AST 105
Intro Astronomy
The Solar System

MIDTERM II: Thursday, October 31
[covering Lectures 10 through 16]
Light as Information Bearer

We can separate light into its different wavelengths (spectrum).

By studying the spectrum of an object, we can learn its:

- Composition
- Temperature
- Velocity
The Electromagnetic Spectrum

- **Wavelength (meters)**
  - Shorter: $10^{-12}$ to $10^{-6}$
  - Longer: $10^{-2}$ to $10^{2}$

- **Frequency (hertz)**
  - Higher: $10^{20}$ to $10^{12}$
  - Lower: $10^{6}$

- **Energy (electron-volts)**
  - $10^{6}$ to $10^{-6}$

- **Visible Range**: 400 - 700 nm

- **Sources on Earth**
  - Radioactive elements
  - X-ray machines
  - Light bulb
  - People
  - Radar
  - Microwave oven
  - Radio transmitter

- **Cosmic Sources**
  - Gamma ray burst
  - Black hole accretion disk
  - Sun's chromosphere
  - Sun
  - Planets, star-forming clouds
  - Cosmic microwave background
  - Radio galaxy
Wave-Particle Duality of Light

- Light can behave like a wave
  - Frequency, wavelength, amplitude

- Light can also behave like a particle
  - Photons = little bundles (bullets) of energy
Light as a WAVE

Wavelength is the distance between peaks

All light travels with a constant speed

Frequency is the number of times (per second) that the wave moves up and down

$\lambda \times f = c$

$\lambda = \frac{c}{f}$

OR

$f = \frac{c}{\lambda}$

• The shorter the wavelength, the higher the frequency
Light as a PARTICLE

• Light can also be modeled as a particle
  - “photon”

• A photon is a massless particle of electromagnetic radiation energy

• Photons travel at, you guessed it, the speed of light, \( c = 300,000 \text{ km/s} \)
Each photon has a unique energy

\[ E = h \times f \]

Photon Energy = Planck’s Constant \( \times \) Frequency
Each photon has a unique energy proportional to its frequency.

\[ E \propto f \]
\[ E \propto \frac{1}{\lambda} \]

Remember: \( \propto \) means “is proportional to”

Higher Frequencies
or
Shorter Wavelengths

MORE ENERGY

Gamma rays, X-rays, & UV are more dangerous than visible, infrared, or radio waves.
When compared to RED light, Blue light is:

A. Longer wavelength
B. Higher Frequency
C. Lower energy photons
D. Faster photons
E. None of the above
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First, a quick review of atoms
Electron Energy Levels in Atoms

- Atoms are made up of protons (+), neutrons (0) and electrons (-)
- Electrons move in different energy states around the nucleus
- Some states have more energy than others.

These energy states are “quantized” – there are only certain energies that the electrons are allowed to have. Details contained in quantum physics.
Example of electron energy levels in a hydrogen atom

- Lower level is lower energy. (think of stairs)

- Units: electronvolt (eV) TINY!
  - 1 Calorie = $3 \times 10^{22}$ eV

<table>
<thead>
<tr>
<th>ionization level</th>
<th>13.6 eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>level 4</td>
<td>12.8 eV</td>
</tr>
<tr>
<td>level 3</td>
<td>12.1 eV</td>
</tr>
<tr>
<td>level 2</td>
<td>10.2 eV</td>
</tr>
<tr>
<td>level 1</td>
<td>0 eV</td>
</tr>
</tbody>
</table>

(ground state)
Two ways to look at energy levels

- Both represent the same thing
  - The higher (or further from the nucleus) the level is, the more energy that level has.
Electrons can move between levels if they are given or lose the exact amount of energy corresponding to the difference in the energy levels.

If an electron gets enough energy, the electron will fly free.

Example: Energy jumps A & C result in the electron losing energy, B & F require energy, and D & E are not possible. F ionizes the atom with an energy gain of ≥3.4 eV.
When an electron drops down a level, it releases energy. Where does that energy go?

PHOTONS!

• The energy change between levels is equal to the energy of the photon.

• Larger energy jumps will be shorter wavelength photons.
What causes spectral lines?

