Refraction

HRW

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Speed of light

- Light rays travel at a speed of 3×10^8 m/s in a vacuum, but ….
- **slow down** when passing through other material
  - Ex. In water light travels at ~ 2.25×10^8 m/s
- This measure of slowing down is called…

What is Index of Refraction (n)?

- **Ratio** of the speed of light in a vacuum (3×10^8 m/s) **to** the speed of light in the material of interest
- $n = c/v$
  - Ex. What is the **index of refraction** of water?
    - $n = \frac{\text{light speed in a vacuum}}{\text{light speed in water}}$
    - $n = \frac{3 \times 10^8}{2.25 \times 10^8}$
    - $n = 1.33$ 

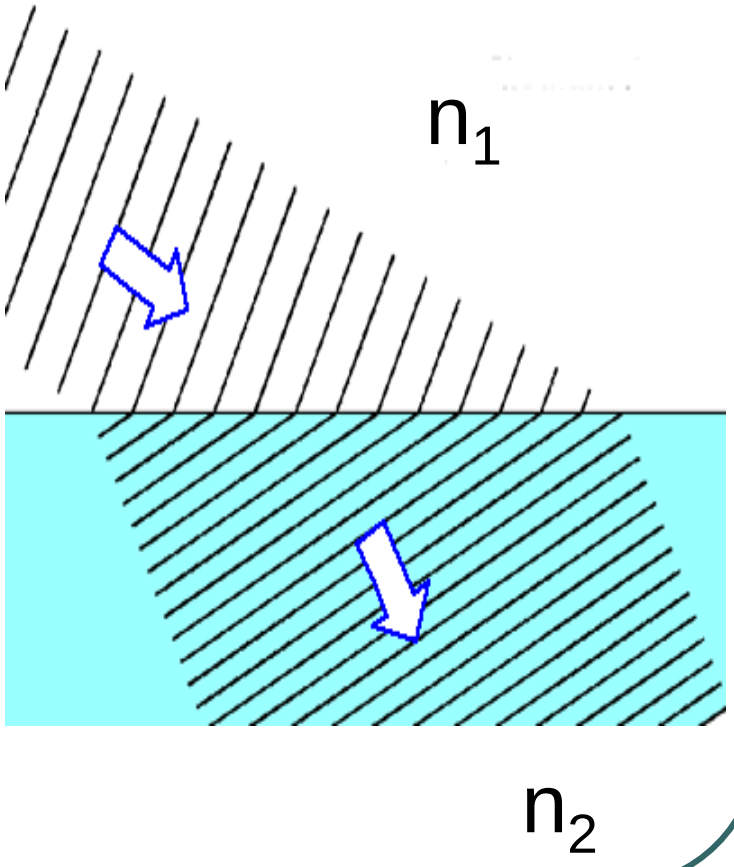
Ex. Indices of Refraction

Material	n
Cubic zirconia	2.20
Diamond	2.419
Glass, crown	1.52
Water	1.333
Ice (@ 0ºC)	1.309

So, what is refraction?

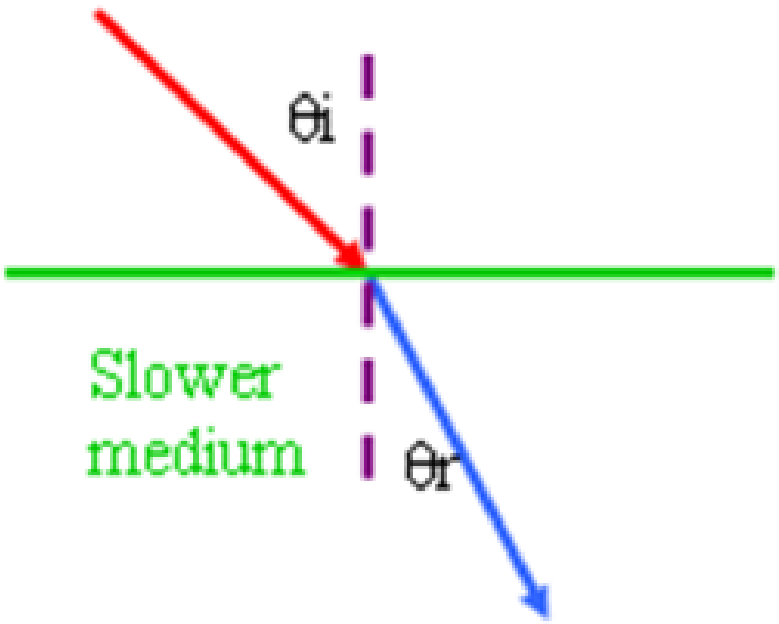
- Refraction is the **bending** of light that takes place at a **boundary** between 2 materials having different indices of refraction, or

