The Nature of Light

• As a wave…
  – A small disturbance in an electric field creates a small magnetic field, which in turn creates a small electric field, and so on…
    • Light propagates itself “by its bootstraps!”
  – Light waves can interfere with other light waves, canceling or amplifying them!
  – The color of light is determined by its wavelength.

• As a particle…
  – Particles of light (photons) travel through space.
  – These photons have very specific energies, that is, light is quantized.
  – Photons strike your eye (or other sensors) like a very small bullet, and are detected.

• Light is radiant energy.
• Travels very fast – 300,000 km/sec!
• Can be described either as a wave or as a particle traveling through space.
The Effect of Distance on Light

- Light from distant objects seems very dim
  - Why? Is it because the photons are losing energy (Tired Light)?
  - No – the light is simply spreading out as it travels from its source to its destination
  - The farther from the source you are, the dimmer the light seems
  - We say that the object’s brightness, or amount of light received from a source, is decreasing

\[
\text{Brightness} = \frac{\text{Total Light Output}}{4\pi d^2}
\]

This is an inverse-square law – the brightness decreases as the square of the distance (d) from the source.
The Nature of Matter

- The atom has a *nucleus* at its center containing protons and neutrons
- Outside of the nucleus, electrons whiz around in clouds called *orbitals*
  - Electrons can also be described using wave or particle models
  - Electron orbitals are quantized – that is, they exist only at very particular energies
  - The lowest energy orbital is called the *ground state*, one electron wave long
- To move an electron from one orbital to the next higher one, a specific amount of energy must be added. Likewise, a specific amount of energy must be released for an electron to move to a lower orbital
- These are called *electronic transitions*
• The number of protons (*atomic number*) in a nucleus determines what *element* a substance is.

• Each element has a number of electrons equal to the number of protons.

• The electron orbitals are different for each element, and the energy differences between the orbitals are unique as well.

• This means that if we can detect the energy emitted or absorbed by an atom during an electronic transition, we can tell what element the atom belongs to, even from millions of light years away!
• If a photon of exactly the right energy (corresponding to the energy difference between orbitals) strikes an electron, that electron will absorb the photon and move into the next higher orbital
  – The atom is now in an excited state
• If the photon is of higher or lower energies, it will not be absorbed – it will pass through as if the atom were not there.

  
  • This process is called absorption
  • If the electron gains enough energy to leave the atom entirely, we say the atom is now ionized, or is an ion.
• If an atom drops from one orbital to the next lower one, it must first emit a photon with the same amount of energy as the orbital energy difference.

• This is called emission.
In Astronomy, it is far too difficult to visit stars and most planets in person.

Astronomers’ primary tool in learning about the universe is electromagnetic radiation, or light.

The colors that the human eye can see define the **visible spectrum**, but there is much more to light than this narrow band of color!
The colors we see are determined by the wavelength of light.

Wavelength is the distance between successive crests (or troughs) in an electromagnetic wave.

This is very similar in concept to the distance between the crests in ocean waves!

We denote the wavelength of light by the symbol $\lambda$.

Wavelengths of visible light are very small!

- Red light has a wavelength of $7 \times 10^{-7}$ meters, or 700 nanometers (nm)
- Violet light has a wavelength of $4 \times 10^{-7}$ meters, or 400 nm
- Colors in between red and violet (remember ROY G BIV?) have intermediate wavelengths
• Frequency and wavelength are related by:

\[ \lambda \times \nu = c \]

‘c’ is the speed of light.

\[ \nu = \frac{c}{\lambda} \]
• Light from the Sun arrives with all wavelengths, and we perceive this mixture of colors as white
• Newton demonstrated that white light could be split into its component colors with a prism, and then recombined into white light with a lens
There is more to light than just the visible part of the spectrum

- Radio waves are very long wavelength photons (not sound!) with wavelengths longer than a meter or so
- Microwaves (yes, the ones we cook with) are at the upper end of the radio part of the spectrum
- Infrared wavelengths are just longer in wavelength than the visible spectrum
The Electromagnetic Spectrum II

- Above the visible...
  - Ultraviolet waves are just shorter in wavelength than visible waves. These are the waves that tan or burn us!
  - X-rays come mostly from stellar sources, and can penetrate many materials, like skin, muscle and bone
  - Gamma rays have the shortest wavelength
A photon carries energy with it that is related to its wavelength or frequency.

\[ E = \frac{h \times c}{\lambda} = h \times \nu \]

From this we see that long wavelength (low frequency) photons carry less energy than short wavelength (high frequency) ones. This is why UV waves give us a sunburn, and X-rays let us look through skin and muscles!

\( h = \text{Planck's constant} = 6.626068 \times 10^{-34} \text{ m}^2 \text{ kg / s} \)
Types of Spectra

A
Emission line spectrum (hydrogen gas)

B
Absorption line spectrum (hydrogen gas)

C
Continuous spectrum
Spectra of Astronomical Objects

A. Spectrum of a comet

B. Solar spectrum

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