Light

October 14, 2002

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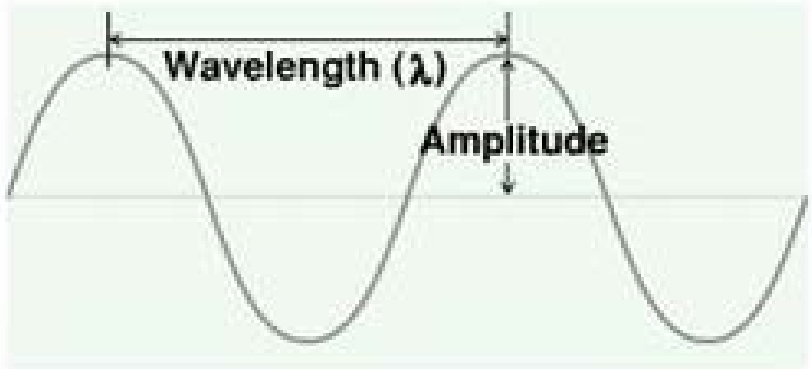
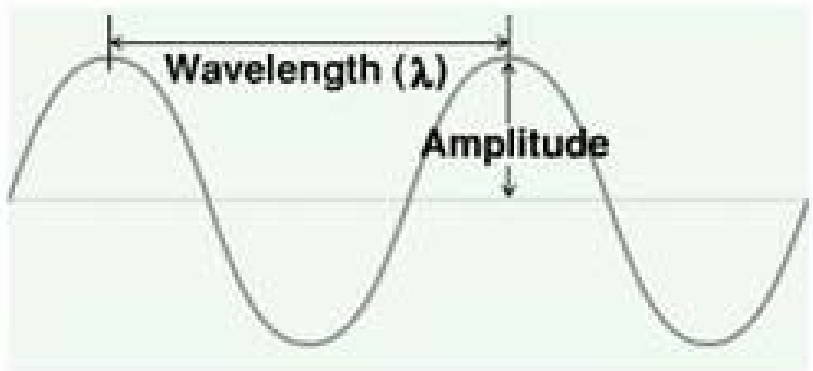
Waves



- You know of many types of waves
  - water, sound, seismic, etc
- A wave is something oscillating back and forth
- Waves has certain properties
  - amplitude – how large the oscillation
  - speed – how fast the wave is moving
  - period – time between wave crests
  - wavelength – distance between wave crests
  - frequency – number of wave crest passing by each second

Period/Frequency/Wavelength

- We can relate a wave's period, frequency and wavelength
  - period (P)
  - frequency (f)
  - wavelength (λ)

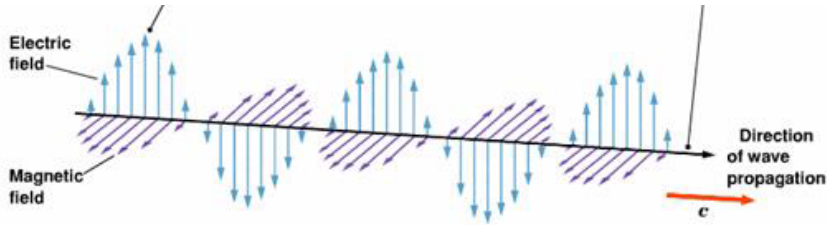


$$f = 1/P$$

$$\lambda = v/f \quad (v = \text{velocity})$$

Electromagnetic Waves

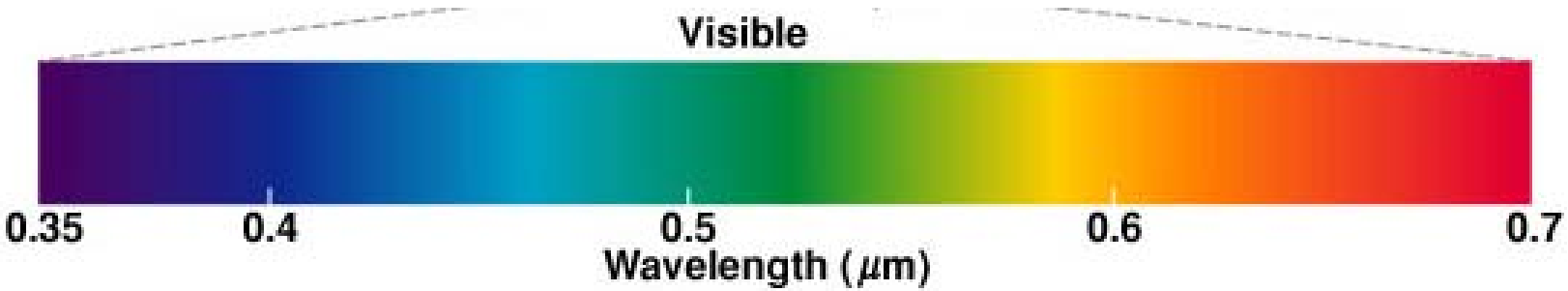
- Electromagnetic waves are oscillating electric and magnetic fields