- Refraction **occurs** due to a change in the speed of light as it passes from one medium to another, according to relative indices of refraction n_1, n_2

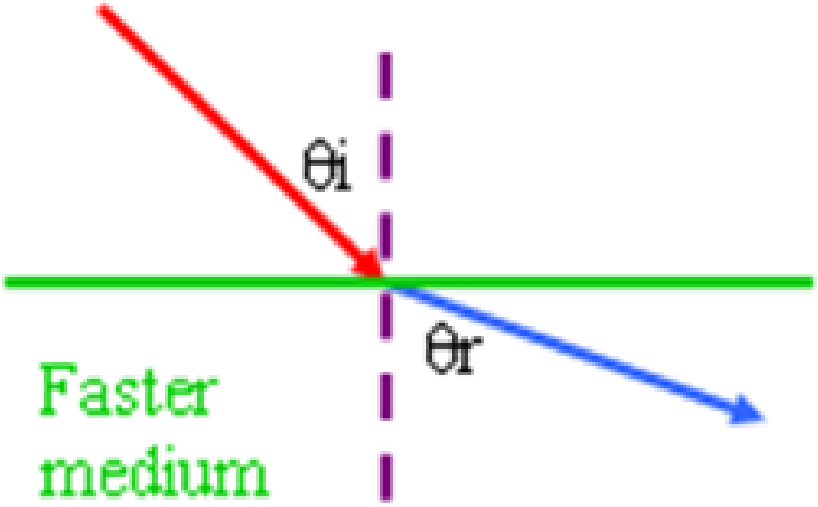


Two Models

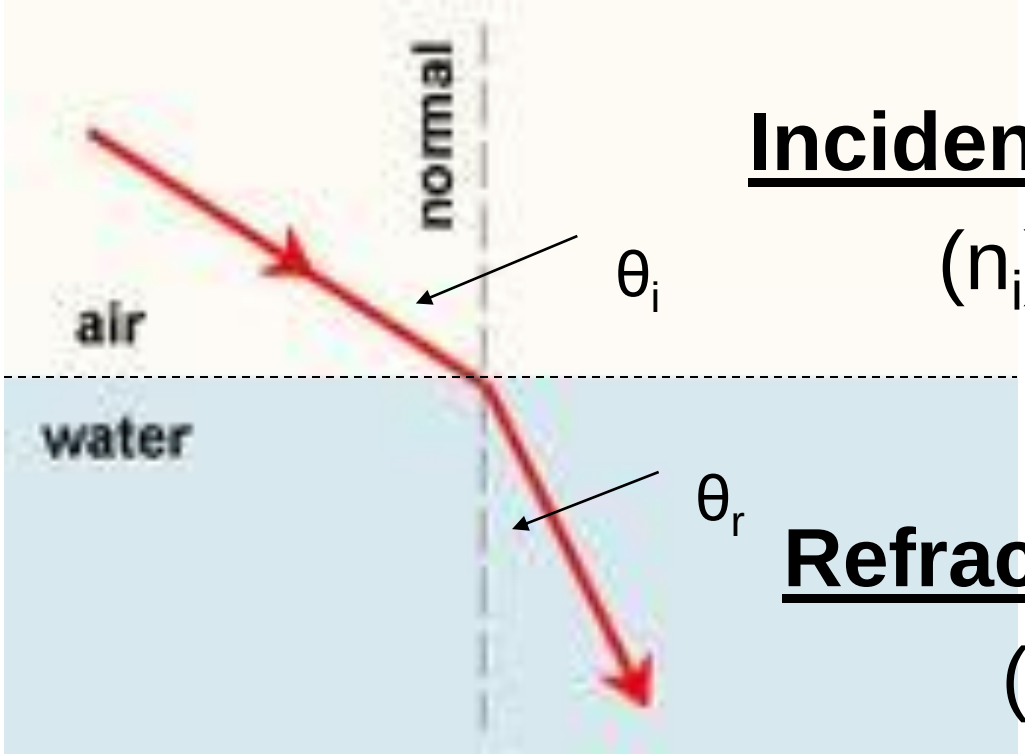
"Fast" to "Slow" medium



