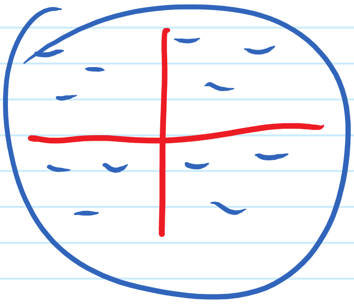
Ch. 11 Bohr Model

Evidence of the elementary particles exists---and the organizational scheme for atoms has been spelled out (periodic table). The big remaining questions are---can we understand how Atoms (and molecules) are constructed?

The most precisely tested system in the universe seems to be the Hydrogen atom--to this day.

Some of the earliest models for Atoms held that (Thomson) the atom was a large blog of POSITIVE Charge, with lumps of negative spread throughout.



Such a model leads to small electric fields throughout the system. Which means if I shoot charges through this---then not a whole lot will happen --not much big scattering.

Upon performing experiments scattering ALPHA particles off of atoms (Hydrogen atoms), Rutherford found some were scattered at very large angles.

Alpha particles ---are a helium atom nucleus (2 protons, 2 neutrons---electrons ripped off).

There can only be large scattering angles if Hydrogen has a lump of positive charge ---all lumped together in one location.

Rutherford Scattering showed that the POSITIVE CHARGE IS GATHERED IN NUCLEUS ~10^{-14}m.

The negative charges surround the nucleus at distances on the order of 10^{-9}m

Rutherford---Density of nucleus ~10^{15} times the density of normal matter.

Atoms have a mass density---and they have a charge density---do the track together?

11.2 Hydrogen Spectra----be the light

Classically --charges emit radiation when they accelerate (they must accelerate--why). If this took place in say ---hydrogen--- then we would expect the electron to spiral into the nucleus and the emission would be over in about 10^{-8} s or so---The emission would be continuous--until---I'm not sure how that would end.

What is observed is:

we will basically measure this in adv lab.

Observed $\nu = 3.29 \times 10^{15}\,\text{Hz}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

n_f & n_i are integers

$n_i > n_f$

We know now that the initial and final n refer to Electron Energy levels. WHAT DOES THAT MEAN?

1885 Balmer observed spectral lines terminating on $n_f = 2$ — Visible

Can put in terms of λ

$$\frac{1}{\lambda} = 1.097 \times 10^7\,\text{m}^{-1}\left|\frac{1}{n_f^2} - \frac{1}{n_i^2}\right|$$

Lyman series → $n_f = 1$

$n_f = 3$ → Paschen series

$n_f = 4$ Brackett

H_{α}, 1 H_{β} 2 H_{γ} 3 H_{δ} 4

Higher energy means shorter wavelength transitions.

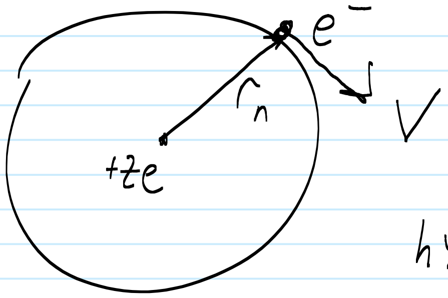
The spectra can be observed in either
ABSORPTION
OR
EMISSION

11.3 The Bohr model

Quantization has been around for a while now---Bohr knows about it with respect to both blackbody radiation and also photoelectric effect.

The world has noted that atoms radiate--but they do not spiral into oblivion---poof--there is no classical model.

Bohr will impose a quantization condition upon a hypothetical stationary state for the system. The hypothetical stationary state (constant energy) is a circular orbit of the electron around the nucleus (a Proton) for hydrogen. The force causing the circular motion is the COULOMB force. The nucleus will---for now---be presumed massive enough that it does not move (so effectively a much bigger mass than the electron). Does the moon tug the Earth around a bit?



$$\frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r^2} = m\frac{V^2}{r}$$

hydrogen $Z=1$

Bohr postulate 1) Some states are stationary and don't spiral in

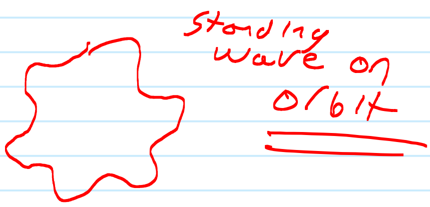
Stationary states are those such that
$2\pi *$ Ang mom $= n\,h$ (equiv to whole # of deBroglie wavelength fitting in orbit)

$$(mvr) * 2\pi = n\,h$$

or

$$mvr = n\,h/2\pi$$
$$= n\hbar$$

$$V = \frac{nh}{2\pi m r}$$



The Bohr statement about angular momentum is equivalent to saying that there are whole number of deBroglie waves along the orbit.

