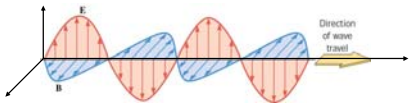
L 29 Light and Optics - 1

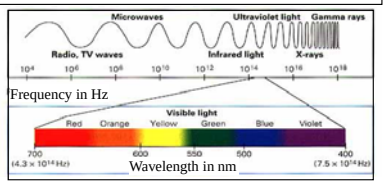
- Measurements of the speed of light: c = 3 × 10^8 m/s = 186,000 miles/s
- light propagating through matter – *transparent vs. opaque* materials
- colors
- The bending of light – refraction
  - dispersion - what makes the pretty colors?
  - total internal reflection- why do diamonds sparkle?
  - how are rainbows formed
- Atmospheric scattering
  - blue sky
  - red sunsets

Electromagnetic Waves



- Synchronized electric and magnetic fields moving through space at the speed of light c = 3×10^8 m/s; it is a *transverse* wave
- **LIGHT** is an electromagnetic wave with a wavelength that our eyes are sensitive to (400 nm to 700 nm) [nm (nanometer) = 10^{-9} m]

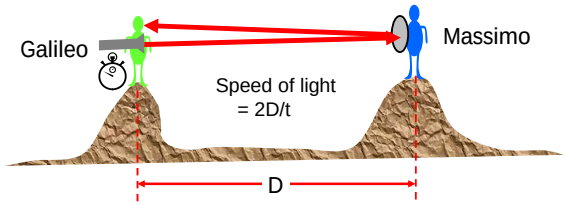
$$c = \lambda f$$



Measurement of the speed of light

- speed of light in vacuum = c
  - c = 300,000,000 m/s = 186,000 miles/s
  - ≈7 times around the earth every second
- the moon is 239,000 miles from the earth, so it takes 239,000 mi/186,000 mi/s =1.3 s for light from the moon to get to the earth
  - 8 minutes from the Sun to Earth
  - 24 minutes across the solar system
- Galileo was the first person to consider whether the speed of light was finite or infinite
- Galileo attempted to measure the speed of light by stationing himself on one mountain and an assistant on a nearby mountain and sending light signals

Galileo attempts to measure the speed of light



- Galileo turns his flashlight on and starts his clock
- His assistant Massimo holds a mirror which reflects the light back to Galileo
- When Galileo sees the light reflected from the mirror, he stops his clock and notes the time

Galileo's result

- "If not instantaneous, it is extraordinarily rapid; at least 10 times faster than sound."
- Suppose D = 2 miles, then the time delay would be t = D/c = 5 millionths of a sec. (The time delay for sound would be about 10 sec.)
- It is not surprising that Galileo was not able to measure this!
- We will measure the speed of light by timing how long it takes for a pulse of light to travel through a long plastic fiber

The speed of light inside matter

- The speed of light c = 3×10^8 m/s in vacuum
- In any other medium such as water or glass, *light travels at a lower speed.*
- The speed of light in a medium can be found by using the formula

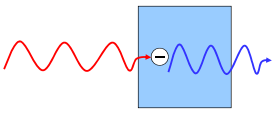
$$v_{medium} = \frac{c}{n}$$

  where c is the speed in vacuum (3×10^8 m/s) and **n** is a number called the **index of refraction**.
- Since n is greater than 1, v_{medium} is less then c.

$V_{medium} = c / n$

MEDIUM	INDEX OF REFRACTION (n)	SPEED OF LIGHT (m/s) (v_{medium})
Vacuum	Exactly 1	300,000,000
air	1.000293	
water	1.33	225,564,000
glass	1.52	197,368,000
diamond	2.42	123,967,000

Transparent and opaque materials



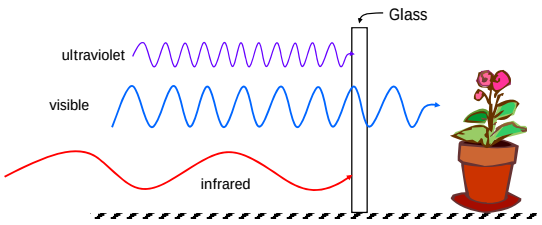
In transparent materials, when a light wave enters it the electrons in the material vibrate. The vibrating electrons re-emit the wave but at a slightly shorter wavelength. This is a resonance effect similar to 2 identical tuning forks

In opaque materials, the electrons also vibrate, but immediately pass their energy to the nearby atoms, so the wave is not re-emitted.

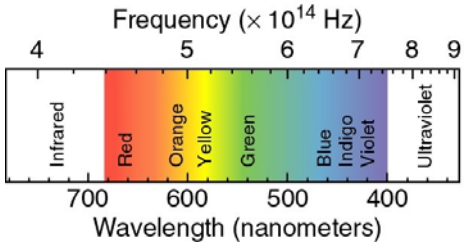
There is a slight delay between the vibration of the electrons and the re-emission of the wave. This delay is what causes a slowing down of light in the material, so that

$v_{medium} < c$

glass blocks both ultraviolet and infrared light, but is transparent to visible light



VISIBLE LIGHT



Color → WAVELENGTH OR FREQUENCY
Wavelength × Frequency = c
e.g., 600×10^{-9} m x 5×10^{14} Hz = 3×10^{8} m/s

COLOR

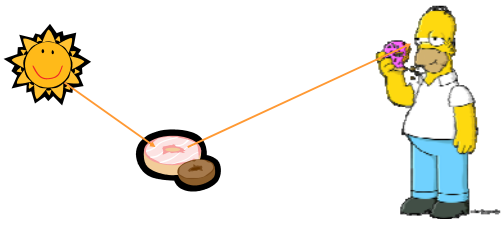
- Any color can be made by combining primary colors → **Red**, **Green** and **Blue**
- A color TV uses mixtures of the primary colors to produce "full color" images
- Perceived color is a *physiological effect*