- Light is an electromagnetic wave
- Unlike mechanical waves, does not travel through a medium
- Speed = speed of light
  - $c = 3.0 \times 10^8$ m/s

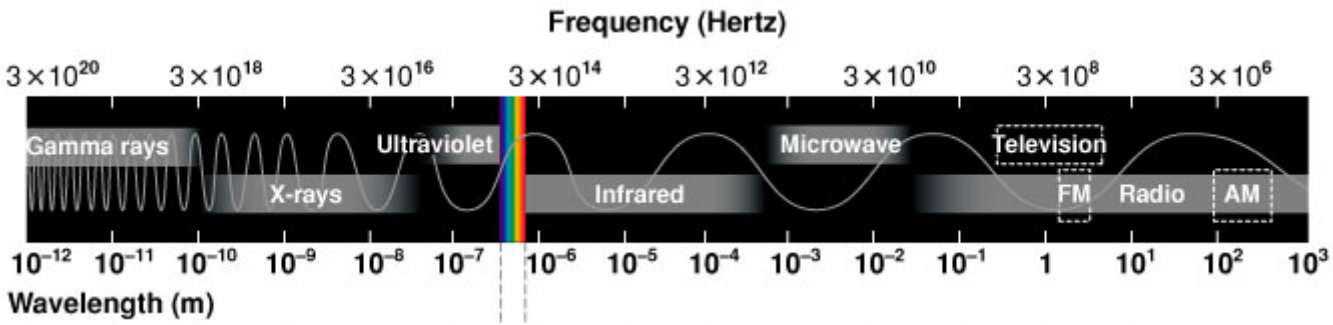
Color of Light

- In the visible spectrum, different wavelength means different color
  - rainbow/prism effect
    - caused by different wavelengths
  - "blue" is a shorter wavelength
  - "red" is a longer wavelength
  - "white" light is a combination of all colors



Wavelength of Light

- Different types of "light" correspond to different wavelengths
  - gamma rays (10^{-10} m)
  - x-rays (10^{-9}-10^{-8} m)
  - ultraviolet light (10^{-7} m)
  - visible light (10^{-6} m)
  - infrared light (10^{-6}-10^{-4} m)
  - microwaves (10^{-3} m)
  - radio waves (10^{-1}-10^{3} m)



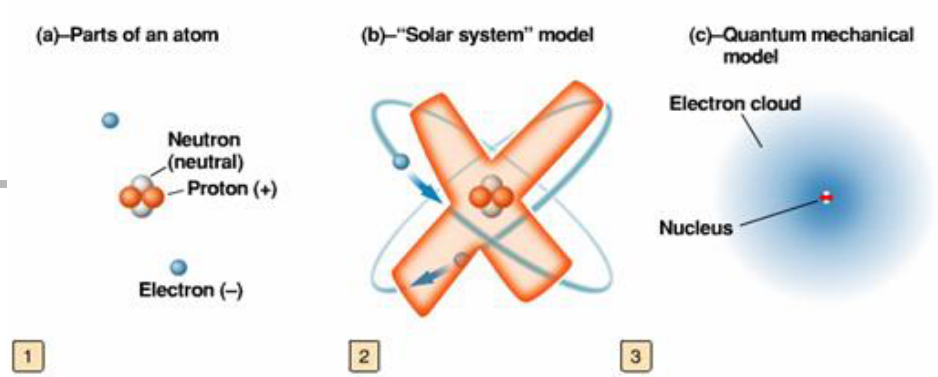
Light as Particle and Energy

- Light is an electromagnetic wave
- Light is also a particle
  - called a photon
- Light is a form of energy
  - $E = hc/\lambda$
    - h = a constant (6.63×10^{-34} joules/sec)
  - Light is the primary method of transferring energy around the Universe
  - e.g. light from the Sun heats the Earth's atmosphere

