CHAPTER 2

BOHR ATOMIC MODEL

A. Introduction

Several concepts as foundation of the Bohr atomic model are:

1. Photon concept which describe the electromagnetic wave as quanta energy that behave as particle give a new paradigm in the study of atomic structure.
2. The experiment result about the hydrogen atomic structure could not be explained theoretically until 1913. The devices to measure the light spectrum developed in the last of nine teen century. The observation about the spectrum which emitted by atomic gas is a line spectrum.

In 1885, JJ Balmer has found a simple empirical formula related with the frequency of hydrogen spectrum in visible area:

Table 2.1. Spectrum of Balmer Series

Hydrogen Line Spectrum	Wave Length (Angstrom)	Frequency (10^{14} Hz)
H_α	6562,8	4,569
H_β	4861,3	6,168
H_γ	4340,5	6,908
H_δ	4101,7	7,310
H_∞	3645,6	8,224

The Balmer formula for the wave length is:

$$\lambda(Angstrom) = \frac{3645{,}6n^2}{n^2 - 4} \quad \text{.......} \quad (2.1)$$

Each wave length can be determined by substitute integer number n>2, as n=3, 4, 5, ...

In the frequency the formula can be written:

$$\upsilon = \frac{c}{\lambda} = c\left[\frac{n^2-4}{n^2}\right]\left[\frac{1}{3645{,}6}\right] = \frac{4c}{3645{,}6}\left[\frac{1}{4} - \frac{1}{n^2}\right] \quad \text{.......} \quad (2.2)$$

In equation (2.2) wave length is stated in angstrom, the speed of light c also must be stated in angstrom/sekon, it obtained:

$$\upsilon_n = 3{,}289.10^{15}\left(\frac{1}{4} - \frac{1}{n^2}\right) \quad \text{.......} \quad (2.3)$$

Where n integer number that bigger than 2.

3. In 1908 Paschen found another spectrum of hydrogen atom in infra red area. The series is according the formula:

$$\upsilon_n = 3{,}289.10^{15}\left(\frac{1}{9}-\frac{1}{n^2}\right) \quad \text{.......} \quad (2.4)$$

Where n must be bigger than 3.

Balmer and Paschen series can be written in:

$$\upsilon_{n.m} = 3{,}289.10^{15}\left(\frac{1}{m^2}-\frac{1}{n^2}\right) \quad \text{.......} \quad (2.5)$$

In Balmer series, m = 2 and n >2; in Paschen series, m=3 and n>3.

4. Rydberg in 1890 found another way which easier to explain wave length equation OF Balmer series by defining the wave length reciprox:

$$\kappa \equiv \frac{1}{\lambda}$$

Using this definition, it is obtainen:

$$\kappa_{n.m} = 1{,}097.10^{7}\left(\frac{1}{m^2}-\frac{1}{n^2}\right) \quad \text{.......} \quad (2.6)$$

Where Rydberg constan $R_H = 1{,}097.10^7\ m^{-1}$.

$$\kappa_{n.m} = R_H\left(\frac{1}{m^2}-\frac{1}{n^2}\right) \quad \text{.......} \quad (2.7)$$

In atomic physics, Bohr atomic model stated that atom consist of nucleus which is rotated by electrons in certain orbits. The experiment result show that the hydrogen spectrum is line spectrum that called Balmer series.

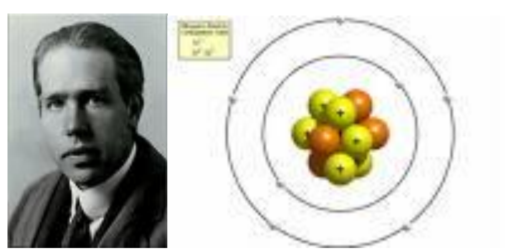

Figure 2.1. Niels Bohr and his Nitrogen Atomic Model

These are several Bohr idea that is used as a foundation of Bohr model:

1. Electron orbits have a discret energy which is quantified.
2. Classical mechanic laws can not be applied when electron jump from permitted orbit to another orbit.
3. When electron jump from certain orbit to another orbit, the difference energy between the two orbits was carried or supplied by photon.

