Gaseous Pillars in M16 - Eagle Nebula
Hubble Space Telescope - WFPC2
Previously on Astro 1

• Light as a wave
• The Kelvin Temperature scale
• What is a blackbody?
  – Wien’s law: $\lambda_{\text{max}}$ (in meters) = (0.0029 K·m)/T.
  – The Stefan-Boltzmann law: $F = \sigma T^4$.
  – Cosmic microwave background
Stargazing event

- When: March 7 (and 8 if necessary)
- Where: Broida Rooftop
- How: sign up with Bill or Sagar. Maximum 50/night. First come first served. If the first night is full we’ll do the second.
Today on Astro 1

- **What are photons?**
  - Light can have particle-light properties. The particles of light are called photons: \( E = h\nu = \frac{hc}{\lambda} \)

- **Why is the sky blue and sunsets red?**
  - Interaction between light and atmosphere

- **What are stars and interstellar gas made of?**
  - The same elements we see on Earth, mostly Hydrogen, He, Oxygen, Carbon

- **What causes spectral lines?**
  - Atomic structure
Question 8.1 (iclickers!)

• If all stars are considered perfect blackbodies, then it should follow that all stars
  • A) of the same composition emit the same energy flux
  • B) of the same size emit the same energy flux
  • C) traveling at the same speed emit the same energy flux
  • D) of the same temperature emit the same energy flux
Light is also a particle: Planck’s Law

\[ E = \frac{hc}{\lambda} \quad \text{or} \quad E = hv \]

- \( E \): Energy of a photon
- \( h \): Planck’s constant = 6.625\( \times \)10\(^{-34} \) J s
- \( c \): Speed of light
- \( \lambda \): Wavelength of light
- \( \nu \): Frequency of light

Example: DNA molecules are easily broken when hit with ultraviolet light at 260 nm (why you get cancer from sunburns). How much energy does a single photon at this wavelength have?

\[ E = \frac{hc}{\lambda} = \frac{(6.625 \times 10^{-34} \text{ Js})(3.00 \times 10^8 \text{ m/s})}{2.60 \times 10^{-7} \text{ m}} = 7.64 \times 10^{-19} \text{ J} \]
Question 8.2 (iclickers!)

• In what way does a photon of blue light not differ from a photon of yellow light in a vacuum
  • A) wavelength
  • B) color
  • C) energy
  • D) speed
Why is the sky blue and the sunset red?
The atmosphere scatters blue light more effectively than red light — hence mostly blue light reaches your eye when you look at the sky.

Why the sky looks blue

Box 5-4a
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The atmosphere scatters blue light more effectively than red light — hence mostly red light reaches your eye when you look through a thick slice of atmosphere at the setting Sun.

Why the setting Sun looks red
Spectra as the “fingerprints” of nature
The Sun’s Spectrum

In 1814 Joseph von Fraunhofer magnified the solar spectrum seen through a prism, and found hundreds of dark lines.
1. Add a chemical substance to a flame

2. Send light from the flame through a narrow slit, then through a prism

3. Bright lines in the spectrum show that the substance emits light at specific wavelengths only
Kirchoff’s Laws

1. A hot, dense object such as a blackbody emits a **continuous spectrum** covering all wavelengths.

2. A hot, transparent gas produces a spectrum that contains bright (**emission**) lines.

3. A cool, transparent gas in front of a light source that itself has a continuous spectrum produces dark (**absorption**) lines in the continuous spectrum.
(a) Continuous spectrum (blackbody emits light at all wavelengths)

(b) Absorption line spectrum (atoms in gas cloud absorb light of certain specific wavelengths, producing dark lines in spectrum)

(c) Emission line spectrum (atoms in gas cloud reemit absorbed light energy at the same wavelengths at which they absorbed it)
The energy output of the sun.
(a) Continuous spectrum (blackbody emits light at all wavelengths)

(b) Absorption line spectrum (atoms in gas cloud absorb light of certain specific wavelengths, producing dark lines in spectrum)

(c) Emission line spectrum (atoms in gas cloud reemit absorbed light energy at the same wavelengths at which they absorbed it)
Figure 5-15

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The glowing gas cloud in this Hubble Space Telescope image lies 210,000 light-years away in the constellation Tucana (the Toucan). Hot stars within the nebula emit high-energy, ultraviolet photons, which are absorbed by the surrounding gas and heat the gas to high temperature. This heated gas produces light with an emission line spectrum. The wavelength of red light emitted by the nebula is 656 nm, characteristic of hydrogen gas.
For each emission line of iron, there is a corresponding absorption line in the solar spectrum; hence there must be iron in the Sun’s atmosphere.
Atomic number is the number of protons in an atom.
What causes spectral lines?
The structure of atoms
Radioactive substance emits alpha particles.

Most alpha particles pass through the foil with very little deflection.

Gold foil (seen edge-on)

Occasionally an alpha particle rebounds (like A or B), indicating that it has collided with the massive nucleus of a gold atom.

Rutherford’s Experiment
Rutherford’s model of the atom.

Today we know this is not exactly correct – electrons do not orbit the nucleus, but the basic idea is right -- protons and neutrons exist in the nucleus, and electrons are outside of it.
In 1885 Swiss schoolteacher Johann Jakob Balmer, by trial and error, created a formula that can predict where lines of hydrogen fall in the spectrum of a star.

We still call these Balmer lines.

\[
\frac{1}{\lambda} = R \left( \frac{1}{4} - \frac{1}{n^2} \right)
\]

\( R = \text{Rydberg constant} = 1.097 \times 10^7 \text{ m}^{-1} \)

\( n = \text{any integer greater than 2} \)
Niels Bohr
1885-1962

Was a postdoc with Rutherford. In 1912, to explain discrete nature of spectral lines, hypothesized that electron orbits are quantized (quantum mechanics!).

The Bohr model of the atom

Bohr and Einstein, 1925
The quantum nature of light is related to the quantum nature of atoms!

(a) Atom absorbs a 656.3-nm photon; absorbed energy causes electron to jump from the $n = 2$ orbit up to the $n = 3$ orbit

(b) Electron falls from the $n = 3$ orbit to the $n = 2$ orbit; energy lost by atom goes into emitting a 656.3-nm photon
Bohr figured out the physical explanation for Balmer’s formula – the spectra from stars depends on the structure of atoms!

\[ \frac{1}{\lambda} = R \left( \frac{1}{4} - \frac{1}{n^2} \right) \]

\[ N = \text{lower orbital} \]
\[ n = \text{higher orbital} \]
Electron Transitions in the Hydrogen Atom
The same wavelength occurs whether a photon is emitted or absorbed.

Lyman series (ultraviolet) of spectral lines: produced by electron transitions between the $n = 1$ orbit and higher orbits ($n = 2, 3, 4, \ldots$)

Balmer series (visible and ultraviolet) of spectral lines: produced by electron transitions between the $n = 2$ orbit and higher orbits ($n = 3, 4, 5, \ldots$)

Paschen series (infrared) of spectral lines: produced by electron transitions between the $n = 3$ orbit and higher orbits ($n = 4, 5, 6, \ldots$)
Most of the mass of ordinary matter resides in the
• A) electrons and nuclei, shared equally
• B) nuclei of atoms
• C) electron around the nuclei of atoms
• D) energy stored within the atom in electromagnetic forces
Summary

• What are photons?
  – light can have particle-light properties. The particles of light are called photons: \( E = h\nu = hc/\lambda \)

• Why is the sky blue and sunsets red?
  – Interaction between light and atmosphere

• What are stars and interstellar gas made of?
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• What causes spectral lines?
  – Atomic structure
The End

See you on wednesday!