A. Blackbody radiation.
B. Electron energy level transitions in an atom.
C. The Doppler shift of rapidly moving objects.
D. High frequency electromagnetic waves.
E. Protons and neutrons spinning in a charged atom.
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Three types of spectra

- Emission Line Spectrum
- Continuous Spectrum
- Absorption Line Spectrum
Emission Spectra

- Emission for thin, hot gas: Gas glows in specific colors.
Why does it need to be a HOT gas to give off an emission spectrum?

A. The electrons need to be in high energy levels
B. Hot gases give off higher energy photons
C. Hot gases glow brighter than cold gases
D. Cold photons don't have enough energy to make it here to Earth
E. Hot things glow, cool things don't.
Clicker Question

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Emission Spectra

- Emission for thin, hot gas: Gas glows in specific colors.
  - Colors represent electrons “falling down” energy levels
  - This is a FINGERPRINT of the elements in the gas.
Each atom has a different set of energy levels

• Just like no two people have the same fingerprints, no two elements have the same emission spectrum
The Crab nebula: remains of an exploded star (supernova)

Spectrum shows bright emission lines from various elements
Continuous Spectrum

- **Hot solids (or dense liquid):** Emit a continuous rainbow of light
  - **Thermal Radiation** (or **Blackbody Radiation**)

![Diagram showing a light source, prism, and intensity vs. wavelength graph for continuous spectrum.](image)
Three types of spectra

- Emission Line Spectrum
- Continuous Spectrum
- Absorption Line Spectrum
Absorption Spectrum

• Hot object viewed through COOL gas: Dark lines on top of a rainbow
  - Gas can only absorb photons OF THE RIGHT ENERGIES to move electrons to excited states
Kirchhoff's Laws

1) Hot solid, liquid, or dense gas

2) Thin, hot gas (compared to background)

3) Continuous spectrum viewed through a cooler gas (compared to background)
Solar Spectrum (as seen from Earth)
**What color are hot objects?**

- *Classic example: red hot pokers:*

  As temperature increases:
  \[
  \text{IR} \rightarrow \text{red} \rightarrow \text{blue}
  \]
Colors of Hot, Solid Objects

- Hotter objects peak at *bluer* wavelengths (photons with a shorter wavelength, higher frequency, and higher average energy)

- **Wien's Law**

\[ \lambda_{\text{Peak}} \propto \frac{1}{T} \]

We won't worry about the other mathematical law presented in the book: the Stefan-Boltzmann law.
Humans in the Infrared (false color)
What can a spectrum tell us?

• Let's use its spectral information to determine what this object is.
What is this object?

Continuous Spectrum:
Spectrum of visible light is like the Sun's except that some of the blue light has been absorbed.
What is this object?

Continuous Spectrum:
Must be a solid object with peak emission at a wavelength corresponding to a temperature of 225 K
What is this object?

Infrared Absorption Lines:
Absorption lines are the fingerprint of CO$_2$ gas
What is this object?

Ultraviolet Emission Lines:
Indicate object is surrounded by a hot upper layer of gas
What is this object?

Mars!
Midterm II (brief) Review
The Planets at a Glance

Small Inner Rocky Planets

Giant Outer Gas Planets

Dwarf Planets - Misfits
Solar Nebula:

- **SPINNING**
  - Conservation of angular momentum
- **HOT**
  - Collapse $\Rightarrow$ compression
- **DISK**
  - Collisions force common motions
Inside the frost line, rocks and metals condense, hydrogen compounds stay gaseous.

Beyond the frost line, rocks, metals, and hydrogen compounds condense.

- **Condensation**
  - The formation of solid/liquid particles from a gas

- **This is first step to forming planets**
Anatomy of a Planet

If defined by **DENSITY**

- **Core**
  - *Metals* (Iron, Nickel)

- **Mantle**
  - *Medium-density Rocks*  
    (Silicates: quartz, olivine)

- **Crust**
  - *Low-density rocks*  
    (Granite, Basalt)
4 Processes that Shape Surfaces

- Volcanism
  - Eruption of molten rock onto surface
- Impact cratering
  - Impacts by asteroids or comets
- Tectonics
  - Disruption of a planet’s surface by internal stresses
- Erosion
  - Surface changes made by wind, water, or ice