Today

Summary of Chapter 3: Light
All of Chapter 4: Spectra & Atoms
Optional: Ast. Toolbox 4-2
Optional: Stephan-Boltzmann Law

Next Homework Oct. 8

Coming up: The Sun (Chapter 10)
Peak Wavelength

A spectrum of a typical star:

Measure how much light is produced of each color/wavelength

More light is produced at one "peak wavelength" than any other.

Call this wavelength: $\lambda_{\text{max}}$
How to Measure a Star’s Temperature

The peak wavelength ($\lambda_{max}$) is longer for stars that are cooler.

...And shorter for stars that are hotter.

This is called Wien’s law:

$$T_K \approx \frac{3,000,000 \text{ nm}}{\lambda_{max}}$$

or

$$\lambda_{max} \approx \frac{3,000,000 \text{ nm}}{T_K}$$

((where $T_K$ is the temperature in Kelvin).
Example of Wien’s Law

Wien’s Law:

\[ T_K = \frac{3,000,000 \text{ nm}}{\lambda_{\text{max}}} \]

Q: What is the Temperature of a star whose spectrum peaks at 1,000nm?

Answer:

\[ \lambda_{\text{max}} = 1,000 \text{ nm} \] is given.

\[ T_K = \frac{3,000,000 \text{ nm}}{\lambda_{\text{max}}} = \frac{3,000,000 \text{ nm}}{1,000 \text{ nm}} = 3,000 \text{ K} \]

The Sun’s temperature is about 6,000 Kelvins, so this star is cooler than the Sun.
Stellar Spectra fall into three categories:

1. Continuum Spectrum

-A rainbow in which all colors are represented
2. Absorption Spectrum

-A rainbow from which some colors missing
3. Emission Spectrum

- Mostly Dark, but a few bright *emission lines* are seen
We can compare these spectra to lab experiments.

- **Continuous Spectrum**
- **Emission Spectrum**
- **Absorption Spectrum**

Very hot bulb

Rainbow

Bright Lines

Rainbow with dark lines
A Spectral Mystery

Most stars’ spectra are **not** perfect rainbows... They are missing light at certain wavelengths/colors. (they have an **absorption** spectrum.) ...Why?

This light was produced by matter.

Since matter is composed of **atoms**, we need to understand atoms & how light interacts with them.
A Spectral Mystery

Most stars’ spectra are not perfect rainbows... They are missing light at certain wavelengths/colors. (they have an absorption spectrum.) ...Why?

This light was produced by matter.

Since matter is composed of atoms, we need to understand atoms & how light interacts with them.
Atoms

- An atom consists of a **nucleus** and a cloud of **electrons** surrounding it.

- The nucleus contains **protons** and **neutrons**.

- Almost all of the **mass** is contained in the nucleus.

- Almost all the **space** is occupied by the electron cloud.

- **Freaky Fact**: The atoms that make us up... are mostly empty space!
Elements & Nuclei

• An **Element** is defined by the number of **protons** in its nucleus.

• Hydrogen (H), is the simplest element: one proton

• Helium (He), is next simplest:
  • 2 protons
  • 2 neutrons
An **isotope** of an element is a nucleus with a different number of *neutrons* than normal.

*Deuterium* is an isotope of Hydrogen.

*Carbon-13* is an isotope of Carbon-12.
Bohr Model of the Atom
(Niels Bohr 1886-1962)

• Every atom consists of a **nucleus** plus **electrons**, which can be in different energy states.

• The farther the electron is from the nucleus, the higher its energy.

  *Freaky Fact*: Electrons can’t be in *any* energy state.

• Allowable energy states are “quantized”
  – (because an electron is a wave)

• This simple model can help us understand the mysterious spectra of stars
Bohr model of an atom

The electron “orbits” the nucleus, in one of these possible levels
Atoms & Light

- Light interacts with atoms by exchanging energy with electrons.
- An electron in a high energy level can "jump" down to a low energy level.
- It loses energy, and emits a photon of light.
- The energy of this photon equals the energy lost by the electron.
- This is the energy difference between the levels.
Photon Emission

Electron jumps to a lower energy level causing it to *emit* a photon.
Atoms & Light

• An electron can jump up from lower to higher energy levels.
• But, it needs energy to do this.
• A photon of light can provide the energy.

