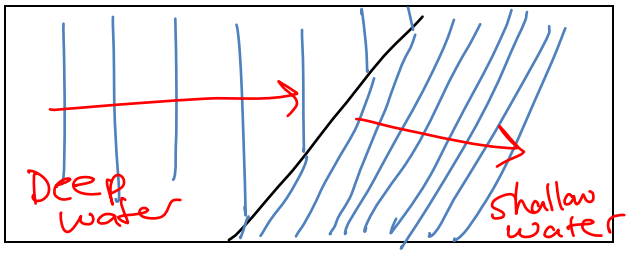
Unit 8: Waves

4 – Refraction

Wave speed depends on the media. What happens when waves travel from one medium into another?
Consider some waves moving from the open ocean to shore. As the water gets more and more shallow, the waves slow down (velocity decreases).



Waves traveling perpendicular to the new medium ($\Theta_i = 0^o$) continue in the same direction.

- Velocity decreases but frequency stays constant
- Therefore wavelength decreases

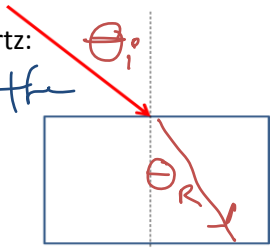
When waves are not perpendicular they will also bend

Refraction: the bending of waves as they move from one medium into another.

Optical density: the difficulty light has in transmitting through a medium

(vacuum < air < water < glass < diamond)

Consider a laser shining into a piece of quartz:



Angle of Incidence: angle between the normal + incident ray

Angle of Refraction: angle between normal + refracted ray

Snell's law

$$n_i \sin\Theta_i = n_r \sin\Theta_r$$

n = the index of refraction (related to optical density)
Θ_i = angle of incidence
Θ_R = angle of refraction

When light travels from:

- **less dense** to **more dense** it _____ _____ and *bends* _____ the normal
- **more dense** to **less dense** medium it _____ _____ and *bend* _____ _____ the normal.

Medium	n	Medium	n
Vacuum		Crown glass	
Air		Quartz	
Water		Flint Glass	
Ethanol		Diamond	

Ex: A ray of light traveling in air strikes a block of quartz at a angle of 15°. Find the angle of refraction.
Draw a diagram.

Ex: A ray of light travels from underwater into air. It travels in the air at an angle of 65°, find the incident angle.
Draw a diagram.

The index of refraction for any substance is:

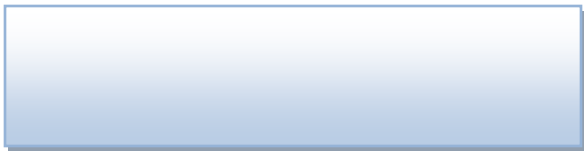
Where:

n =
c =
v =

Ex: What is the speed of light in water?

Total Internal Reflection

When passing from a more dense to a less dense medium, light refracts away from the normal.



If the angle is large enough then the angle of refraction will be parallel to the medium boundary. (i.e. $\Theta_r = 90^o$)

Critical angle:

Total Internal Reflection:

Ex: Find the critical angle for light traveling from water into air. Draw a diagram.

Snell's Law

1) Light travels at 2.62×10^8 m/s in a new clear type of plastic. What is this new product's index of refraction?

2) How fast does light travel in zircon (n = 1.92)?

3) Light traveling in air hits a diamond surface at 42° to the normal. To what angle is it refracted in the diamond?

4) Light leaves a ruby and enters water. If the angle of refraction is 60°, what was the incident angle inside the ruby? The index of refraction for ruby is 1.55.

5) An experiment is done with an unknown substance. Light entering the substance from air at 38° to the normal is refracted to 23.6°.
What is the sample's index of refraction?
What might the sample be made of?
How fast does light travel in the sample?

6) What is the critical angle for light leaving zircon and entering glass of the flint variety?

7) What is the critical angle for light leaving diamond and entering air?

8) A killer whale in its pool observes total internal reflection when it looks at the glass wall at a certain angle (it sees the reflection of the pool, and things in it). At what boundary does this reflection occur, water to glass or glass to air?

1) 1.15 2) 1.56×10^8 m/s 3) 16° 4) 48° 5) 1.54, quartz, 1.95×10^8 m/s 6) 59° 7) 24° 8) Glass to air