Astro110-01
Lecture 15

Light and Matter (Cont’d)
What have we learned?

• Three basic types of spectra
  — continuous spectrum
  — emission line spectrum
  — absorption line spectrum

• Light tells us what things are made of
  — Each atom has a unique fingerprint
  — We can determine which atoms something is made of by looking for their fingerprints in the spectrum
What have we learned?

• How light tells us the temperature of planets and stars
  — Nearly all large or dense objects emit a continuous spectrum that depends on their temperature
  — The spectrum of that thermal radiation tells us the object’s temperature
How light tells us the speed of a distant object: The Doppler Effect
Mathematically speaking

\[ \frac{v_{\text{rad}}}{c} = \frac{(\lambda_{\text{shift}} - \lambda_{\text{rest}})}{\lambda_{\text{rest}}} \]

**Example:** If observe H\(\alpha\) spectral line (normally at 656.285 nm) from the star Vega at 656.255 nm, then Vega is moving at:

\[ \frac{v_{\text{rad}}}{c} = -4.57 \times 10^{-5} \]

or 13.7 km/s away from us.
The Doppler Effect
Doppler effect: Same for light
Measuring the Shift

We generally measure the Doppler effect from shifts in the wavelengths of spectral lines.

Stationary: Reference
- Moving Away
- Away Faster
- Moving Toward
- Toward Faster
The amount of blue or red shift tells us an object’s speed toward or away from us:

The Doppler Shift of an Emission-Line Spectrum

Spectrum of Stationary Hydrogen Gas (Laboratory)

Spectrum of Moving Cloud of Hydrogen Gas

Speed of Gas Cloud (relative to us) 3000 (Moving toward us km/s)

Speed = 0 km/s

Speed = 3000 (Moving away from us km/s)
Doppler shift tells us ONLY about the part of an object’s motion toward or away from us.

Star 1 is moving directly away from us. Doppler shift tells us its full speed.

Star 2 is moving across our line of sight, but not toward or away from us. Doppler shift = 0.

Star 3 is moving diagonally away from us. Doppler shift tells us the part of the star’s speed away from us. But not the part of the speed across our line of sight.
Thought Question

I measure a line in the lab at 500.7 nm. The same line in a star has wavelength 502.8 nm. What can I say about this star?

- It is moving away from me.
- It is moving toward me.
- It has unusually long spectral lines.
Thought Question

I measure a line in the lab at 500.7 nm. The same line in a star has wavelength 502.8 nm. What can I say about this star?

- It is moving away from me.
- It is moving toward me.
- It has unusually long spectral lines.
The Doppler Shift of an Emission-Line Spectrum

Spectrum of Stationary Hydrogen Gas (Laboratory)

Spectrum of Moving Cloud of Hydrogen Gas

(Moving toward us km/s) Speed of Gas Cloud (relative to us) 3000

(Moving away from us km/s) Speed = 0 km/s
Doppler Shift of Absorption Lines

Measuring Redshift
Determining the Velocity of a Gas Cloud

Measuring Velocity

Spectrum of Stationary Hydrogen Gas (Laboratory)

Rest wavelength: 400.0 nm

Spectrum of Moving Cloud of Hydrogen Gas

Observed wavelength: 400.0 nm

Wavelength shift: ----- nm

Relative speed: ----- km/s
Determining the Velocity of a Cold Cloud of Hydrogen Gas

Measuring Velocity

![Spectrum Diagrams](Image)
What have we learned?

• Light tells us the speed of a distant object:
  — The Doppler effect tells us how fast an object is moving toward or away from us

• Blueshift (shortened wavelength):
  – objects moving toward us

• Redshift (lengthened wavelength):
  – objects moving away from us
Reviewing the properties of spectra
Spectra of astrophysical objects are usually combinations of these three basic types:

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

• The spectrum of a common (incandescent) light bulb spans all visible wavelengths, without interruption.
Emission Line Spectrum

- A thin or low-density cloud of gas emits light only at specific wavelengths that depend on its composition and temperature, producing a spectrum with bright emission lines.
Absorption Line Spectrum

- A cloud of gas between us and a light bulb can absorb light of specific wavelengths, leaving dark absorption lines in the spectrum.
Chemical Fingerprints

Each type of atom has a unique spectral fingerprint
Transitions yielding emission lines

- Downward transitions produce a unique pattern of emission lines.
Transitions yielding absorption lines

- Because those atoms can absorb photons with those same energies, upward transitions produce a pattern of absorption lines at the same wavelengths.
Production of Absorption Lines
Wien’s Law

\[ \lambda_{\text{max}} = 2.9 \times 10^6 / T \text{ (K)} \]
Some Exercises
Thought Question
Which letter(s) labels absorption lines?

A  B  C  D  E
Thought Question

Which letter(s) labels absorption lines?

A B C D E
Thought Question

Which letter(s) labels the peak (greatest intensity) of infrared light?
Thought Question

Which letter(s) labels the peak (greatest intensity) of infrared light?
Thought Question
Which letter(s) labels emission lines?
Thought Question
Which letter(s) labels emission lines?

A  B  C  D  E
Interpreting an Actual Spectrum

- By carefully studying the features in a spectrum, we can learn a great deal about the object that created it.
What is this object?

Reflected Sunlight: Continuous spectrum of visible light is like the Sun’s except that some of the blue light has been absorbed—object must look red
What is this object?

Thermal Radiation: Infrared spectrum peaks at a wavelength corresponding to a temperature of 225 K.
What is this object?

Carbon Dioxide:
Absorption lines are the fingerprint of CO$_2$ in the atmosphere
What is this object?

Ultraviolet Emission Lines:
Indicate a hot upper atmosphere
What is this object?

Mars!