

## The Properties of Light



Review: The distance between similar parts of a wave is referred to as

- a) Frequency
- b) Wavelength
- c) Wave speed
- d) Refraction

Review: The number of wave crests that pass a point in a given time is a measure of

- a) Frequency
- b) Wavelength
- c) Wave speed
- d) Refraction

Review: A pencil appears “bent” when placed partially under water. This is due to

- a) Reflection
- b) Interference
- c) Diffraction
- d) Refraction



## Measuring the speed of light: Galileo

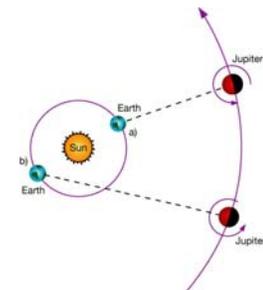


I was unable to make sure whether the facing light appeared instantaneously. But if not instantaneous, light is very swift.

Galileo



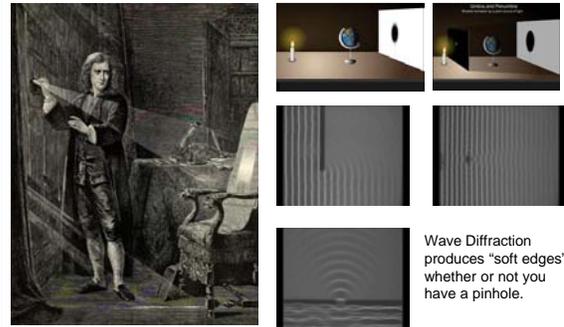
## Measuring the speed of light: Roemer



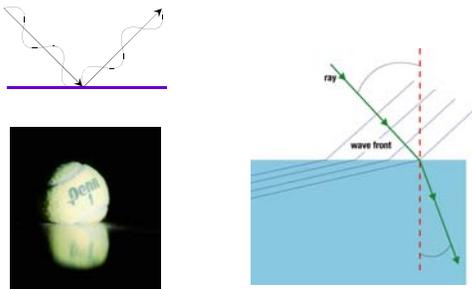
Measuring the speed of light:  
Armand Fizeau



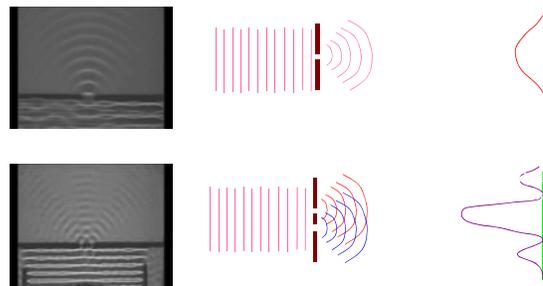
So what is light? Newton thought light was a particle because it cast sharp shadows



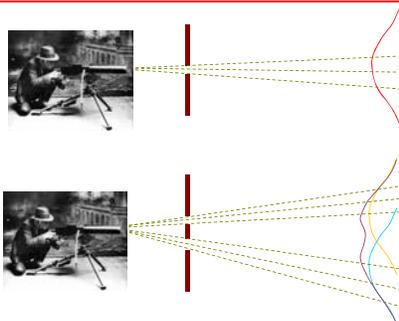
Particles also reflect and refract when certain assumptions are made about an interface



Diffraction is distinctly a wave phenomenon



What happens when particles strike slits?



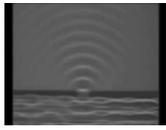
Thomas Young showed that light showed wave properties, it just has a very short wavelength



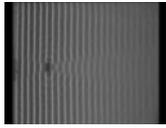
## Light exhibits diffraction



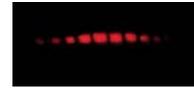
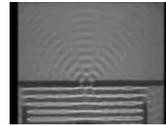
Thomas Young



Simeon Poisson



## Thomas Young showed that light showed wave properties, it just has a very short wavelength



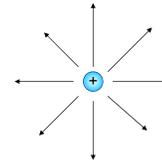
Light exhibits interference

## So light has wave properties. What is waving?

- A "field" associate attributes with a point in space.
  - A temperature field:



## Electric and Magnetic fields describe how a magnet or charged particle respond



## Maxwell came up with equations that showed that the electric and magnetic fields could "wave"

God said

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

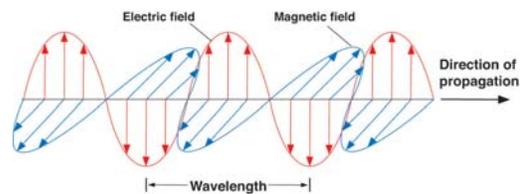
$$\nabla \times \mathbf{E} + \frac{\partial \mathbf{B}}{\partial t} = 0$$

$$\nabla \times \frac{\mathbf{B}}{\mu_0} - \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} = \mathbf{J}$$

and there was light!

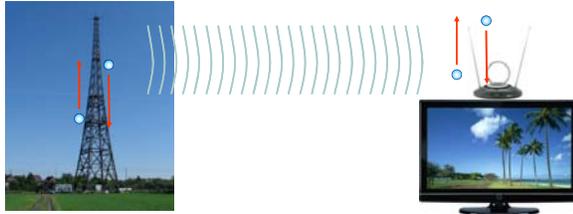


## Light as an electromagnetic wave



No need for a propagation medium!

