Chapter 6: Electronic Structure of Atoms

Tonight’s Goals
- Catching Waves: Frequency/Amplitude/Velocity
- Electromagnetic radiation: The seen and unseen
- Electrons and energy: Quantization
- Line spectra: Over the Rainbow
- Identity crisis: Matter vs. Energy
- Not too sure about that: The Uncertainty Principle

Light Waves

- Understanding the electronic structure of the atom began with a study of light
- Light is a form of energy
  - No mass/speedy/travels in waves
- Characteristics of light waves

Wavelength: \( \lambda, \text{lambda} \)
Amplitude: height from midline
Frequency: \( \nu, \text{nu} \) waves/sec
Speed: \( c, 3.00 \times 10^8 \text{ m/sec} \)
Electromagnetic Radiation

- Radiation: radiant energy of any wavelength
- Our eyes can see only ~1.5% of the EM spectrum
- Our skin can sense infra-red radiation and be damaged by UV and X-rays

Color, Wavelength and Energy

- Shorter $\lambda$, higher $\nu$, higher $E$
- Longer $\lambda$, lower $\nu$, lower $E$

The visible wavelength range: 400 nm - 700 nm.
The energy of visible photons is 3.1 eV - 1.8 eV
Frequency range ($\nu$) is between 750 THz and 428 THz.
Maximum sensitivity of our eyes is usually 500 and 550 nm.
• All EMR travels at the speed of light (in a vacuum)
• Wavelength ($\lambda$) times the frequency ($\nu$) = speed of light ($c$)
• Different forms of EMR have different properties due to their wavelengths (huge differences in $\lambda$s from $\gamma$ to radio waves)

Black Body Radiation:
- Why do hot objects glow?
- Wavelength depends on temp

Photoelectric effect:
- How can light cause electrons to escape the surface of a metal?

Emission spectra
- Why are only certain colors of light seen when a given element is heated or electricity is run through it?
Quantization of Energy

Max Planck (1858–1947)

- Working with electric companies on a practical problem: How to get more light out of a light bulb
- He was trying to resolve conflicts in 2 approaches to describing emitted energy. Reluctantly proposed that energy can be only released or absorbed in discrete “packets” or quanta.
- His proposal: Matter is only allowed to emit energy in whole number multiples of $\hbar$:
  \[ E = \hbar \nu \]
  $E$ equals the energy of just one quantum (or one step).
  $\hbar =$Planck’s constant = $6.26 \times 10^{-34}$J-s

When a photon strikes the clean surface of a metal, electrons are emitted if the frequency of the photon is above a minimum threshold for the metal and it has enough energy. If the photon has more than the minimum energy, the excess goes into the kinetic energy of the emitted electron.

Einstein: Light energy striking the metal behaves like a particle
- The energy of a photon is also equal to $E = \hbar \nu$.
- The smallest value for $\hbar \nu$ is the energy of one photon
RAINBOWS vs LINES

White light can be split into a continuous spectrum of colors

Why?

If we seal an element in gas form in a tube and apply a high voltage across the tube, light will be emitted, but not a continuous spectrum.

Instead we get emission at specific wavelengths for each element.

Why?

LINE SPECTRA

- Line spectra for different elements were observed and formulas for calculating the $\lambda$s were found long before we figured out why line spectra occurred.
- The Rydberg equation allows calculation of $\lambda$ for all the spectral lines of hydrogen:

$$\frac{1}{\lambda} = R_{\infty} \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

Where $\lambda$ is the wavelength of electromagnetic radiation emitted in vacuum, $R_{\infty}$ (or $R_H$) is the Rydberg constant ($1.096776 \times 10^7$ m$^{-1}$); $n_1$ and $n_2$ are positive integers with $n_2 > n_1$.
- Still didn’t know why it worked......
**BOHR TO THE RESCUE**

Throw out the old assumptions, try something new:

- Electrons in orbit around the nucleus but can only exist in orbits of certain radii which correspond to certain energies.
- These orbits represent ‘allowed’ energy states. Electrons in these orbits won’t spiral into the nucleus.
- Energy is emitted or absorbed *only as electron changes from one allowed state to another*. Energy is emitted as a photon (E=\(h\nu\)) of a specific energy equal to the difference in allowed energy states: \(\Delta E = E_{\text{final}} - E_{\text{initial}} = E_{\text{photon}} = h\nu = hc/\lambda\). (Remember \(\lambda \nu = c\), so \(\nu = c/\lambda\)).

**ENERGY STATES OF HYDROGEN ATOM**

- \(n\)= principal quantum number and corresponds to the energy level of the orbits. \(n=1\): smallest and lowest energy orbit.
- Bohr calculated the energies of the hydrogen atom orbits using:
  \[ E = (hcR_H)(1/n^2) = -2.18 \times 10^{-18} \text{ J} / n^2 \]
  where \(h\)= Planck’s constant, \(c\)=speed of light and \(R_H\)= Rydberg’s constant.
- The difference in energies of the orbits, \(\Delta E\), equals the energy of the photon emitted:
  \[ h\nu = |\Delta E| = -2.18 \times 10^{-18} \text{ J} (1/n_f^2 - 1/n_i^2) \]
- Note the sign is negative (energy is emitted).

*Alas, this only works for H, He\(^+\) and Li\(^{2+}\). Bigger atoms are too complicated and require quantum mechanics to describe.*
THE FINE LINE BETWEEN ENERGY AND MATTER

Light is energy, has no mass, takes up no space and travels in waves, yet can behave as a particle.

Electrons are matter, have mass, take up space, yet show wave behavior and are very hard to locate.

Louis De Broglie steps into the debate, “If those e’s don’t want to behave like proper matter, we’ll just assign them a wave function and see how they like it.”

Turns out, the e’s were happy with their new dual identity. Not just the e’s got a wavelength, but so did all matter with De Broglie’s new equation:

\[ \lambda = \frac{h}{mv} \]

where \( h \) is Plank’s constant and \( mv = \text{mass} \times \text{velocity or momentum} \)

The catch is that \( \lambda \) is incredibly tiny for anything we can see!

THE OBSERVER EFFECT: TROUBLE TRACKING e’s

• Dual nature of matter → limitation on how precisely we can know both location and momentum of any subatomic object

\[ (\Delta x)(\Delta mv) \geq \frac{h}{4\pi} \]

Where: \( \Delta x \) is uncertainty of the position \n\( \Delta mv \) is uncertainty in momentum

• For an electron with a mass of \( 9.11 \times 10^{-31} \) kg and a speed of \( 5 \times 10^6 \) m/s (1%), the uncertainty in the location of the electron is 10-fold greater than the size of a hydrogen atom (\( 10^{-9} \) m vs \( 10^{-10} \) m)

The guy in the hat? Werner Heisenberg, but I’m not certain.
UNCERTAINTY IN MEASUREMENT

• Photo 1: Can determine speed & direction, but not exact position
• Photo 2: Can determine position, but not speed or direction

How radar works

Use reflected signal to detect location of moving object

ODDS AND ENDS

• Pick up copy of new lab schedule – slight adjustment due to Memorial Day holiday affecting Monday labs
• Mastering Chemistry:
  – Chapter 5
  – Calorimetry

  05/20/10 06:00 pm
  05/22/10 11:00 pm
• Thursday:
  – Heats of Reaction Lab due
  – Prelab for Green Crystals due
  – Chapter 4 - 5 Lecture Exam