$$\frac{\lambda}{r} = \frac{h}{pr}$$

deBroglie

$$= \frac{h}{(L)} \rightarrow \frac{\lambda}{2\pi r} = \frac{h}{(mvr)(2\pi)}$$
$$= \frac{h}{n\,h}$$

$$n\lambda = 2\pi r$$

OK--so we have a quantization condition (hypothetical) to apply to hydrogen, and we have F=ma at the top of this page (ok to use if the motions are slow compared to speed of light) ---

Goal--remember, we can see the spectra for hydrogen. Our goal is to predict that--so we will be taking a path to Energies permitted by the quantization condition.

$$F = ma$$

$$\frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r^2} = m\frac{v^2}{r}$$

$$= m\left(\frac{nh}{2\pi mr}\right)^2\frac{1}{r}$$

$$= \frac{n^2h^2}{4\pi m r^3}$$

$$r_n = \frac{n^2}{Z}(52.9 \text{ pm})$$

0.0529 nm

We have the radius of electron orbits for HYDROGEN LIKE ATOMS---what is "Hydrogen like"??????? (it will be important to know what "HYDROGEN LIKE" means ----one electron around nucleus).

r_n has different values for different n's and of course z's

We also have v now

$$v_1 = \frac{h}{2\pi m r_1} \approx \frac{c}{137}$$

The ~1/137 is also called the fine structure constant, and as you can see brings in relations among very fundamental parameters in physics. h, c, m, r----and it is seen as one of the mysterious quantities---why this specific value?

Now that we have the orbital radii (potential energy) and the speeds (kinetic energy) we are ready to talk about Energy. Also remember that our speed is kinda slow---so we don't need to be relativistic (at this time)

$$E = KE + PE$$

$$= \frac{1}{2}mv^2 + \left(-\frac{(ze)(e)}{4\pi\epsilon_0 r}\right)$$

(PE = qV)

& recall

$$\frac{m_e v^2}{r} = \frac{z e^2}{4\pi r^2 \epsilon_0}$$

see the mv^2

Plug in the mv^2 and gather terms that look very similar now to get E, then we just need to plug in our result for r_n

$$E = -\frac{z e^2}{8\pi\epsilon_0 r}$$

and

$$r_n = \frac{n^2}{z}\left(\frac{\epsilon_0 h^2}{m\pi e^2}\right)$$

(52.9 pm)

$$E_n = -\frac{z^2 m e^4}{n^2 8\epsilon_0^2 h^2}$$

(13.61)

$$= -\frac{z^2}{n^2}(13.6\ eV)$$

of course for Hydrogen z = 1

n = Principal Quantum #

These results give energy transitions that match observed spectra really well. That 13.6 eV needs some touch ups right away. 1) we assumed that the proton had effectively infinite mass and did not wiggle around (this is the infinite mass result).

2) we did not take special relativity (or general) into account---the electron moves fast. With bigger z it moves faster.
3) In fact if we make z> 137 then, v (without fixups) becomes the speed of light. Unfortunately there is no element with Z=137

So--at Z=137 the non-existent element does have a name: Feynmanium (after Richard Feynman).
----let's call Tony (https://www.youtube.com/watch?v=y0brSA1cyzw back in hardware mode). ---I believe Vibranium is well below Feynmanium.

- It takes 13.6 eV to Ionize hydrogen E_1=-13.6eV
- E_2=-3.40 eV ……so it takes a photon with 10.2eV to bring electron from the lowest (ground, n=1) energy level to the next.
- The spectra is well predicted
- The angular momenta of states are NOT CORRECT
    - Bohr has the right idea that Angular Momentum is quantized, but there are zero angular momentum states---you can't get that with circular orbits.
    - The ground state should have zero angular momentum.

The accurate prediction of this---well--one of the foundational successes in physics, even if not perfected.

https://www.nobelprize.org/prizes/physics/1922/summary/#:~:text=The%20Nobel%20Prize%20in%20Physics%201922%20was%20awarded%20to%20Niels,the%20radiation%20emanating%20from%20them.%22

Because we don't yet understand gravity---we can't really claim to have a full working model of Hydrogen today.

In Bohr model--what is the acceleration of the electron in the circular orbit of the ground state? Do you think there should be some general relativity stuff going on there-why, why not?