Relativity

- Theoretical and experimental evidence showed light (and other things) didn't exactly follow Newton's Laws
  - OK when things are moving slow, but breakdown when things are moving fast
- Albert Einstein developed the Special Theory of Relativity
- Relativity has a number of consequences
  - No. 1: Nothing moves faster than the speed of light
    - ~3.0×10^8 m/s
  - Does NOT say "everything is relative"
  - Does predict time dilation and length contraction
- Relativity has withstood numerous experimental tests

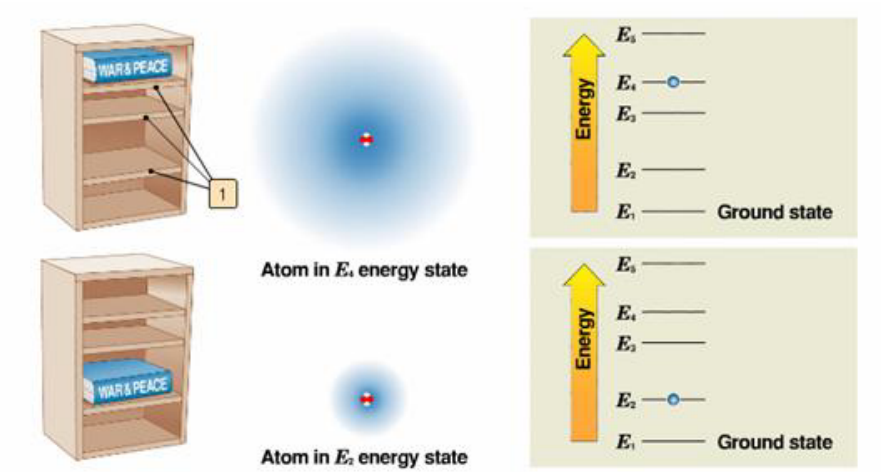
Atoms



- Atoms make up almost everything you know
  - nucleus – protons and neutrons
  - electrons surround the nucleus
  - number of protons and electrons determines the type of atom (e.g. hydrogen, helium, oxygen, nitrogen,…)
- Energy levels
  - electrons in an atom can only have very specific energies
    - like a set of stairs, you can be on one stair or the next, but not in between
  - each type of atom has a specific set of energy levels
    - hydrogen's levels are different than oxygen which is different than nitrogen

