6.1: Older Models of the Hydrogen Atom

Two of the most important (historically) models of the hydrogen atom and it's energy levels/spectra were proved by Johannes Balmer, a high school teacher, and Niels Bohr, a Danish physicist. Balmer's model was a completely empirical fit to existing data for the emission spectrum of hydrogen, whereas Bohr provided an actual theoretical underpinning to the form of the model which Balmer derived. In this section, we will discuss the development and ramifications of these two models.

Balmer's Formula

Balmer (Balmer, 1885) was the first to provide an empirical formula that gave a very good fit to the data, but offered no theoretical reasoning as to why the formula had the simple form it did. Balmer felt, however, that despite the lack of a theoretical foundation, such a simple pattern could not be the result of an "accident".

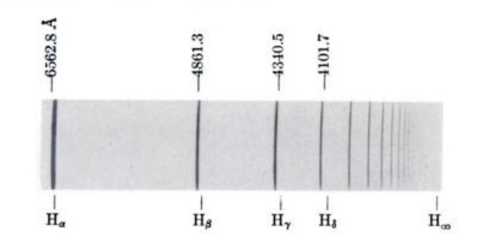

Figure 6.1.1

Balmer suggested the formula

$$\lambda = G\left(\frac{n^2}{n^2-4}\right)$$

to calculate the wavelengths (λ) of the lines in the visible emission spectrum of hydrogen. In this formula, $G = 3647.053$ Å, which is the series limit (depicted as H_∞ in the figure above.) Balmer considered this to be a "fundamental constant" for hydrogen and fully expected other elements to have similar fundamental constants.

In modern terms, Balmer's formula has been extended to describe all of the emission lines in the spectrum of atomic hydrogen.

$$\tilde{\nu} = R_H\left(\frac{1}{n_l^2} - \frac{1}{n_u^2}\right)$$

where n_l and n_u are integers with $n_l < n_u$. R_H is the Rydberg constant for hydrogen and has the value

$$R_H = 109677\ cm^{-1}$$

The job of subsequent investigators was to provide a theory that explained the form of the Rydberg Equation shown above and to correctly predict the value of the Rydberg Constant.

This model describes all known series of emission lines in the spectrum of atomic hydrogen. Each series is characterized by the lower state quantum number. The following table summarizes the names of these series.

n_l	Name	Region
1	Lyman	Vacuum Ultraviolet
2	Balmer	Visible/Ultraviolet
3	Paschen	Near Infrared
4	Brachen	Infrared
5	Pfund	Far Infrared

The Bohr Model

Niels Bohr (Bohr, 1913) was the first person to offer a successful quantum theory of the hydrogen atom in his 1913 paper. He was later awarded the Nobel Prize in Physics in 1922 for his contributions to the understanding of atomic structures (as well as many other significant contributions.) And while the Bohr model has significant shortcomings in terms of providing the best description of a hydrogen atom, it still provides the basis (a "solar system model") for how many people view atoms today.

Bohr's model was mostly an extension of the Rutherford model of an atom, in which electrons exist in a cloud surrounding a dense, positively charged nucleus. The Bohr model suggested a possible structure to this cloud in an attempt to give an explanation of the empirical formula presented by Balmer. The strength of the Bohr model is that it does provide an accurate prediction not only of the form of Balmer's formula, but also of the magnitude of the Rydberg constant that appears in the formula.

Bohr's approach was to balance the electrostatic attractive force between an electron and a positively charged nucleus, with the centrifugal force the electron feels as it orbits the nucleus in a circular orbit. He derived these orbits by making the assumption that the angular momentum of an orbiting electron is an integral multiple of $\hbar$.

While successful in predicting the form of the Rydberg Equation and the magnitude of R_H, the Bohr model presented some difficulty. First, it ignored the reality that a charged particle orbiting another (oppositely) charged nucleus would see its orbit decay over time, eventually colliding with the nucleus. This clearly does not happen with hydrogen! Also, the Bohr model was not extendable to larger atoms. Quantum mechanics would have to address these problems, while also providing the kind of explanations for the Rydberg Equation provided by Bohr.
