AST 105
Intro Astronomy
The Solar System

MIDTERM II: Tuesday, April 5
[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

<table>
<thead>
<tr>
<th>Wavelength (meters)</th>
<th>Frequency (hertz)</th>
<th>Energy (electron-volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-12}$</td>
<td>$10^{20}$</td>
<td>$10^6$</td>
</tr>
<tr>
<td>$10^{-10}$</td>
<td>$10^{18}$</td>
<td>$10^4$</td>
</tr>
<tr>
<td>$10^{-8}$</td>
<td>$10^{16}$</td>
<td>$10^2$</td>
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<tr>
<td>$10^{-6}$</td>
<td>$10^{14}$</td>
<td>$1$</td>
</tr>
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<td>$10^6$</td>
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**Visible**

- 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

\[ \lambda \times f = c \]

OR

\[ f = \frac{c}{\lambda} \]

OR

\[ \lambda = \frac{c}{f} \]

- The shorter the wavelength, the higher the frequency
Infrared light with a wavelength of 3 microns (3x10^{-6} m) has a frequency of 1.0x10^{14} Hz. What is the wavelength of light that has a frequency of 0.5 x10^{14} Hz?

(Hint: What is the relationship between wavelength and frequency?)

A. 1.5 microns
B. 2.0 microns
C. 2.5 microns
D. 3.5 microns
E. 6.0 microns
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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, 300,000 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
Clicker Question

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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Light as Information Bearer

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

• Composition
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We can separate light into its different wavelengths (spectrum).
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>
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<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>
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</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.
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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**)
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 ENERGY to move electrons to excited states
Absorption/Emission Line Applet

http://spiff.rit.edu/classes/phys301/lectures/spec_lines/Atoms_Nav.swf
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
The three spectral curves shown in the graphs below illustrate the total energy output (over the whole surface) versus wavelength for three unknown objects. Which of the objects has the highest temperature?

Clicker Question
Clicker Question

The three spectral curves shown in the graphs below illustrate the *total* energy output (over the whole surface) versus wavelength for three unknown objects. Which of the objects has the highest temperature?

- **A**
- **B**
- **C**

[Graphs showing three spectral curves]
Humans in the Infrared (false color)
What can a spectrum tell us?

• Let's use its spectral information to determine what this object is.
Continuous Spectrum:
Spectrum of visible light is like the Sun's except that some of the blue light has been absorbed
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!