Excitation and Emission

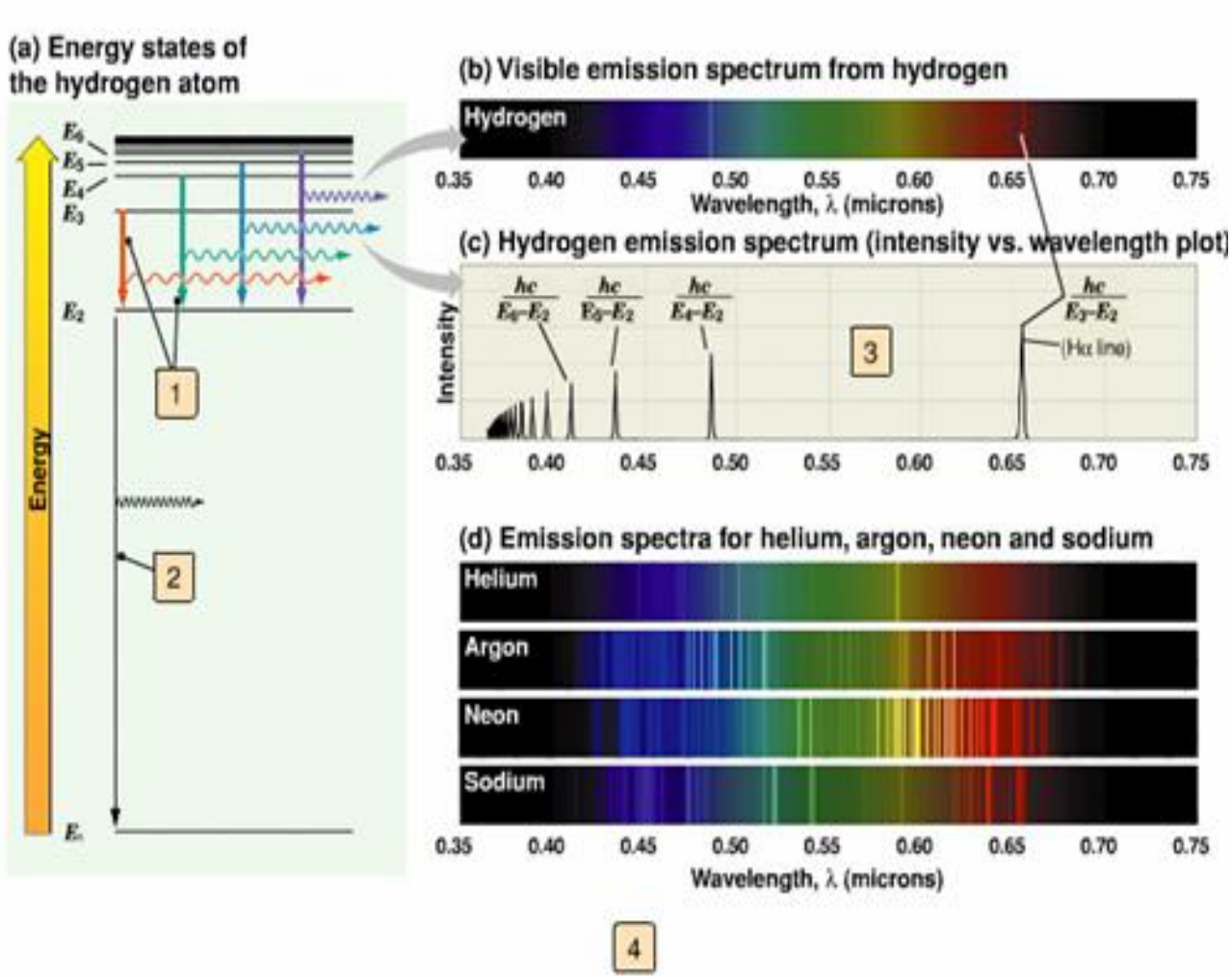
- Electrons can be excited to a higher energy level
  - collisions with other atoms
  - absorption of a photon



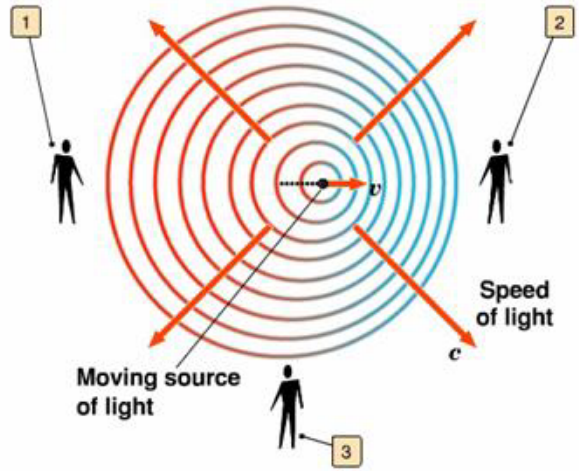
- Electrons can be un-excited be emitting a photon
  - electron drops from a higher to a lower energy level
  - photon is a very specific wavelength

Different Atoms/Different Colors

- Each atom has it's own set of energy levels and it's own set of light emissions
- This can be used to identify atomic composition



Doppler Effect



- Motion affects waves
  - motion of the source or receiver
  - example: sound of a passing siren
- Blue-shift
  - motion towards each other will shorten wavelength
- Red-shift
  - motion away from each other will lengthen wavelength
- Amount of wavelength change is related to the velocity
- Can be used to measure relative speeds

Temperature and Light

- Hot objects give off light
- Temperature is a measure of how fast the atoms/molecules are moving
  - hot atoms move faster than cooler atoms
    - faster movement means more collisions
- Collisions of atoms can convert energy to light
  - This is how an incandescent light bulb glows

