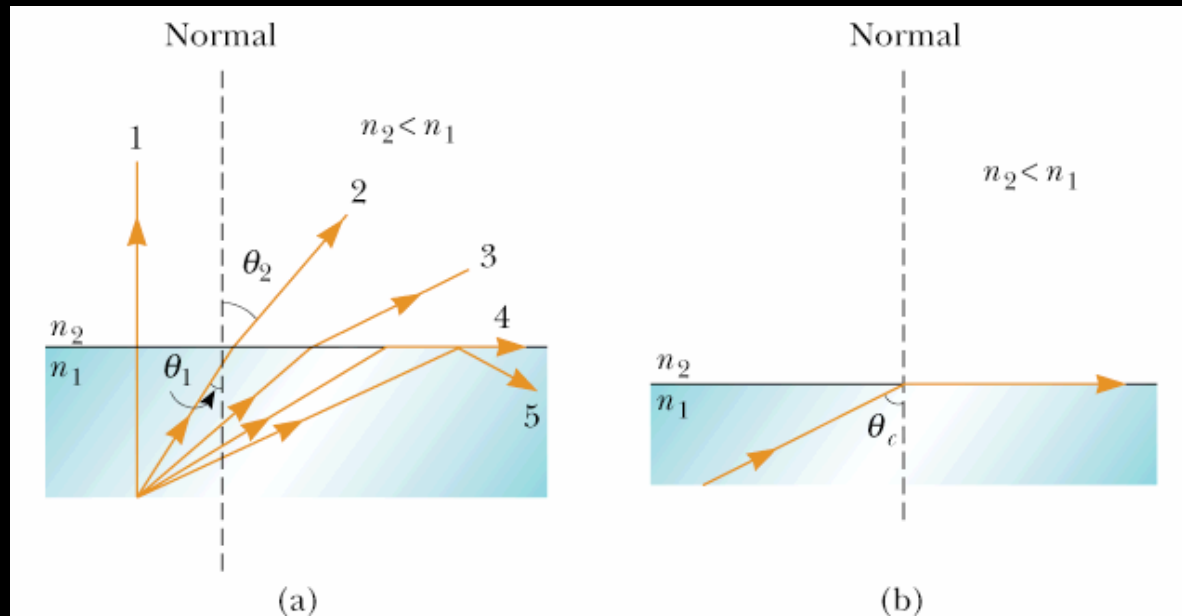
# Angle of Deviation

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$$\delta = \theta_1 + \theta_4 - \alpha$$

