Light

The Speed of Light

- Galileo (1638)
- Ole Rœmer (1675)
- James Bradley (1728)
- Hippolyte Louis Fizeau (1849)
- Leon Foucault (1862)
- Albert Michelson (1877)

Newton’s Particle Model of Light

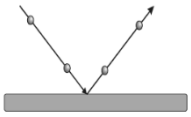
- Light is made up of little particles
- They obey the same laws of physics as other masses like baseballs and planets
- They are tiny so the particles in two intersecting beams do not scatter off each other

Rectilinear Propagation

- When a ball is thrown, it follows a parabolic path due to gravity
- If the ball is thrown very fast, the path of the ball appears straight
- Newton reasoned that light particles travel very fast and thus appear to travel in straight lines

Reflection

- Newton showed that, in an elastic collision (no energy loss) between a hard sphere and a hard surface, the angle of incidence equals the angle of reflection



Dispersion

- When white light passes through a glass prism, different wavelengths are refracted through different angles, generating a display of colors
- Newton's particle model explained this by saying that each particle in the spectrum had a different mass
- He suggested that the lower mass particles would get diverted more easily
  - red particles would have a higher mass than blue particles

Refraction

- Newton believed that water attracts approaching particles of light in much the same way that gravity attracts a rolling ball on an incline
- As particles of light travel from one medium to another they encounter a net force at the boundary
- This speeds up the particles of light
- Pushing them to take a direction closer to the normal

Problems with Particle Model

- Partial Reflection/Refraction
  - Newton proposed that some particles hit the surface and get reflected and some particles hit the surface and get refracted
  - But how did the particle know whether to reflect or refract?
  - The explanation is insufficient

- Diffraction
  - Newton argued that light does not travel around corners
  - Newton thought that the effect around a barrier was just particles colliding at the edges
  - In other words, diffraction cannot be explained by the particle model of light

Huygens' Wave Model of Light

- Light is a wave
- Huygens' principle
  - Every point on a wave front can be considered as a point source of tiny secondary wavelets that spread out in front of the wave at the same speed as the wave. The surface envelope, makes the wave front.

Rectilinear Propagation

- Huygens thought of light rays as the direction of travel of the wave
- Waves travel in straight lines (as does light)

Reflection

- It can be demonstrated using water waves that the angle of incidence is equal to the angle of reflection for waves

Refraction

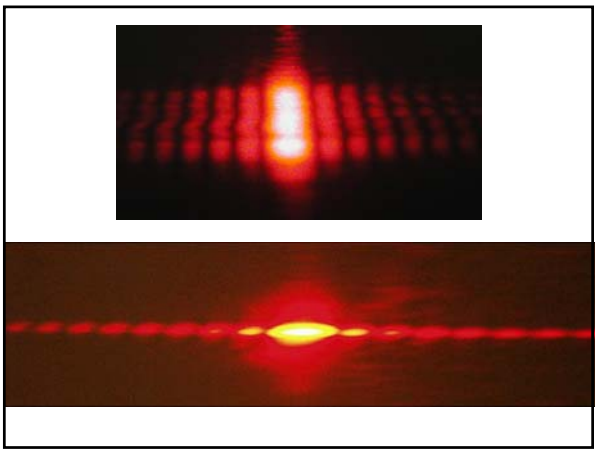
- While passing from the air to water, a light ray deviates towards the normal
- This is explained by proposing that the speed of light decreases in the heavier medium
- According to Huygens, the speed of light in water is less than in air

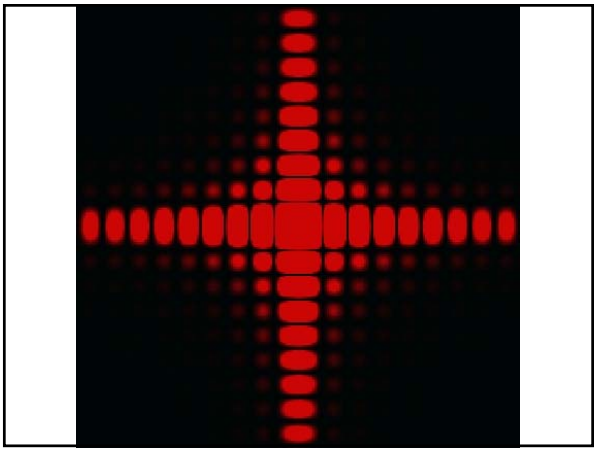
Partial Reflection/Refraction

- When one varies the angle of incidence of a wave passing from one medium to another, part of the wave is reflected and part of it is refracted