Temperature and Light

- Hotter objects give off more light
  - luminosity is proportional to temperature raised to the fourth power

$$L \propto T^4$$

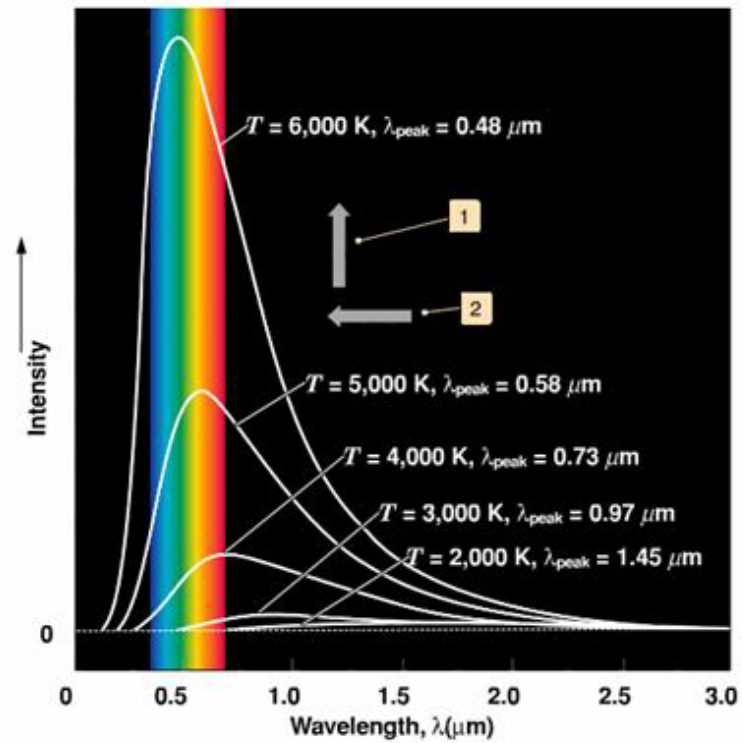
  - e.g. if you double an object's temperature, the luminosity goes up by a factor of 16 (2^4)
- Hotter objects give off bluer light
  - the wavelength is proportional to the inverse temperature

$$\lambda \propto 1/T$$

  - e.g. if you double an object's temperature, the wavelength drops in half

Blackbody Radiation

- Light radiated due to temperature, follows a pattern
  - blackbody radiation
  - all objects radiate light
- This can be used to measure the surface temperature of an obje
  - this is how we know our Sun has a temperature of 5,800 K

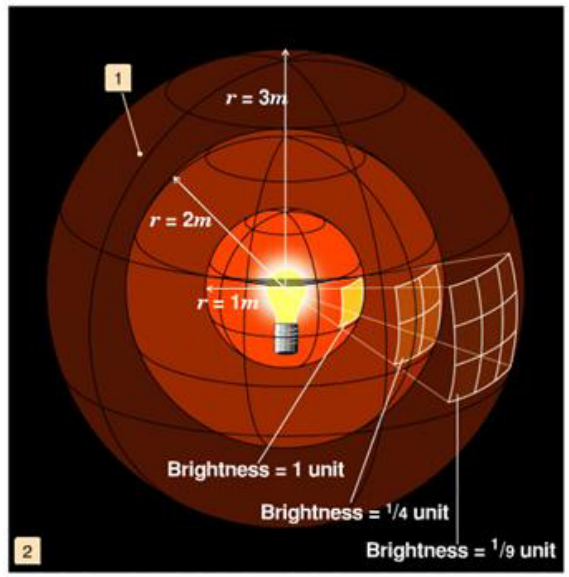


Intensity and Luminosity

- Luminosity is the total amount of light given off by an object
- Intensity is how much light we observe
  - if an object radiates light evenly in all directions…
  - the intensity goes as $1/r^2$ (r = distance from the source)

$$I = L/4\pi r^2$$

  - think of a sphere



- We can use the observed intensity to measure the distance if we know the luminosity

Sources of Light

- Several primary sources of light
  - reflection of light from another source
    - how we see most objects in this room
    - how we see planets, the Moon, asteroids, etc
  - creation of light from energy
    - glow of hot materials or from fusion
    - how the Sun glows
    - how we see comets
  - atomic emission of photons
    - could be from absorption
    - how we identify gases on a remote body