The Bohr Theory of the Hydrogen Atom

Prior to the work of **Niels Bohr**, the stability of the atom could not be explained using the then-current theories.

In 1913, using the work of Einstein and Planck, he applied a new theory to the simplest atom, hydrogen. Before looking at Bohr's theory, we must first examine the "line spectra" of atoms.

Atomic Line Spectra

– When a heated metal filament emits light, we can use a prism to spread out the light to give a **continuous spectrum**-that is, ***a spectrum containing light of all wavelengths.***

– The light emitted by a heated gas, such as hydrogen, results in a **line spectrum-*a spectrum showing only specific wavelengths of light.***

– In 1885, J. J. Balmer showed that the wavelengths, λ, in the visible spectrum of hydrogen could be reproduced by a simple formula.

$$\frac{1}{\lambda} = 1.097 \times 10^{7}\, m^{-1}\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

– The known wavelengths of the four visible lines for hydrogen correspond to values of n = 3, n = 4, n = 5, and n = 6.

Bohr's Postulates

– Bohr set down postulates to account for (1) the stability of the hydrogen atom and (2) the line spectrum of the atom.

1. Energy level postulate An electron can have only specific energy levels in an atom.

2. **Transitions between energy levels** An electron in an atom can change energy levels by undergoing a "transition" from one energy level to another.

- **Bohr's Postulates**

– Bohr derived the following formula for the energy levels of the electron in the hydrogen atom.

$E= -R_h/n^2$ n= 1,2,3………∞ (for H atom)

– R_h is a constant (expressed in energy units) with a value of 2.18×10^{-18} J.

Bohr's Postulates

– When an electron undergoes a transition from a higher energy level to a lower one, the energy is emitted as a photon.

Energy of emitted photon $h_v = E_i - E_f$

From postulate 1.

$Ei = -R_h/n_i^2$ $Ef = -R_h/n_f^2$

– If we make a substitution into the previous equation that states the energy of the emitted photon, hv, equals Ei- Ef,

$$hv = E_f - E_i = \left(\frac{-R_h}{{n_f}^2}\right) - \left(\frac{-R_h}{{n_i}^2}\right)$$

$$\mathrm{Re}\,arranging, we...obtain$$

$$hv = -R_h\left(\frac{1}{{n_f}^2}\right) - \left(\frac{1}{{n_i}^2}\right)$$

Bohr's theory explains not only the emission of light, but also the absorption of light.

– When an electron falls from n = 3 to n = 2 energy level, a photon of red light (wavelength, 685 nm) is emitted.

– When red light of this same wavelength shines on a hydrogen atom in the n = 2 level, the energy is gained by the electron that undergoes a transition to n = 3.

Calculate the energy of a photon of light emitted from a hydrogen atom when an electron falls from level n = 3 to level n = 1.

$$E = hv = -R_h(1/n_f^2 - 1/n_i^2)$$

$$E = -(2.18*10^{-18} J)\ (1/1^2 - 1/3^2)$$

$$E = -1.94*10^{-18}\ J$$

The sign of energy is negative because is emitted when an electron falls from a higher to lower level.

