Lecture 16
Atomic Spectra
Doppler Effect
October 29, 2018
Comet 96P does this every 5.24 years. It is a short period comet that experiences frequent blasts of solar heat. During a similar flyby in 2002, SOHO observed two tiny fragments ahead of the main nucleus. This means the comet may be actively evolving, and it could shed more pieces during this week's dive. 

This is no ordinary comet. Its orbit connects it with a bewildering menagerie of other things in the solar system: Comet 96P is linked to as many as three meteor showers (the Daytime Arietids, Southern Delta Aquarids, and Quadrantids), two families of sungrazing comets, and an asteroid (2003 EH1). Millennia ago, the whole ensemble was probably part of the same parent object that exploded or fell apart.

Does this comet even belong to our own solar system? A scientific study published in 2008 found that 96P/Machholz has "extremely anomalous molecular abundances." Chemically speaking, it's not like other comets that have been studied in the same way. Perhaps it comes from another star system, flung into space and later captured by our own sun's gravity. (Spaceweather.com from October 27, 2017)
Continuous Spectrum

• Blackbody radiation = continuous radiation

• Light is emitted at all wavelengths.
Kirchhoff’s First Law

- A luminous solid or liquid or dense gas emits light of all wavelengths and so produces a continuum spectrum.

![Graph showing the intensity of light at different wavelengths for blackbody temperatures of 3000 K, 6000 K, and 12,000 K. The graph illustrates that as the temperature increases, the intensity of light across all wavelengths also increases.]

The higher the temperature of a blackbody, the more light it emits at all wavelengths.
Atoms

• An element is characterized by the number of protons in the nucleus.
  – Hydrogen = 1 proton
  – Helium = 2 protons
  – Carbon = 6 protons

• The number of electrons usually equals number of protons
  – Atom is electrically neutral
  – Ion: atom where number of electrons does not equal number of protons
Atoms and Spectral Lines

The Atom

Nucleus (protons and neutrons)

Low energy orbit

High energy orbit

Protons: + charge
Electrons: − charge
Neutrons: neutral
Electrons

- Electrons can move to different orbits, but they must gain or lose energy to do so.
- Energy difference between levels is unique for each element.
- The emitted or absorbed photon energies, and hence wavelengths, correspond to the difference between energy levels.
Hydrogen atoms in tube
Atom emits at wavelength set by the orbit its electron happens to be in. Thus, if electron jumps from orbit $3 \rightarrow 2$, the atom emits red light. If the electron jumps from $5 \rightarrow 2$, it emits violet, etc. No orbit jump corresponds to yellow or green light so those colors do not appear in the hydrogen spectrum.

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Emission Lines

- Hydrogen
- Helium
- Neon
- Sodium
- Krypton
- Mercury

https://en.wikipedia.org/wiki/Gas-discharge_lamp
Emission Spectrum

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Emission Spectra

- Observe a hot, thin gas
- Electron gives off a photon of light to move to a lower energy level

Photon energy must be equal to energy difference in atom

$\begin{align*}
n &= 1 \\
n &= 2 \\
n &= 3
\end{align*}$
Kirchhoff’s Second Law

- A low density, hot gas emits light
- The spectrum consists of a series of bright emission lines
- Lines are characteristic of the chemical composition of the gas.
Absorption Spectrum in the Sun

Fraunhofer Lines
Absorption Lines

Transmittance

Wavelength (nm)

117.8  118.0  118.2

0.0   0.2   0.4   0.6   0.8   1.0

Missing light is absorbed by hydrogen atoms in gas.
Absorption Spectra

- Continuum radiation observed through cool gas
- Electron absorbs a photon of light to move to a higher energy level

Photon energy must be equal to energy difference in atom
Kirchhoff’s Third Law

- A cool, thin gas absorbs certain wavelengths from a continuous spectrum.
- Leaves dark **absorption lines** in their place.
- Lines are characteristic of the chemical composition of the cool gas.
- Lines occur at the same wavelengths as the emission lines produced when gas is heated.
Hot, thin Gas → Continuum Source → Cool, thin Gas
Kirchhoff’s Laws: Interactive Applet
The star P Cygni has a thick, low-density atmosphere. Its spectrum is continuous with many absorption lines and a few emission lines. The bright continuous part of the spectrum is produced by

A. both the stellar surface and atmosphere equally.
B. the hot, dense, opaque stellar surface.
C. the low density atmosphere emitting light in all directions.
D. the portion of the atmosphere between us and the surface.

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Uses in Astronomy

• Because each element has a characteristic set of lines associated with it, astronomers can determine the compositions of many objects in the universe
  – Fraunhofer lines in the Sun
  – Clouds of gas
  – Distant galaxies
Ionization

- Electron absorbs enough energy from a photon to leave the atom

![Diagram showing electron levels and photon interaction](image)

- $n = 1$
- $n = 2$
- $n = 3$
Recombination

- Another electron recombines with the atom and the atom emits a photon or photons
Doppler Shift

- The wavelength of light is affected by the motion of either the source or the observer.

Applet 1
Applet 2
Doppler Shift

\[ \frac{\Delta \lambda}{\lambda} = \frac{v}{c} \]

- \( \Delta \lambda \) = wavelength shift amount
- \( \lambda \) = rest wavelength
- \( v \) = line-of-sight velocity
- \( c \) = speed of light

• The larger the line-of-sight velocity \( v \), the greater the wavelength shift \( \Delta \lambda \).

• Measuring the wavelength shift \( \Delta \lambda \) allows astronomers to determine \( v \), the line-of-sight component of velocity.
Suppose a spectral line with a normal wavelength of 633.000 nm is measured at 633.225 nm by a telescope spectrograph. What is the speed (relative to Earth, along the line of sight) of the object that emitted the spectral line?

A. 355 km/s
B. 633 km/s
C. 107 km/s
D. 225 km/s
Suppose a spectral line with a normal wavelength of 633.000 nm is measured at 633.225 nm by a telescope spectrograph. What is the speed (relative to Earth, along the line of sight) of the object that emitted the spectral line?

A. 355 km/s  
B. 633 km/s  
C. 107 km/s  
D. 225 km/s

\[ v = c \frac{\Delta \lambda}{\lambda} = \left( 3.0 \times 10^8 \text{ m/s} \right) \frac{0.225 \text{ nm}}{633.0 \text{ nm}} \]

\[ = 1.07 \times 10^5 \text{ m/s} = 107 \text{ km/s} \]
Doppler-shifted Stellar Spectra – Interactive Applet

Animated Figure 10-3 stellar Doppler shift

- Object moving toward observer: wavelength gets shorter (blue-shifted)
- Object moving away from observer: wavelength gets longer (red-shifted)
- NOTE: No shift for side-to-side motion.
The spectra of the ice in Saturn’s rings are different when observed from points A, B, and C, as compared with the spectrum collected when the ice particles are at rest.
Spectrum of Saturn’s Rings

Spectrum of ice when at rest → I
The spectrum at the bottom is emitted by an object

A. moving toward the observer
B. moving away from the observer
C. at rest with respect to the observer
D. moving sideways to the observer
Exam 2 Information

• Bring a #2 pencil!
• Bring a calculator. No cell phones or tablets allowed!
• Contents:
  – Free response questions (2 questions, 10 points)
  – True/False (10 questions, 20 points)
  – Multiple Choice (35 questions, 70 points). Two of these require a calculation.