"Slow" to "Fast" medium



Snell's Law of Refraction

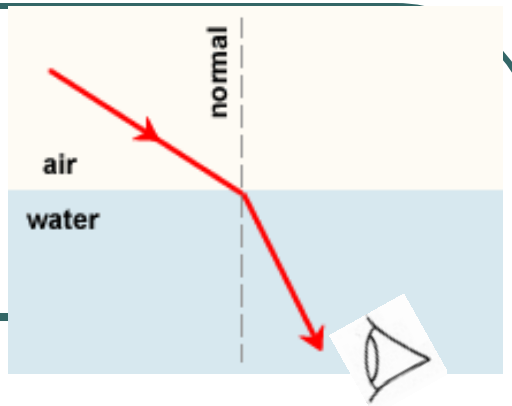


Incident side (n_i)

Refracted side (n_r)

- $n_i * \sin(\theta_i) = n_r * \sin(\theta_r)$

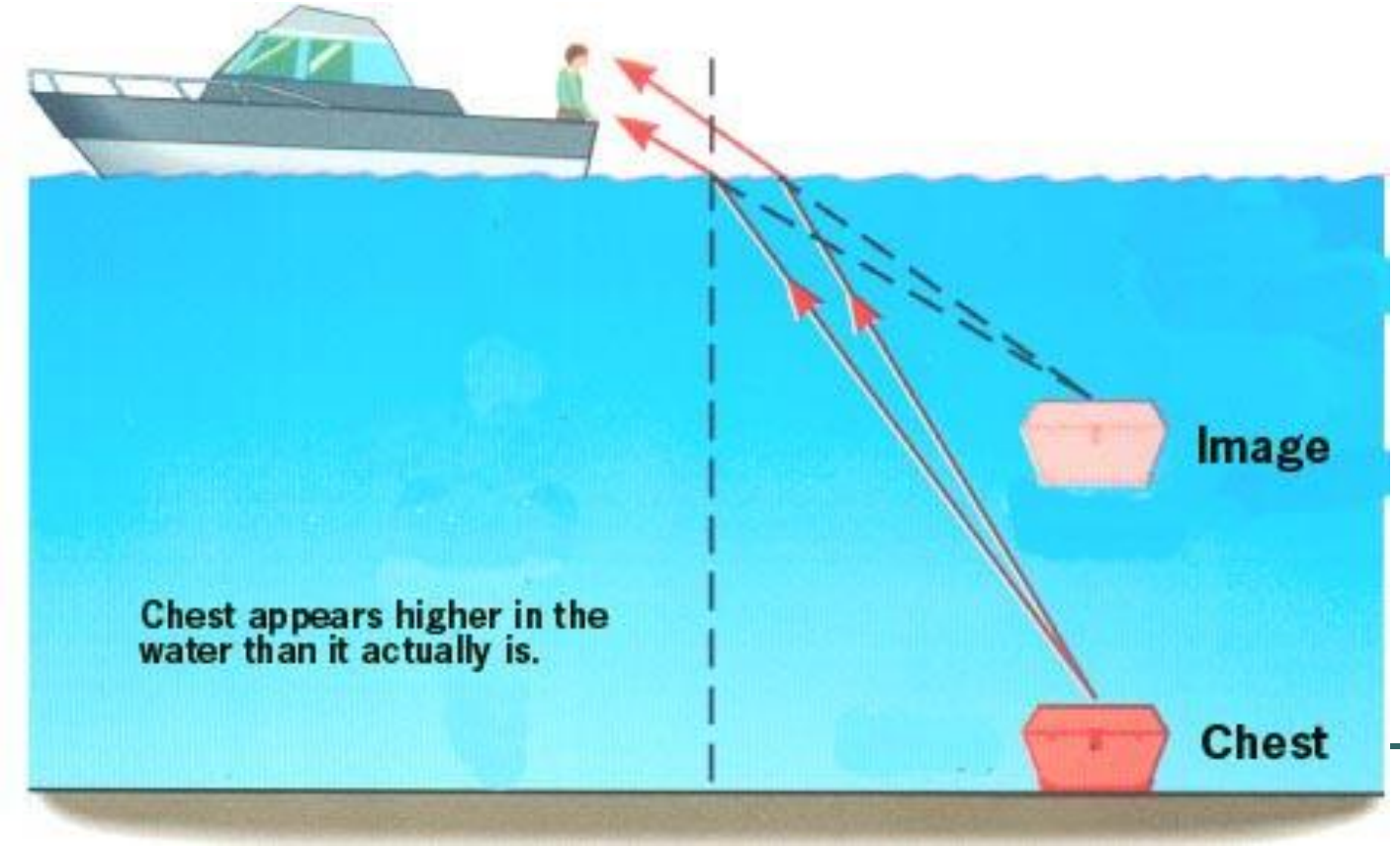
Incident side vs Refracted side?