• However not every photon can do the trick.
• If the photon’s energy matches the energy difference between the levels, the photon will be absorbed.
• If not, it will fly through the atom.
Photon Absorption

Electron *absorbs* a photon, causing it to jump to a higher energy level.
Because electrons exist only at specific energy levels, photons are emitted & absorbed with specific energies.
Absorption Spectrum

The center of a star is very hot, but the outer layers are cooler.

So light from a star is similar to this experiment:

Photons of different wavelength have different energy. So atoms only absorb certain wavelengths of light! That’s why their spectra have dark lines.
Each element’s electrons have different energy levels

Hydrogen

Helium

Calcium

Iron

So each element has a different spectrum
Low-Resolution Spectrum of the Sun

We can barely see some absorption lines
A very high resolution spectrum of the Sun
What are Stars Made Of?

In the 1900s, people assumed that stars were made of the same elements as Earth (eg. Iron, Silicon).

To find out, Harvard student Cecilia Payne analyzed the spectra of many stars.

She discovered that most stars are made of Hydrogen (H) & Helium (He).
A Difficult Discovery

Since Payne’s discovery was so controversial, her advisor discouraged her from publishing it.

Later, other astronomers (including him) agreed she was right: Stars are mostly H & He

Payne overcame many challenges....

to become the first female science professor at Harvard, and the first female Director of Harvard Observatory
The Power of Starlight

We have seen that by analyzing starlight we can determine:

1. Temperature - From Wien’s Law
2. Composition - from spectral lines
3. Next: Motion - From Doppler Effect.
Doppler Effect
Doppler Effect

Stationary source of waves
Moving source of waves

Nice Demo: http://www.astro.ubc.ca/~scharein/applets/
Doppler Effect: sound waves

As the train approaches, the sound waves get crunched together. The wavelength gets shorter. (higher pitch)

As the train recedes, the sound waves get stretched apart. The wavelength gets longer. (lower pitch)
Doppler Effect: Light Waves

• If a source of light is *approaching*, the waves of light will be crunched, and smaller.
  • Smaller wavelength $(\lambda) = \text{blue}$.
  • This is called *blueshift*.

• If a source of light is receding away, the waves will be stretched and the light will become redder.
  • Longer wavelength $(\lambda) = \text{red}$
  • This is called *redshift*.
Doppler Shift of Spectral Lines

We can determine if a star is moving toward us or away from us based on its spectral lines, which are shifted from their usual “rest wavelength” $\lambda_0$.
Doppler Effect Calculation

The light of a moving source is blueshifted or redshifted by

\[ \frac{\Delta \lambda}{\lambda_0} = \frac{v_r}{c} \]

- \( \lambda_0 \) = rest wavelength emitted by the source
- \( \Delta \lambda \) = wavelength change due to Doppler effect
- \( v_r \) = radial velocity (speed)
- \( c \) = speed of light

The faster something moves, the bigger the change in wavelength.
Example:
A certain spectral line \((H_\alpha)\) has a rest wavelength of 656 nm.

Suppose we observe a star’s spectrum with the \(H_\alpha\) line at \(\lambda = 658\) nm.

Question: How Fast is this Star moving?

Is it moving toward us or away?
Example:

\[ \lambda_0 = 656 \text{ nm} \quad (\text{rest wavelength}) \]
\[ \lambda = 658 \text{ nm} \quad (\text{observed wavelength}) \]

The change in wavelength is:

\[ \Delta \lambda = \lambda - \lambda_0 = 2 \text{ nm.} \]

\[ \frac{v_r}{c} = \frac{\Delta \lambda}{\lambda_0} \]

We find \( \frac{\Delta \lambda}{\lambda_0} = \frac{2 \text{ nm}}{656 \text{ nm}} = 0.003 = 3 \times 10^{-3} \)

\[ \frac{v_r}{c} = \frac{\Delta \lambda}{\lambda_0} = 0.003 \]

\[ v_r = 0.003 \times c \]

\[ v_r = 0.003 \times (300,000 \text{ km/s}) = 900 \text{ km/s.} \]

The star is **receding** from us at 900 km/s.
Doppler Effect: Applications

- The Doppler Effect can be used to measure how fast something is moving
- Police: Speeding Tickets
- Weather: Doppler Radar
- Astronomy: Motions of stars, including planet detection.
Chapter 4 Summary

- Wien’s Law: Measure Temperature
- Bohr model
- Atoms & Light
- How a spectrum is formed.
- Doppler Effect: Measure motion
The Sun – Our Star