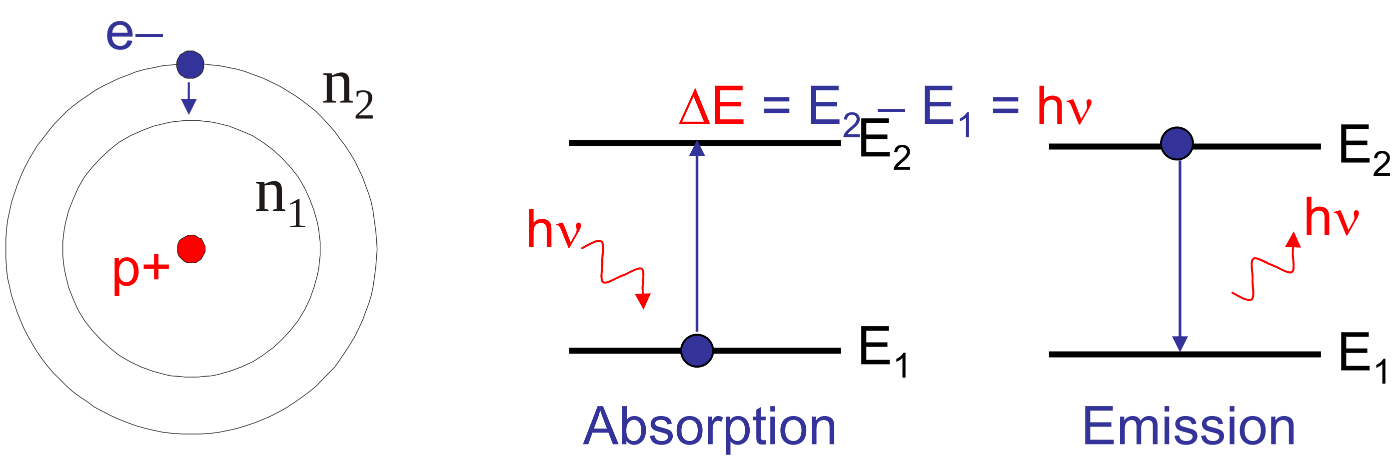
Bohr's theory established the concept of atomic energy levels but did not thoroughly explain the "wave-like" behavior of the electron.

– Current ideas about atomic structure depend on the principles of **quantum mechanics**, a theory that applies to subatomic particles such as electrons.

1.5 The Bohr Model of the Atom

The H-atom emission spectrum was rationalized by Bohr (1913):

- Energies of H atom are restricted to certain discrete values
  (i.e. electron is restricted to well-defined circular orbits, labelled by quantum number n).
- Energy (light) absorbed in discrete amounts (quanta = photons), corresponding to differences between these restricted values:

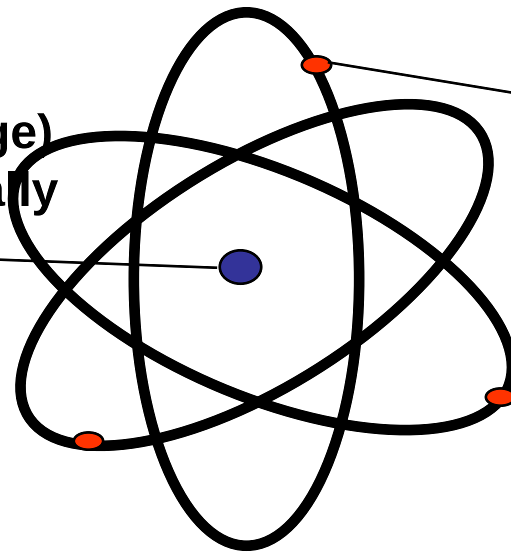


Conclusion: Spectroscopy provides direct evidence for quantization of energies (electronic, vibrational, rotational etc.) of atoms and molecules.

Bohr Model of the Atom

- Famous, but historically superseded by later and better models
- Still used today in the legal seal of the US Department of Energy and the Richardson, Texas public school system, etc. etc.

Nucleus consists of protons (positive charge) and neutrons (electrically neutral)



Point object electrons whirling around the nucleus in specific circular or elliptical orbits.

This frequently shown Picture (symbolic of Lithium) is known to be wrong in several ways.

Niels Bohr, Danish physicist, invented this theoretical model ca. 1913.

Known to be Wrong

Bohr got around some self-contradictory problems of “classical” (non-quantum) physics by assuming certain unexplainable and unexplained things:

- Why don’t whirling electrons radiate light energy continuously and thus fall into the nucleus?
- Why do atoms cling together to make molecules or solids (solids are giant molecules with billions of atoms or more)

Later theories (particularly Schrödinger’s wave theory*) give a better explanation. Erwin Schrödinger, Austrian physicist, invented wave (quantum) mechanics in 1926.

***also written Schroedinger**

Limitations of Bohr Model &

The model only works for hydrogen (and other one electron ions) – ignores e-e repulsion.

Does not explain fine structure of spectral lines.

Note: The Bohr model (assuming circular electron orbits) is fundamentally incorrect.