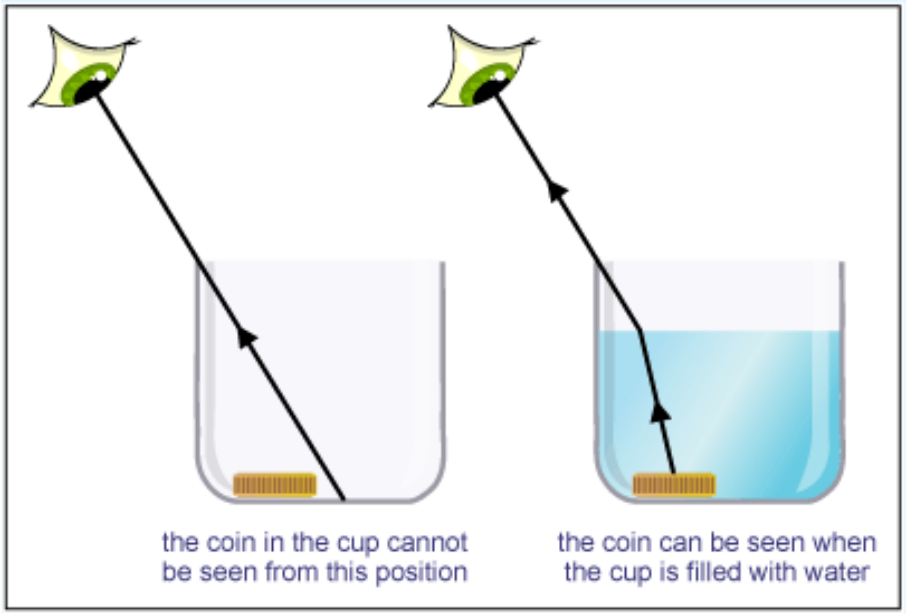
- Ask yourself
  - *Where is the observer (eye)?*
    - *refracted side of the boundary*
  - *Where is the object that is emitting or reflecting light?*
    - *incident side of boundary*
- Light travels from the object to the observer
- Draw a boundary diagram to aid in incident vs refracted media determination

Incident or Refracted?