# Total Internal Reflection



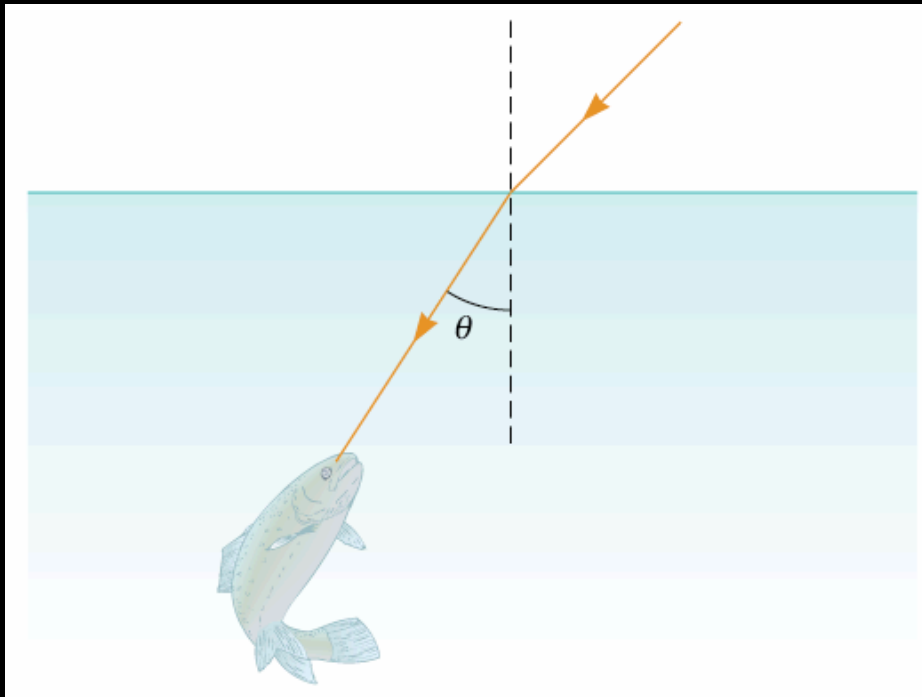
Critical Angle,  $\theta_c$

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

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

Only for  $n_1 > n_2$

# View From a Fish Eye



$$\sin \theta_c = \frac{n_2}{n_1} = \frac{1}{1.33} = 0.752$$
$$\theta_c = 48.8^\circ$$

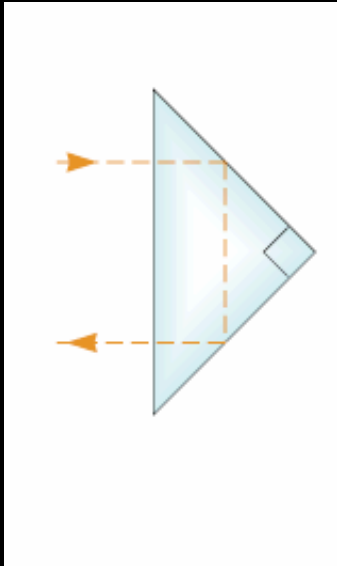
**For  $\theta < \theta_c$ : The fish sees above the water**

**For  $\theta = \theta_c$ : The fish sees the shoreline**

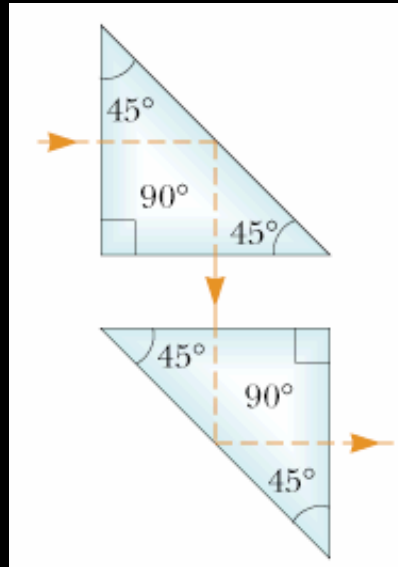
**For  $\theta > \theta_c$ : The fish sees the pond bottom**

# Applications of TIR

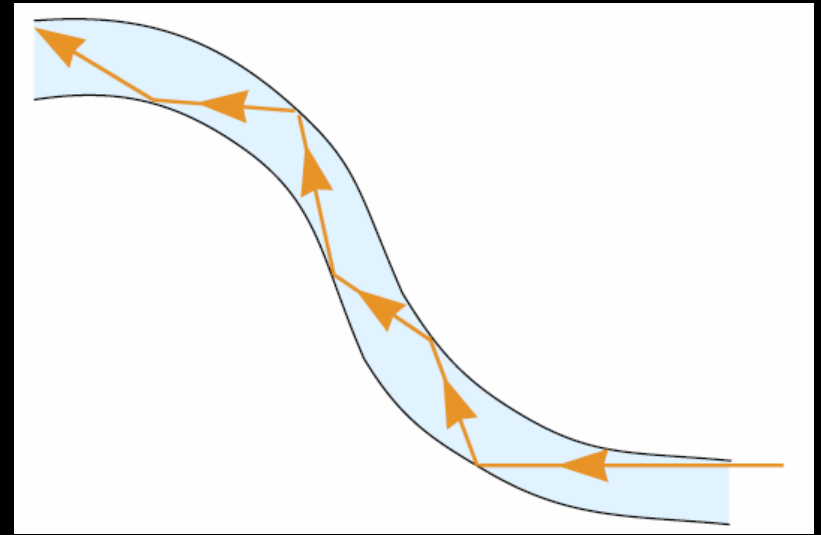
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**Retroreflector**



**Periscope**



**Fiber Optic Cable**

# For Next Class

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