## Accelerating Electrons



- Electromagnetic radiation is given off whenever electrons *accelerate*.
- Electromagnetic radiation, in turn, causes other electrons to accelerate. (TV, microwave oven)

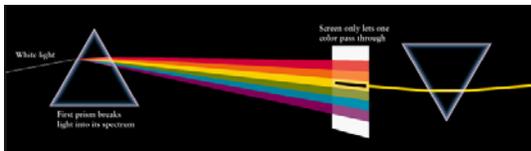
## Color

- Is the color in the glass or the light?



## Color is associated with the frequency (wavelength) of the light

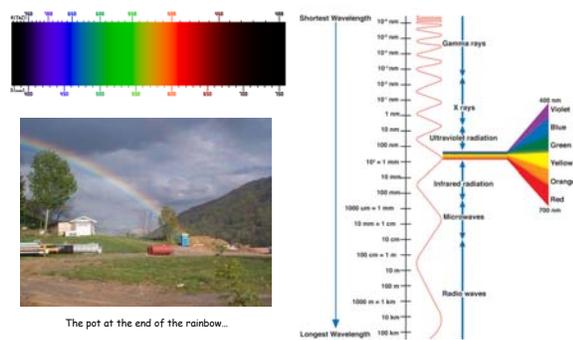
- Newton demonstrated that the colors were in the light and not created by the prism.
- Thomas Young demonstrated that color was associated wavelength.



## Come up with a model for why parts of this apple look red and other parts look green



## The electromagnetic spectrum



## What we knew about light at 1900

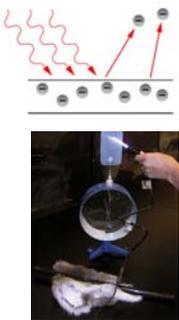
- Light behaves as an electromagnetic wave
- Light diffracts, refracts, interferes, and reflects
- The frequency of light waves is perceived as color
- No propagation medium is required

Objects glow with a characteristic color depending on temperature. The emission spectrum doesn't match what would be expected using classical electromagnetic theory.

Color Visible	Temperature
White	5,800 K 10,000 F
Orange	2,500 K 4,000 F
Red	900 K 1,400 F

### The photoelectric effect

- Energy in a normal wave is proportional to amplitude.
  - What determines if a wave has enough energy to knock you over at the beach?
- However, in the photoelectric effect, it is the frequency, not the amplitude, that determines whether light can eject electrons!
  - Energy =  $h \times$  (frequency)
  - ( $h$  is just a small number)



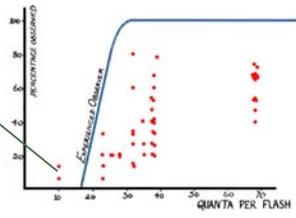
### The Photoelectric Effect

- Explained if light is interacting like a *particle* with the electrons in the metal!
  - Each individual "photon" has an energy of  $hf$  where  $h$  = Planck's constant (very small) and  $f$  = frequency.
- Consider how film works...



### How many photons can you see?

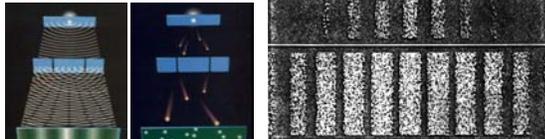
Light as the source of light was too weak. The filter was therefore removed. For example, 24 hours' starvation produces an increase in sensitivity. An apparatus is described which produced regular, carried out as the sensitivity influences is not the greatest possible. The nerve impulses meet on their way to the brain certain resistances. There are, however, conditions when these resistances are partially removed and all the senses attain special sharpness. For example, 24 hours' starvation produces and increase in sensitivity. The same effect can be obtained more conveniently, however, by the injection or consumption of some "tonic" drug. It was interesting to see if a trained observer could improve his flash-sensitivity in such a way, or if the training itself consisted in diminishing the resistances mentioned. For this purpose a dose of strychnine (1/13 of a grain) was taken by an observer 1 hour before the experiment began. The results obtained showed that the limit was considerably lowered - to about 12 quanta. It must be mentioned, however, that only one such experiment was carried out and the result obtained is therefore not very reliable.



From Charlton and Lea (1929)

### What gives?

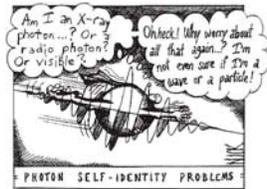
- How can a particle make an interference pattern?
- How can a wave make individual spots?



Double slit pattern with very low intensity light

### Wave Particle Duality

- Light has both wave and particle properties
  - It behaves like a wave when unobserved (It travels through both slits like a wave)
  - It is detected like a particle (It hits the screen as individual dots)
- Light is light. Waves and particles are our conceptual models. Light doesn't have to match our models, we have to match our models to light.



LIGHT IS A Particle!

If this bothers you, you are in good company!

---



"All these 50 years of pondering have not brought me any closer to answering the question, 'what are light quanta?' These days every Tom, Dick, and Harry thinks he knows it, but he is mistaken."

~ A. Einstein