- Light travels from source to observer (eye)



Examples of Refraction



Practice

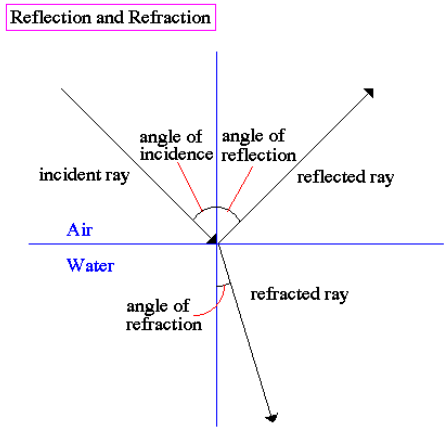
- Example: If the index of refraction of diamond is 2.42,
  - what is the speed of light in diamond?
- Solve n = c/v for v:
  - n = c/v
  - 2.42 = 3e8/v
  - v = 3e8/2.42 = 1.24e8 m/s

Practice

- If light travels at 2.25×10^{8} m/s through water, how long does it take for light to pass through a 30 cm deep trough filled with water?
- Solve d = v*t for t
  - $30/100 = 2.25 \times 10^{8} * t$
  - $t = 1.3 \times 10^{-9}$ seconds

Practice

- Example: A light ray traveling through air strikes some crown glass at an angle of 40° to the normal. If the index of refraction for the glass is 1.52,
  - *What is the angle of refraction (θ_r)?*
- Solution: use Snell's Law to find θ_r
  - $n_i * \sin(\theta i) = n_r * \sin(\theta_r)$
  - $1 * \sin(40) = 1.52 * \sin(\theta_r)$
  - $\theta_r = 25$ º



