Lecture 11
Atoms and Spectral Lines

Photons
Atomic Energy Levels

Line Spectra

"Line" spectra come from transparent gases and depend on composition, temperature, pressure, etc:

• 2. A hot, rarefied (transparent) gas produces an emission line spectrum - a series of bright spectral lines against a dark background.

• Line spectra: wavelengths of lines are unique to the substance- a unique fingerprint
  – Line Spectroscopy led to our modern understanding of what makes up substances at a sub-microscopic level.
Atoms

- **Atoms**: Made up of three subatomic particles
  - **proton**: Mass \(1.7 \times 10^{-24}\) gm. It takes \(600,000,000,000,000,000,000,000\) protons to make a gram! Each carries one positive electric charge.
  - **neutron**: Very similar to proton, but no charge.
  - **electron**: Mass \(1/2000^{th}\) of the proton. Carries one negative charge.

Atomic Structure

- All the protons and neutrons pack together in extremely dense **nucleus**. (positively charged)
- Electrons (negatively charged) in **cloud around nucleus**. Most of atom is empty space!
- The **electrostatic force** ("Coulomb force") holds electrons near nucleus. (electrostatic force: attracts opposite charges, repels like ones, falls off as \(1/distance^2\) like gravity)
- The **strong** and **weak nuclear force** hold the protons and neutrons together
Substance Terminology

- **Chemical element**: Defined by the number of protons in the atomic nucleus ("atomic number")
- **Isotope**: Each element can have different isotopes, defined by number of neutrons.
  - Only a few isotopes of each element are stable (the others are radioactive and come apart quickly):
  - there are typically a few more neutrons than protons in a stable isotope.
  - The sum of the number of protons and neutrons is atomic mass.

Atom Naming

- Nucleus (Element/Isotope) name: abbreviation of element name, with atomic mass as superscript on left:

<table>
<thead>
<tr>
<th>Element</th>
<th>Protons</th>
<th>Neutrons</th>
<th>Atomic Mass</th>
<th>Symbol</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>^1H</td>
<td>common Hydrogen</td>
</tr>
<tr>
<td>&quot;</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>^2H</td>
<td>Deuterium</td>
</tr>
<tr>
<td>Helium</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>^4He</td>
<td>common Helium</td>
</tr>
<tr>
<td>&quot;</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>^3He</td>
<td>Helium-3</td>
</tr>
<tr>
<td>Carbon</td>
<td>6</td>
<td>6</td>
<td>12</td>
<td>^12C</td>
<td>Common carbon</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>7</td>
<td>13</td>
<td>^13C</td>
<td>Carbon-13</td>
</tr>
<tr>
<td>Uranium</td>
<td>92</td>
<td>143</td>
<td>235</td>
<td>^235U</td>
<td>U-235 (bad stuff)</td>
</tr>
</tbody>
</table>

- All summarized in the "Periodic Table"

URL: [http://www.visualentities.com/applets/periodictable.htm](http://www.visualentities.com/applets/periodictable.htm)
Outside the nucleus

• **Ion:** Each atom can have a different number of electrons.
  - In a *neutral ion*, number of electrons = number of protons. (On the earth, almost all atoms are neutral)
  - In a hot gas (a "plasma"), electrons can be ripped off; this is *ionization*. eg: twice ionized oxygen = O^{++} has 8-2=6 electrons.
  - Most of the visible matter in the universe consists of plasmas.

• **Molecules:** The atoms can get together (H_{2}O).
  - Outermost electrons form cloud surrounding all atoms.

Explaining Spectral Lines

Spectral lines exist because light and atoms interact on an extremely tiny scale, where nature does not obey common sense laws ("classical Physics"). Explaining it required invention of:

• **Quantum Mechanics.** On a very tiny scale, things don't behave continuously, but in very small jumps in energy ("quanta").

• Emission and absorption of light involves exchanging these energy packages between light and atoms
1) **Light**: energy-wise, it behaves not as a wave, but as a particle, a "**photon**". A photon associated with a particular wavelength carries a specific amount of energy "E".

\[ E(\text{photon}) = h \times \text{frequency} = h \times \frac{c}{\text{wavelength}} \]

"h" is a very tiny constant called "Planck's Constant"

- So here is the electromagnetic spectrum again:

<table>
<thead>
<tr>
<th>Gamma-ray</th>
<th>X-Ray</th>
<th>Ultraviolet</th>
<th>Blue</th>
<th>Yellow</th>
<th>Red</th>
<th>Infrared</th>
<th>Microwave</th>
<th>Radio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>Frequency</td>
<td>Photon energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Spectral Fingerprints**

- H
- He
- N
- O
- Ne
- S
- Fe
- Hg
Atomic Structure

Figure 3.7, p105, Arny