4. Electron’s orbits which permitted depend on the quantification of the orbital angular momentum:

$$L = n\hbar = n\frac{h}{2\pi}.$$

Bohr atomic model some time known as a semiclassic model, because it combines classical and quantum physics.

B. Bohr Postulates

Postulate 1

Hydrogen atom consist of one electron which moves in a circular orbit rotates the nucleus, the electron motion is effected by Coulomb attractive force according the classical mechanics. Postulate 1 give the arrangement of hydrogen atom and force which exert between nucleus and electron.

Postulate 2

The stable orbits of electron is belong to electron which has an angular momentum equal to $L = n\hbar = n\frac{h}{2\pi}$. Postulate 2 give quantification of angular momentum anda quantification of electron orbit.

Postulate 3

In a stable orbit the electron which rotates the nucleus does not emit lectromagnetic energy. It means, the total energy of atom does not change. Postulate 3 states that electron in stationer orbit does not emit electromagnetic energy.

Postulat 4

Electromagnetic energy is emitted by atomic system if electron jumps from certain orbit to another orbit is occurred. The frequency of electromagnetic wave which emitted by atom is: $\upsilon = \frac{E_i - E_f}{h}$. Postulate 4 states that in the electron transition from a certain stable otbit to another stable orbit emits photon which its energy equal to the difference of the two orbits.

C. Quantification of Angular Momentum L

A certain circular orbit has angular momentum equal to integer number times de-Broglie wave length.

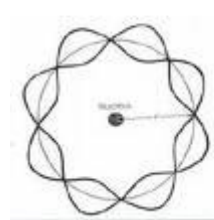

Figure 2.2. de-Broglie and de-Broglie Wave Length of Elektron

$n\lambda = 2\pi r_n$ where n = pricipal quantum number = 1, 2, 3, ... (2.8)

$$\Leftrightarrow n\frac{h}{mv} = 2\pi r_n$$

$$\Leftrightarrow mvr_n = n\frac{h}{2\pi} \qquad \text{..........} \qquad (2.9)$$

$$\Leftrightarrow L = mvr_n = n\hbar$$

Where m = electron mass = 9.1 x 10^{-31} kg
v = orbital speed of electron
r_n = orbit radius of elektron
h = $6{,}625.10^{-34}$ Js
$\hbar = \frac{h}{2\pi}$

In a certain orbit, electron move in circular motion without loosing energy. This orbit is known stationer orbit:

D. Wave length of orbital electron:

$$\lambda = \frac{h}{mv}$$

$$\lambda = \frac{h}{m\left(\frac{e}{\sqrt{4\pi\varepsilon_o mr}}\right)}$$

$$\lambda = \frac{h}{me}\sqrt{4\pi\varepsilon_o mr}$$

$$\Leftrightarrow \lambda = \frac{h}{e}\sqrt{\frac{4\pi\varepsilon_o r}{m}} \qquad \text{..........} \qquad (2.10)$$

E. Requirement of stable orbit of electron:

Electron orbit will bw stable if the orbit circumference of electron equal to integer number times de-Broglie wave length of the electron.

$n\lambda = 2\pi r_n$ where n = 1, 2, 3, …

Substitute $\Leftrightarrow \lambda = \frac{h}{e}\sqrt{\frac{4\pi\varepsilon_o r}{m}}$ in equation (2.8) it obtained:

$$n\frac{h}{e}\sqrt{\frac{4\pi\varepsilon_o r_n}{m}} = 2\pi r_n$$

$$\Leftrightarrow \sqrt{r_n} = \frac{1}{2\pi}\frac{nh}{e}\sqrt{\frac{4\pi\varepsilon_o}{m}}$$

$$\Leftrightarrow r_n = \frac{1}{4\pi^2}\frac{n^2h^2}{e^2}\frac{4\pi\varepsilon_o}{m}$$

$$\Leftrightarrow r_n = \frac{n^2h^2\varepsilon_o}{\pi m e^2}$$ orbit radius in Bohr atom ……….......................……(2.11)

For first orbit n = 1 it is obtained the first orbit radius $r_1 = a_o = 5{,}292.10^{-11}m$ Which is known as *Bohr radius*. Equation (2.11) can be written in equation (2.12):

$$r_n = n^2 a_o$$ …………………………………………..…..................….. (2.12)

Based on equation (2.12) it can be described electron only move in certain orbit with certain radius without emit electromagnetic energy.