Homework

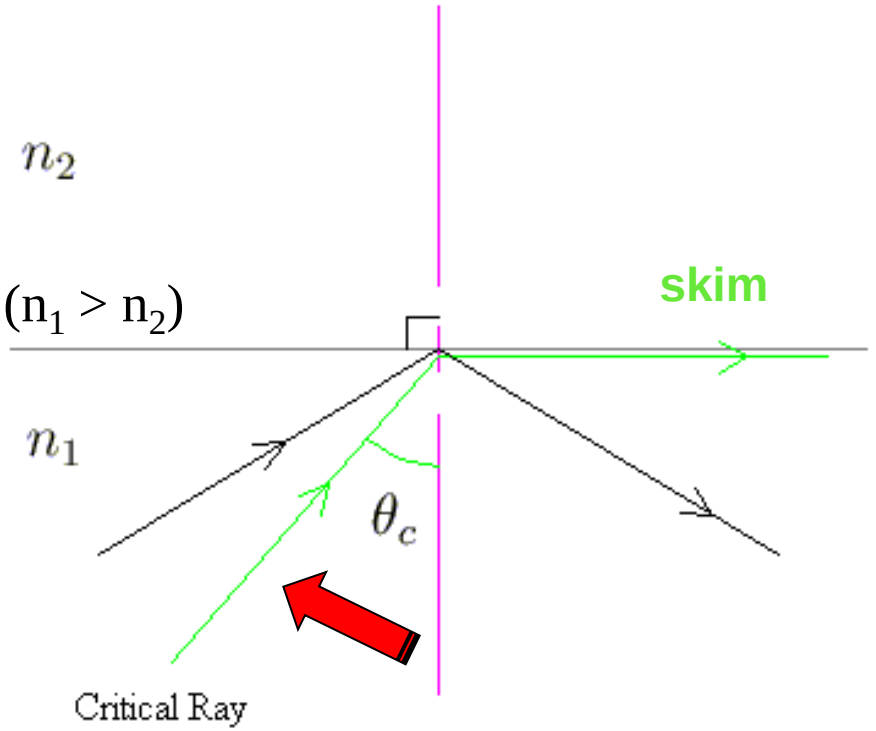
- P493
  - Practice A
    - q1-3

Thus far…

- We have been focusing on light traveling **from** a "fast" medium (ex. air) **to** a "slower" medium (ex. glass), such that:
  - ***Refracted ray bends toward the normal***
- What if the light ray is traveling **from** a "slow" medium **to** a "faster" medium?
  - ***Refracted ray bends away from the normal***
  - **Until** a critical incident angle is reached at which the refracted ray **skims** the boundary,
  - $\theta_c = \sin^{-1}(n_r/n_i)$

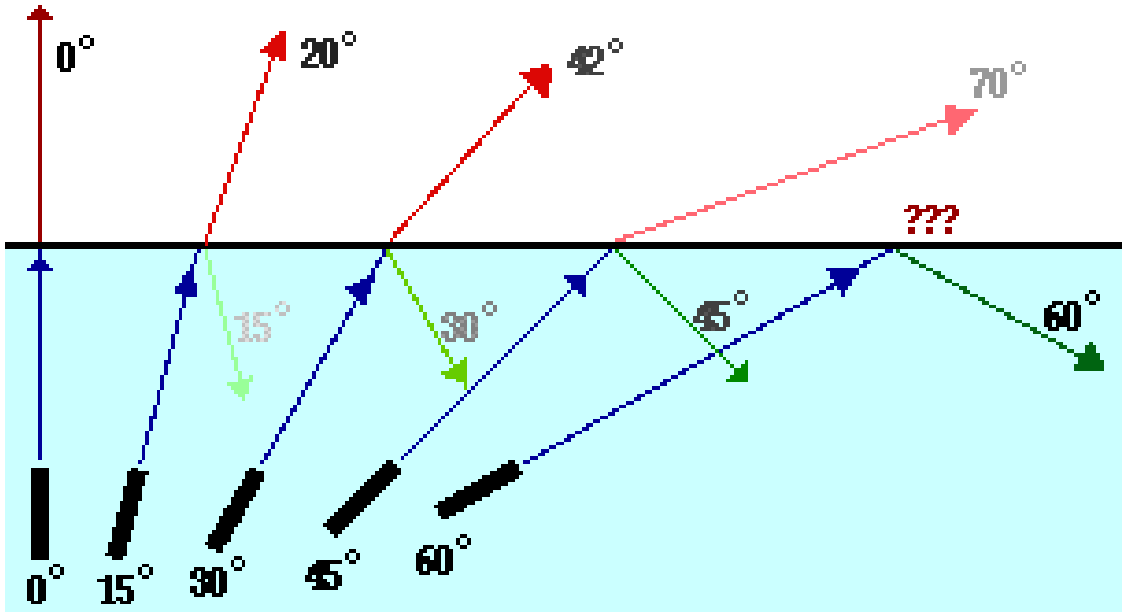
Total Internal Reflection (TIR)?

- A phenomenon that occurs when:
  - Light passes from a medium of **higher** refractive index (slower) to a medium of **lower** refractive index (faster), **and**
  - The angle of incidence exceeds a **critical** angle (θ_c), giving:
- TOTAL INTERNAL REFLECTION (TIR)



Refraction

As the angle of incidence increases from 0 to greater angles ...