Diffraction

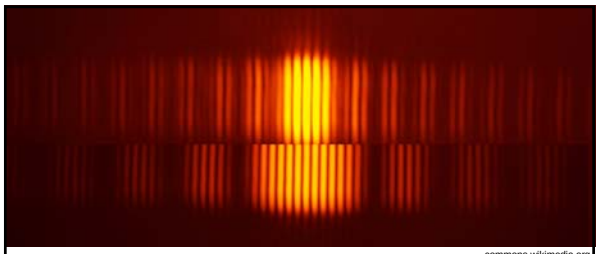
- When a wave hits a barrier, it bends
- When a wave passes through a narrow opening or slit, it bends
- When light is incident on a narrow slit, it also bends and produces a visible pattern





Two Slits

- If a wave passes through two slits a pattern of constructive and destructive interference appears
- This type of interference pattern also appears when light is incident on a pair of slits, thus confirming that light behaves as a wave



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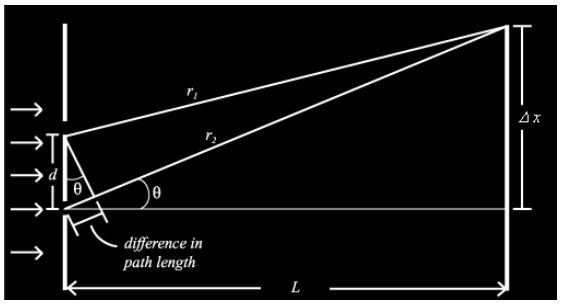
Young's Double-slit Experiment



- The path difference is $d \sin\theta$

- If the rays were in phase when passing through the slits, then the path length difference for constructive interference is an integer number of wavelengths
- So…

$$d \sin\theta = n\lambda$$

(For simplicity, we will use n=1)

- We can also see that $\tan\theta = \frac{\Delta x}{L}$
- For small angles $\sin\theta \approx \tan\theta$
- So, if $L >> \Delta x$, then $\sin\theta \approx \frac{\Delta x}{L}$
- Substituting gives…

$$\lambda = \frac{\Delta x\, d}{L}$$

- The wave theory better fit the evidence
- So light was considered to be a wave

Photoelectric Effect

- When light of a certain frequency shines on a metal surface, electrons are released from the metal
- To dislodge an electron a certain amount of energy must be transferred to the electron

Prediction of Wave Model

- Waves carry energy
- Energy from the light waves will build up and eventually dislodge an electron (or electrons)
- Any frequency of light should work
  - Lower frequencies (which have less energy) should take longer to release electrons than higher frequencies

Problem with Wave Model

- Electrons are only released when light higher than a specific frequency is used
- If the frequency is less than this threshold frequency, then no electrons will ever be released
  - The intensity of the light or the length of time that the light shines on the metal do not matter

Prediction of Particle Model

- Einstein proposed that light consists of packets call “photons”
  - (Einstein’s model is not the same as Newton’s)
- The amount of energy that a photon has is fixed and depends on its frequency
- Photons with enough energy knock the electrons out of the metal
  - If the photon does not have enough energy, nothing happens

Wave/Particle

- Young's double-slit experiment provides strong evidence that light is a wave
- The photoelectric effect provides strong evidence that light is a particle
- So which model is correct?

BOTH ARE!

Wave Particle Duality

- Our current understanding of light is that it behaves as both a wave and a particle
  - It is really both at the same time
  - It appears to be a wave when we do an experiment that requires it to be a wave
  - It appears to be a particle when we do an experiment that requires it to be a particle
  - It has also been shown that all particles can also act as waves