Each electron orbit have each energy state. If electron jump from energy state E_i to the lowe energy state E_f, it will be emitted photon energy hυ.

$$\Delta E = E_i - E_f = h\upsilon$$ .... (2.13)

where υ frequency photon emitted.

On the other hand if electron jump from lower energy state to the higher energy state, so energy is absorbed by atom. It means that electron does not emit energy continously. Energy states for hydrogen atom in n orbit:

$$E_n = -\frac{e^2}{8\pi\varepsilon_o r_n}$$ ……………………………………………………………….. (2.14)

Substitute $\Leftrightarrow r_n = \frac{n^2h^2\varepsilon_o}{\pi m e^2}$ in equation (2.14) it obtained:

$$E_n = -\frac{me^4}{8\varepsilon_o^2 h^2}\left(\frac{1}{n^2}\right)$$

$$E_n = \frac{E_1}{n^2}, n = 1,2,3,...$$ ……………………………………….................. (2.15)

In Figure 2.3, it is shown energy states of hydrogen atom.

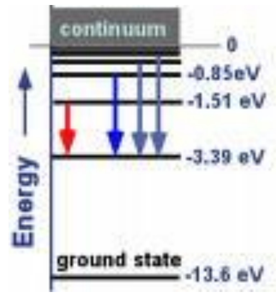

Figure 2.3 Hidrogen's energy states

All of energy states are negative, it means electrons do not have enough energy to leave nucleus. The lowest energy state E_1 is called *ground state*), and the higher energy stated E_2, E_3, E_4, ... is called *excited state*. For n=∞, E_∞=0, it means electron is not binded again by nucleus to form atom.

Energy required to release electron from its ground state is called ionization energy. Ionization energy of hydrogen atom:

$$E_{ionization} = -E_1$$
$$atom.H \Rightarrow E_{ionization} = 13{,}6 eV \qquad \text{...} \quad (2.16)$$

F. Spectral Series

If the initial quantum number n_i (higher energy) and the final quantum number n_f (lower energy), when exitation of electron is ocrred photon energy is emitted from atom.

$$E_{foton} = E_{awal} - E_{akhir}$$
$$h\nu = E_i - E_f$$

Frequence of photon which emitted:

$$\nu = \frac{1}{h}(E_i - E_f)$$
$$\nu = \frac{1}{h}\left(\frac{E_1}{n_i^2} - \frac{E_1}{n_f^2}\right)$$
$$\nu = \frac{-E_1}{h}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

Because of $c = \nu\lambda$ so the photon frequency:

$$\frac{c}{\lambda} = \frac{-E_1}{h}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$
$$\frac{1}{\lambda} = -\frac{E_1}{ch}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \qquad \text{hydrogen spectrum} \quad \text{..............................} \quad (2.17)$$

Table 2. 2. Spektral Series

Series	**n_f**	**Formulation**	**n**
Lyman	1	$\frac{1}{\lambda}=-\frac{E_1}{ch}\left(\frac{1}{1^2}-\frac{1}{n^2}\right)$	n = 2, 3, 4, …
Balmer	2	$\frac{1}{\lambda}=-\frac{E_1}{ch}\left(\frac{1}{2^2}-\frac{1}{n^2}\right)$	n = 3, 4, 5, …
Paschen	3	$\frac{1}{\lambda}=-\frac{E_1}{ch}\left(\frac{1}{3^2}-\frac{1}{n^2}\right)$	n = 4, 5, 6, …
Bracket	4	$\frac{1}{\lambda}=-\frac{E_1}{ch}\left(\frac{1}{4^2}-\frac{1}{n^2}\right)$	n = 5, 6, 7, …
Pfund	5	$\frac{1}{\lambda}=-\frac{E_1}{ch}\left(\frac{1}{5^2}-\frac{1}{n^2}\right)$	n = 6, 7, 8, …

Calculation of Ryberg constant (R):

$$R_H = -\frac{E_1}{ch} = --\frac{me^4}{8\varepsilon_o^2 h^2}\left(\frac{1}{ch}\right)$$

$$R_H = \frac{me^4}{8\varepsilon_o^2 ch^3}$$

$$R_H = \frac{(9{,}1.10^{-31}\,kg)(1{,}6.10^{-19}\,C)^4}{8(8{,}85.10^{-12}\,F/m)^2(3.10^8\,m/s)(6{,}625.10^{-34}\,Js)}$$

$$R_H = 1{,}097.10^7\,m^{-1}$$

Substitute Rydberg constan in equation (2.17) it obtained formulation of spectral series in hydrogen atom:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right) \quad \text{……………………………………………..................……(2.18)}$$

Transition of the state energi in atom produce spektral spectral series as shown in Figure 2.4 below.