Refraction→ the bending of light

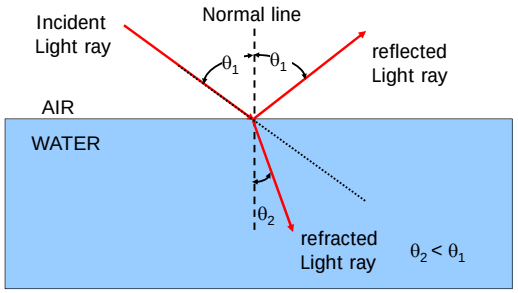
- One consequence of the fact that light travels more slowly in say water compared to air is that a light ray must bend when it enters water→ this is called **refraction**
- the amount of refraction (bending) that occurs depends on how large the index of refraction (n) is, *the bigger n is, the more bending that takes place*

What does it mean to “see” something?

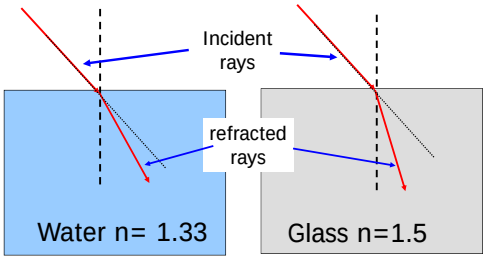
- To “see” something, light rays from an object must get into your eyes and be focused on the retina.
- unless the object is a light bulb or some other luminous object, the light rays from some light source (like the sun) must reflect off the object and enter our eyes.



Reflection and refraction at a surface



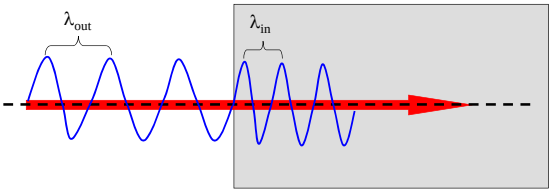
Refraction of light



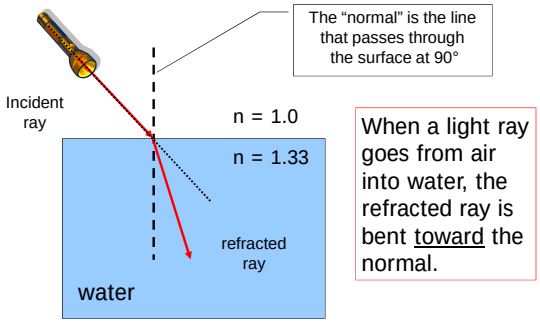
The refracted ray is bent more in the glass

Normal incidence

- If the ray hits the interface at a right angle (we call this *normal* incidence) there is no refraction even though the speed is lower
- The wavelength is shorter, however

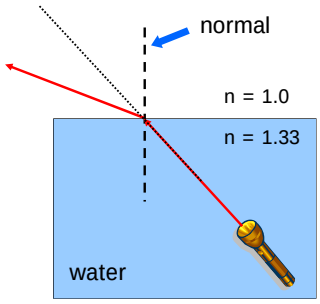


Refraction from air into water



When a light ray goes from air into water, the refracted ray is bent toward the normal.

Refraction from water into air

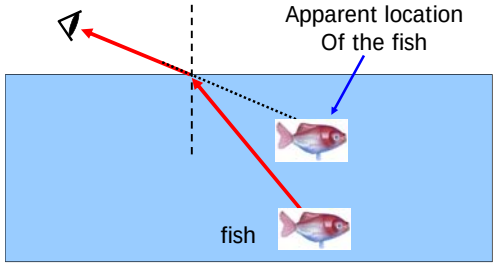


When a light ray goes from water into air, the refracted ray is bent away from the normal.

Effects caused by refraction

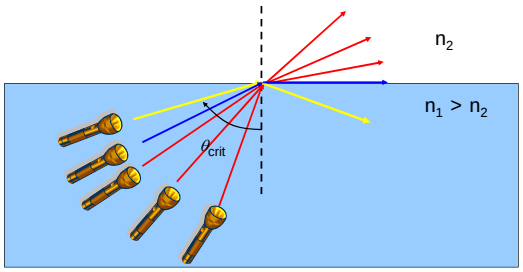
- An underwater object appears to be closer to the surface than it actually is
- Total internal reflection➔ fiber optics
- Seeing through a window
- Dispersion ➔ rainbows

Looking at objects that are underwater



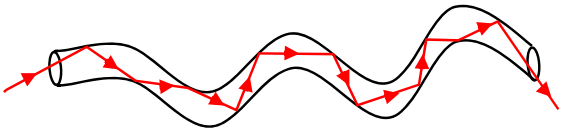
Underwater objects appear to be closer to the surface than then actually are

Total internal reflection, $n_1 > n_2$



When, $n_1 > n_2$ and the incident angle is greater than a certain value (θ_{crit}), the refracted ray disappears, and the incident ray is totally reflected back into the medium.

Fiber optics (light pipes)



- A fiber optic cable is a bunch (thousandths) of very fine (less than the diameter of a hair) glass fibers clad together.
- The light is guided through the cable by successive internal reflections.

fiber optic communications

- can carry more info with less distortion over long distances
- not affected by atmospheric conditions or lightning and does not corrode
- copper can carry 32 telephone calls, fiber optics can carry 32,000 calls
- takes 300 lbs of copper to carry same info as 1 lb of fiber optics
- downside ➔ expensive

Where is the pencil?