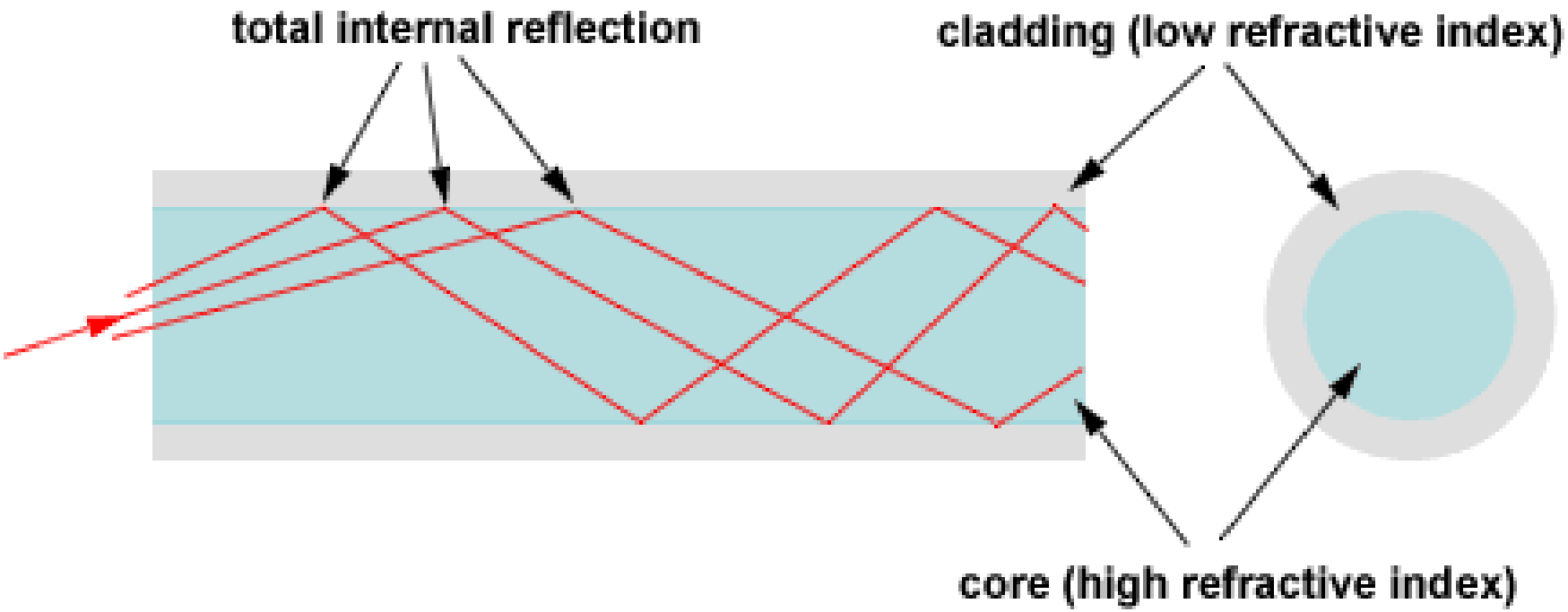
...the refracted ray becomes dimmer (there is less refraction)

...the reflected ray becomes brighter (there is more reflection)

...the angle of refraction approaches 90 degrees until finally a refracted ray can no longer be seen.

Example of Total Internal Reflection

- Fiber Optics



Summary

IF Incident Ray	THEN Refracted Ray
• Fast medium -> slow medium (Ex. Air -> water)	• Moves towards the normal (perpendicular)
• Slow medium -> fast medium (Ex. water -> air) • When angle of incidence (θ_i) = critical angle (θ_c) • When $\theta_i > \theta_c$	• Moves away from the normal, until… • **Skims** along the boundary between the 2 media, or… • Reflected internally (**Total Internal Reflection**)

Practice

- Example: What is the critical angle for light passing from ice (n=1.31) to air (n=1)?
- Solve $\Theta_C = \sin^{-1}(n_r/n_i)$ for Θ_C
  - $\Theta_C = \sin^{-1}(n_r/n_i)$
  - $\Theta_C = \sin^{-1}(1/1.31)$
  - $\Theta_C = 49.76$ degrees

Practice

- What is the critical angle of light traveling <u>from</u> the following substances into air?
  - Quartz (n = 1.46)
  - Acrylic resin (n = 1.51)
- Solve $\Theta_C = \sin^{-1}(n_r/n_i)$ for Θ_C
  - $\Theta_C = 43.2^\circ$
  - $\Theta_C = 41.5^\circ$

Homework

- Page 508
  - Practice C = q1-4