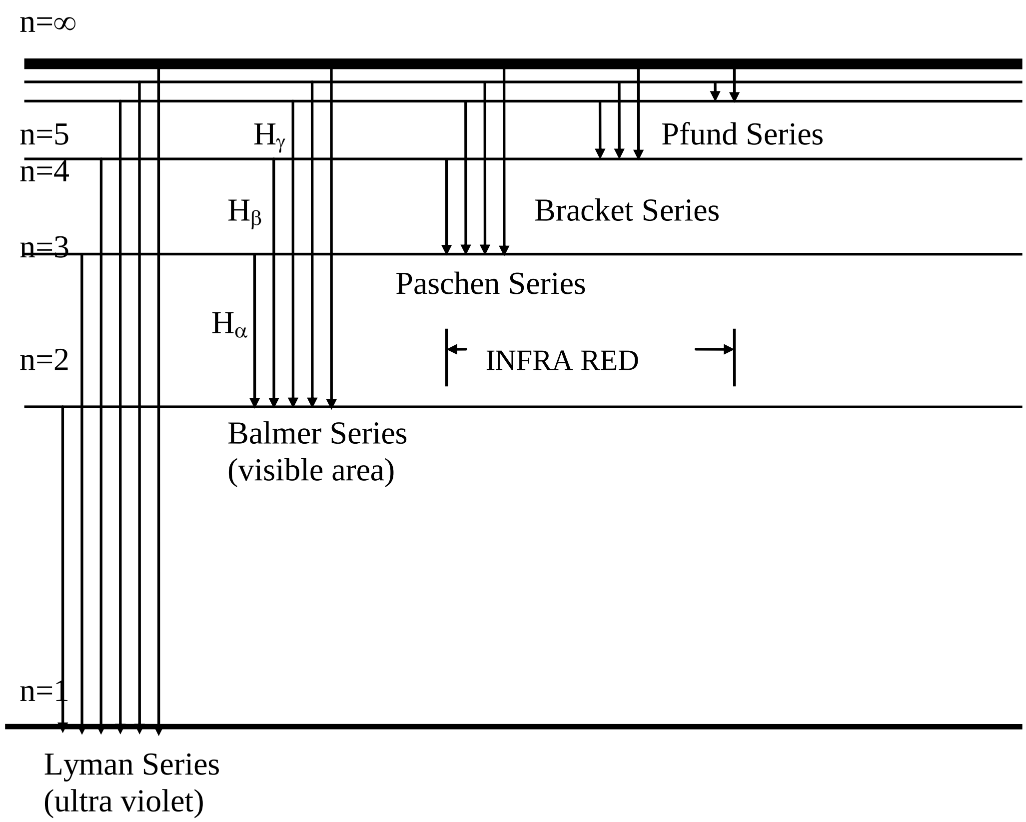

Figure 2.4 Spektral Series in Hydrogen Atom

In Figure 2.5 below, it shown Balmer series.

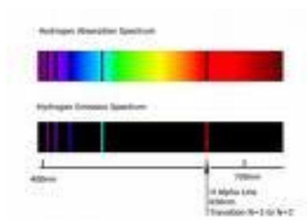

Figure 2.5 Spectrum of Balmer Series

G. Problems

1. Analize equation of hydrogen atom spectrum based on Bohr theory!
2. Determine 5 energy states of hydrogen atom based on the energy quantification principle!
3. Determine the minimum voltage must be used in order electron in hydrogen atom can be released from its ground state.
4. Electron in hydrogen atom has energy of -13,6 eV. Determine the photon energy which absorbed by electron in order jump to orbit with energy of -3,4 eV! Determine wave length and frequency of the photon!

H. Reference

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