Midterm: March 17

No homework next week.

Midterm Tuesday, March 17.

Review Sheet Tuesday.
Spectrum of Hydrogen

Observations of Hydrogen in a lab show it gives off light of specific wavelengths, given by the empirical formula:

\[
\frac{1}{\lambda} = R_H \left( \frac{1}{m^2} - \frac{1}{n^2} \right),
\]

...where n & m are integers & \( R_H = 1.1 \times 10^7 \text{ m}^{-1} \)
Electron ‘orbits’ nucleus under the electrical force, \( F \), & potential energy, \( U \)

\[
F = \frac{1}{4\pi \varepsilon_0} \frac{q_1 q_2}{r^2} \hat{r},
\]

Assuming uniform circular motion:

\[
a_c = \frac{v^2}{r}.
\]

Newton’s 2nd Law, \( (F = m \ a) \), gives an expression for kinetic energy of the electron.
Classical Physics Fail!

This picture failed to explain emission lines of Hydrogen.

Worse, classical physics (specifically via the Larmor Formula) predicted that such atoms would radiate.....BUT that this radiation would cause the electron to spiral in to the nucleus.

Every atoms should collapse on itself .... in 16 femtoseconds!!!

Since atoms can survive for more than a nanosecond, classical physics must be wrong!
Bohr’s “Semi-Classical” Atom

By assuming quantized angular momentum:

\[ L = \mu vr = n\hbar, \]

Bohr showed that electrons orbit at specific distances:

\[ r_n = \frac{4\pi \varepsilon_0 \hbar^2}{\mu e^2} n^2 = a_0 n^2, \]

...and have specific (quantized) energies:

\[ E_n = -\frac{\mu e^4}{32\pi^2 \varepsilon_0^2 \hbar^2} \frac{1}{n^2} = -13.6 \text{ eV} \frac{1}{n^2}. \]
Transitions

Emission & Absorption of light can now be explained by assuming that electrons transition from one “energy state” to another.

The energy lost in going down (eg. n=3 -> n=2) goes into a photon of light:

\[ E_{\text{photon}} = h\nu = \frac{hc}{\lambda} = \Delta E = E_1 - E_2 \]
Bohr Atom

Solving for $1/\lambda$ gives the Rydberg Formula, but with the constant now defined!

$$\frac{1}{\lambda} = \frac{\mu e^4}{64\pi^3\epsilon_0^2 \hbar^3 c} \left( \frac{1}{n_{\text{low}}^2} - \frac{1}{n_{\text{high}}^2} \right).$$

$$\frac{1}{\lambda} = R_H \left( \frac{1}{m^2} - \frac{1}{n^2} \right),$$

$R_H = 1.1 \times 10^7 \text{ m}^{-1}$

So assuming quantized energy states gives us the observed wavelengths. Woo hoo!
But....WHY are an atom’s energy states quantized?

Recall: light is quantized into photons with Energy & Momentum:

\[ E = h \nu = \frac{hc}{\lambda} \quad \text{and} \quad p = \frac{h}{\lambda} \quad (E = pc) \]

In 1923, a grad. student, **Louis de Broglie**, suggested that if light waves can be particles (photons) then particles could be waves! He simply solved for their wavelength, assuming they were waves:

\[ \lambda = \frac{h}{p} \]
If matter is wave-like, it should have the properties of a wave. Eg. Water waves *interfere* (either constructively or destructively).

In 1800, Thomas Young showed that *light* waves also interfere, producing bright and dark *fringes*.
Shine it through two slits.

Start w/ coherent light (use a single slit or a laser)

The pattern you see is this. Light and dark “fringes”
Interference produces fringes ... proof of the wave nature of light!
Is an electron a particle, or a wave?

Particles fired at a double slit will produce two stripes.

But Waves fired at a double slit produce an interference pattern.
If particles are really waves they should exhibit wave-like behavior such as interference.

Photons or particles

Fire electrons at a double slit and you will get...?
The wave nature of matter has been **confirmed** for: electrons, atoms, and even large molecules such as C-60 (Buckyball)!

Fringes produced by electrons passing through a double slit.

Clearly electrons can interfere with each other.
But wait, try this... fire the electrons at the double slit *one at a time*. The electron has to go through one slit or the other...right? It has no other electron to interfere with...right?

So, when we fire them one at a time we won’t get an interference pattern...will we?
We do!

So even a single electron is a wave that “interferes with itself”!

Wait a minute!! The electron has to go through one slit or the other!

What if we insist on knowing \textit{which} slit the electron went through. (eg. using a detector)....

Then the interference pattern disappears!!
Conclusion:

Electrons are waves or particles depending on how we observe them.
The observer is a crucial part of the experiment

#1 Most Beautiful Physics Experiment:
Electron Double Slit

Go here to try for yourself:
http://www.upscale.utoronto.ca/PVB/Harrison/DoubleSlit/Flash/Histogram.html

Explanation:
http://www.upscale.utoronto.ca/PVB/Harrison/DoubleSlit/DoubleSlit.html
Stable Orbitals

So, if an electron in an atom is a wave, then it must be a standing wave to remain stable.

Not all radii meet this criterion. So the electron’s orbital radius and its energy are quantized.

That’s why.