Class 17: Properties of Light [2/23/07]

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- Electromagnetic Spectrum
- Wavelength, frequency and energy
- Light and Matter
  - Energy levels reprise
  - Absorption and Emission
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Now Playing: Ray of Light – Madonna
Announcements

- **Test #1:**
  - In-class: Wednesday Feb 28
  - Chapters 1-5
  - Guidelines to be posted on class web-site
  - 1-page 1-side handwritten “cheat sheet”
Properties of Light

YET another unit definition: \(1 \text{ Watt} = 1 \text{ Joule/s}\)

A Watt is a unit of power, i.e. the rate of energy use

YET another astronomy definition:
light is a collection of wavelengths (colours) which we call a spectrum

Prism

Diffraction Grating
Matter interacts with light in four general ways:

**EMISSION**
- e.g. heating of an object causes it to glow (*emitting light*)

**ABSORPTION**
- e.g. objects convert light into heat by soaking up (*absorbing*) energy
  - Opaque objects absorb light

**TRANSMISSION**
- e.g. light can pass through (*is transmitted by*) some objects
  - Transparent objects transmit light

**REFLECTION**
- e.g. light can bounce off (*is reflected by*) some “shiny” objects
Wave or particle?

Another weird and wonderful consequence of the quantum nature of matter and energy is that sometimes light acts like it is made up of particles and sometimes it acts like a wave! [wave-particle duality]

**Light is a wave**

Wavelength is the distance between adjacent peaks of the electric field.

Frequency is the number of waves (cycles) passing any point each second.

\[ \lambda \times f = c \]

All light travels with speed \( c = 300,000 \text{ km/s} \).

**Light is a particle**

Like particles, light comes in distinct pieces called photons.
Light (and other similar radiation) is generated by the oscillations of electric and magnetic fields and is consequently called an **electromagnetic wave**.

We will refer to **ALL** electromagnetic radiation as light.
Energy in a wave

\[ \lambda \times f = c \]

All electromagnetic waves move at the speed of light, \( c \).

Units:
- Typically measure wavelength in nanometers
  \( 1 \text{ nm} = 10^{-9} \text{ m} \)
- Typically measure frequency in Hertz
  \( 1 \text{ Hz} = 1 \text{ cycle/s} \)

The energy carried by a light wave is proportional to its frequency:

\[ E \propto f \quad (E \propto \frac{1}{\lambda}) \quad \Rightarrow \quad E = hf \quad \text{Joules} \quad (E = \frac{hc}{\lambda}) \]

\( h = \text{Planck's constant} = 6.626 \times 10^{-34} \text{ Joule x s} \)

\( f = 241 \text{ THz} = 2.41 \times 10^{14} \text{ Hz} \)
\( \lambda = 1242 \text{ nm} \)

\( \Rightarrow \quad E = 1 \text{ eV} \)
Each celestial object has a distinct spectrum generated by the allowed transitions in each of the elements contributing to the light it emits.
An atom emits or absorbs light only at specific energies (or wavelength or frequency) that correspond to the discrete ‘jumps’ available to the electrons in the atom.
Emission and Absorption

If a gas is low-density, the atoms in the gas can emit and absorb photons revealing the distinctive fingerprints of each element present.

\[ \Delta E = \frac{hc}{\lambda} \]

e.g. transitions between levels 2 and 3 in Hydrogen

\[ \Delta E = 1.9\text{eV} \rightarrow \lambda = 656.3 \text{ nm} \]
Emission and Absorption

Ions also produce distinctive fingerprints:

Emission line spectrum of Orion Nebula in the ultraviolet range (350-400 nm)

So do molecules:

Spectrum of molecular Hydrogen (H₂) showing distinctive molecular bands.
Thermal Radiation

If the gas is not low density, any photon emitted by any atom gets quickly re-absorbed by neighbouring atom and cannot easily escape to the outside.

The process of multiple emission and re-absorption essentially randomizes the radiative energies of the photons producing a “continuous spectrum”.

This spectrum depends only upon the temperature of the dense gas and is consequently called a “thermal radiation spectrum” or “blackbody spectrum”.

![Graph showing the thermal radiation spectrum of different temperatures, including the Sun (5,800 K), 15,000 K star, 3,000 K star, and 310 K human. The graph plots intensity (relative) against wavelength (nm).]