Lecture 11 + 12
The Nature of Matter

- **Gas**: Total disorder; much empty space; particles have complete freedom of motion; particles far apart.
- **Liquid**: Disorder; particles or clusters of particles are free to move relative to each other; particles close together.
- **Crystalline solid**: Ordered arrangement; particles are essentially in fixed positions; particles close together.

The States of Matter
The Nature of Matter

Molecules

Atoms
Atoms
Atomic Terminology

- Atomic Number = # of protons in nucleus
- Atomic Mass Number = # of protons + neutrons
- Isotope: same # of protons but different # of neutrons. (\(^4\)He, \(^3\)He)
Inside the Atom

Atoms have no net charge:
\[ N_{\text{Protons}} = N_{\text{Electrons}} \]
Nuclear Volume ~ $10^{-15}$ Atomic Volume
Nuclear Mass ~ 99.95% of Atomic Mass

Mass in Proton (Nucleus)
Volume in Electronic Shells

We are mostly Empty!

Atomic Scale:
1 Ångstrom = $10^{-10}$ m

Nuclear Scale:
1 Fermi = $10^{-15}$ m

Mass of Proton ~ Mass of Neutron
Mass of Proton ~ $2000 \times$ Mass of Electron

Ten million atoms could fit end to end across this dot.
The nucleus is nearly 100,000 times smaller than the atom but contains nearly all of its mass.

1 Ångstrom = $10^{-10}$ m

1 Fermi = $10^{-15}$ m
Isotopes

Hydrogen
1 proton

\[ _1^1H \quad _2^2H \quad _3^3H \]

Helium
2 protons

\[ _3^3He \quad _4^4He \]

Lithium
3 protons

\[ _6^6Li \quad _7^7Li \]
Atomic Energy Levels: The Atomic Staircase

Electrons can drop to a lower level
Or
Get kicked “upstairs”
Summary I

- Atoms are made of protons and neutrons (the nucleus) and electrons.
- Almost all the mass in the atom is in the nucleus.
- Elements are made of atoms.
- Atoms combine chemically to form molecules which make up most of the world around us.
Summary II

- Atomic electrons can only exist in discrete energy states.
- Transitions between these states requires the absorption or emission of the exact energy difference between the final and initial states.
- This energy can be in the form of a photon – a bundle of electromagnetic energy.
Photons: Matter and Energy

Photons have:

A characteristic wavelength $\lambda$ (wave)

Localized energy $E \propto \text{freq}$ (particle)
Light
Light is an electromagnetic wave

Waves have:
- a **wavelength**, \( \lambda \)
  [distance between crests]
- a **frequency**, \( f \)
  [number of crest passing per sec]
- a **speed**, \( v = \lambda \times f \)
  [length of wave passing a point per sec]

For sound waves: \( v \sim 345 m/s \)
For light waves: \( v = c = 3 \times 10^8 m/s \)
Thought Question
The higher the photon energy…

a) the longer its wavelength.
b) the shorter its wavelength.
c) energy is independent of wavelength.
The higher the photon energy…

a) the longer its wavelength.

b) the shorter its wavelength.

c) energy is independent of wavelength.
Summary

• Light is an electromagnetic wave that exists in quantum bundles called photons.
• Each photon has a precise wavelength, frequency and energy.
• Electromagnetic waves have different names - radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays - depending on where they fall in the electromagnetic spectrum
• The product of the wavelength and frequency is a constant, the speed of light.
Light and Matter Interactions

• Emission
• Absorption
• Transmission
• Reflection or Scattering

Terminology:
• Transparent: transmits light
• Opaque: blocks (absorbs) light
Light – Matter Interactions

- Emission
- Absorption
- Transmission – we say the matter is transparent
- Reflection or Scattering – Gives color
Thought Question
Why is the rose red?

a) The rose absorbs red light.
b) The rose transmits red light.
c) The rose emits red light.
d) The rose reflects red light.
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Light is how astronomy gets information about the universe.

What we can learn from light:

• Composition
• Temperature
• Speed
What can we learn from light?
Composition: What are atomic spectra?

- Electrons in atoms have distinct energy levels.
- Each chemical element, ion, molecule, has a unique set of energy levels.

The “staircase” is unique to each element.

The Logic of Atomic Spectra

• *Element Name* → Number of protons in the nucleus.
• Number of protons → Electron energy levels
• Electron energy levels → Transition energies
• Transition energies → Possible photon energies
• Possible photon energies → *Element Spectrum*
Observing Spectra:
Example: Solar Spectrum
Chemical Fingerprints

• Every atom, ion, and molecule has a unique spectral “fingerprint”
• We can identify the chemicals in gas by their fingerprints in the spectrum.
• With additional physics, we can figure out abundances of the chemicals, and much more.
Thought Question

Which letter(s) labels absorption lines?
Which letter(s) labels absorption lines?
Thought Question

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