

The Rutherford-Bohr Model of the Atom

Michael Brodskiy

Professor: Q. Yan

March 30, 2023

Contents

1	Basic Properties of Atoms	3
2	Scattering Experiments and Thomson Model	3
3	The Rutherford Nuclear Atom	3
4	Line Spectra	5
5	The Bohr Model	6

1 Basic Properties of Atoms

- Around 1900, knowledge about atoms was:
 - Size: Small, $1[\text{\AA}]/.1[\text{nm}]$
 - Stable: Forces balance
 - Atoms contain electrons (e^-) and maintain neutral charge
 - Atoms can emit and absorb electromagnetic radiation

2 Scattering Experiments and Thomson Model

- An early atom model: J.J. Thomson (1904):

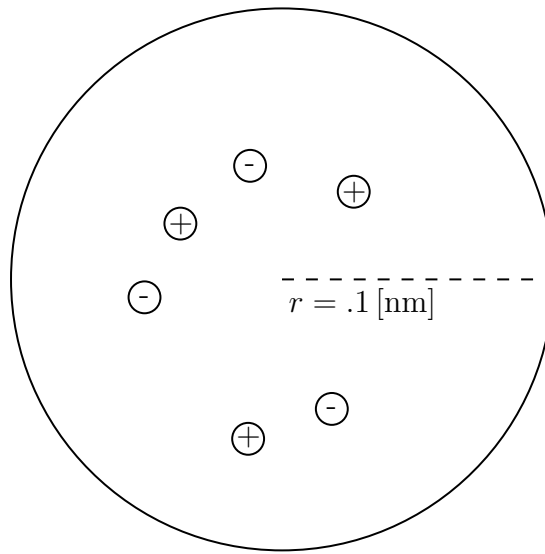


Figure 1: The Jelium Model (“Plum-pudding Model”)

3 The Rutherford Nuclear Atom

- Rutherford discovered two rays, α and β -rays, which he used to experiment with atoms
 - α rays are essentially He^{2+} atoms
 - * The positive charge would mean that the atoms should deflect α rays
- The Geiger-Marsden Observation

- Their observation found:

$$p(\text{backscattering}) \approx 10^{-4}$$

- This is much larger than expected
- Rutherford proposed that the charge and mass of atoms are concentrated in a region called the nucleus

- The Bohr Model

- Proposed by Niels Bohr (1913)
- Atoms resembled a miniature planetary system

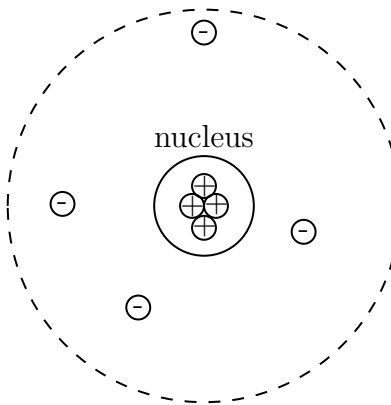


Figure 2: The Bohr Model

- From this, the Coulomb interaction (force) was determined:

$$F = \frac{1}{4\pi\epsilon_o} \frac{|q_1||q_2|}{r^2}$$

- The kinetic energy was determined as:

$$K = \frac{1}{8\pi\epsilon_o} \frac{e^2}{r}$$

- If the electron is radiating, it slows down and moves toward nucleus to collapse?
 - * Niels Bohr hypothesized that electrons may exist in “stationary states” without radiating electromagnetic energy
- $L = rp = rmv = n\hbar \rightarrow v = \frac{n\hbar}{mr}$
 - * Where L is the angular momentum, r is the radius, n is a quantized number, and m is the mass

- Substituting this into kinetic energy, we get the permitted radius, r :

$$r_n = \frac{4\pi\epsilon_o\hbar^2}{me^2}n^2$$

- Using electron information, we get:

$$\frac{4\pi\epsilon_o\hbar^2}{me^2} = .0529[\text{nm}]$$

- This value is known as the Bohr radius

- Hydrogen Atom and Bohr Model:

- Radius: $r_n = a_on^2$, $n = 1, 2, 3$
- Energy: $E_n = \frac{-13.6[\text{eV}]}{n^2}$
- $\Delta E = E_n - E_1$ is the excitation energy, where E_n is the n th excited state, and E_1 is the ground state
 - * $|E_n|$ is the binding energy of e^- in state n (ionization energy)
- Optical transitions¹ result in absorption or emission of a photon
 - * In stationary state, there is no electromagnetic energy radiation
 - * e^- can emit radiation when moving from n_1 to n_2

4 Line Spectra

- The absorption or emission from atoms may be used to create an emission spectra
- A general equation was generated:

$$\lambda = \lambda_{\text{limit}} \frac{n^2}{n^2 - n_o^2}, \quad n = n_o + 1, n_o + 2, \dots$$

- For the Balmer series, $n_o = 2$
- For the Lyman series, $n_o = 1$
- The Ritz combination principle:

$$f_1 + f_2 = f_3$$

- This principle shows that the sum of any two emission frequencies results in a frequency that is also in the spectrum

¹Transitions using a photon

- The wavelength of the transition becomes:

$$\lambda = \frac{c}{f} = \frac{64\pi^3 \epsilon_o^2 \hbar^3 c}{m e^4} \frac{n_1^2 n_2^2}{n_1^2 - n_2^2} = \frac{1}{R_\infty} \frac{n_1^2 n_2^2}{n_1^2 - n_2^2}$$

- Where R_∞ is the Rydberg constant, equal to $1.097 \cdot 10^7 [\text{m}^{-1}]$
- Lyman series are only observed in the absorption spectrum
- The following summarizes emission spectra
 - Isolated atoms are in the ground state most of the time
 - Excited state lives for a short time (picoseconds to femtoseconds)
 - The absorption spectrum only occurs from the ground state
 - Balmer series are not found in the absorption spectrum

5 The Bohr Model

- For an atom with $z > 1$
 - For a nucleus of charge ze , the Coulomb force is:

$$F = \frac{1}{4\pi\epsilon_o} \frac{|q_1||q_2|}{r^2} = \frac{ze^2}{4\pi\epsilon_o r^2}$$