Niels Bohr: The Father of the Atom

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Abstract

The purpose of this research project is to understand Bohr Model of atoms. It is so important to know his atomic theory because it not only played an important role in classical physics but also helped to develop quantum mechanics. To interpret Bohr's theory exactly, this study includes contents about his background such as personal characteristics, family, and academic history. This information is directly connected to Bohr, which may help to get the picture about what led him to find out a new atomic theory. Bohr Model explains a structure of an atom including a nucleus and surrounding electrons. In addition, it represents several characteristics of the electrons such as the movement through orbital shells, potential energy electrons have, and excitation and de-excitation. Criticism of the theory shows some drawbacks that Bohr Model had as well as several new, important points Bohr uncovered. The criticism is also so crucial to grasp how other scientists developed a new physical world after Bohr's discovery and how his study had an impact on it.

Introduction

This literature review focuses on background of Bohr Model and its influence on new world of physics. To put it concretely, it covers how Niels Bohr discovered a new atomic theory and how it changed the study of physics.

Niels Henrik David Bohr is a prominent Danish physicist who contributed to both theoretical and quantum mechanical model of atoms. Before Bohr proposed a new theory regarding an atomic structure, people believed that electrons were moving around a nucleus without certain routes, which looked like planets and the sun of the solar system. Furthermore, they thought these electrons were continuously releasing energy according to the classical theory (Narins, 2008).

In 1915, however, Bohr broke the common sense by showing his atomic theory. According to Lerner, Bohr argued an atomic structure differed from the classical belief and asserted there were a lot of orbital shells around a nucleus of an atom, which were certain routes electrons existed. In addition, he figured out several characteristics of each orbital shell especially about the potential energy that electrons could get on a specific position. It explained the movement of the electrons and the amount of energy released or absorbed (2007).

Bohr Model pointed out significant problems of the original theory and opened a new way toward quantum mechanics. Even though it included some errors, these limitations rather helped scientists to develop the field of physics. Bohr and other physicists' efforts to redeem the defects of Bohr Model finally helped to derive various principles and also develop nuclear physics (Aaserud, 2017).

Literature Review

This literature review contains a lot of specific information regarding background and criticism of Bohr Model other than the theory itself. All these contents are vital to understand the essence of Bohr's theory.

Background

Niels Bohr was born into a rich family on October 7, 1885, in Copenhagen, Denmark. His household atmosphere and education environment had a great influence on his achievement, which provided proper circumstances to show off his ability. Bohr was talented to physics, so there was no doubt to select physical science as a major when he entered the university. Throughout undergraduate and graduate courses, he studied deep on the atomic structure, and finally he became a Nobel laureate for the quantum mechanical model of the atom (Aaserud, 2017).

Figure 1. Danish Physicist Niels Bohr ("Niels Bohr", 2013)

Family. His Mother, Ellen Alder Bohr, was a daughter of a rich Jewish banker, and his father, D. B. Adler, was a professor of physiology at the University of Copenhagen. Narins states Bohr was raised in the atmosphere of supportive, wealthy domesticity by his parents with two siblings. His brothers were talented at playing soccer, and his younger brother, Harald Bohr, was an outstanding mathematician who found the field of almost periodic functions (2008).

Academic History. Bohr had had an interest on science since he was young. He graduated from the Gammelholm School in Copenhagen as primary and secondary education. He did very well in school, especially in physics. Bohr also enjoyed having meeting with his closest friends every Friday night to discuss various issues (Narins, 2008). Narins says that Bohr could learn many things through these conversations. Bohr graduated from high school in 1903 and entered the University of Copenhagen. His major was physics, and he got the bachelor of science degree in 1907. During the undergraduate program, he was awarded a gold medal by the Royal Danish Academy of Science due to his remarkable research project (Aaserud, 2017). He achieved a master of science degree in 1909 and a doctorate degree in 1911. Under the doctorate course, Bohr started to doubt atomic theory. He found the problem of classical physics that could not explain quantitative properties of metal electrons through his research. To continue the study, he decided to work with J. J. Thomson, an English physicist, at the Cambridge University, but Thomson did not seem to be interested in his research. So, Bohr moved to the University of Manchester to work with Ernest Rutherford, an English physicist who welcomed him.

Figure 2. A page from the work of Copernicus showing the position of planets in relation to the sun (Copernicus, 1534)

Rutherford focused on nuclear model of the atom, and finally he found the existence of nucleus. At this point, however, the discordance between classical laws and a new atomic model was represented again (Lerner, 2007). Before the Bohr theory, scientists believed that atoms looked like Copernicus's heliocentric model of the solar system as shown in figure 2: As planets were moving around the sun, electrons rotated around a nucleus at any distance from the nucleus. They also trusted that electrons would release energy continuously over and over.

At this point, Bohr had two questions. The first one was that the electrons should have become closer to the nucleus and eventually collided with it if the classical electromagnetism was correct. But electrons kept orbiting without any collisions, which made Bohr noticed the problem of classical laws. The other one he doubted was about a spectrum. According to the classical theory, a hydrogen spectrum should have represented the continuous colors as an atom was heated and released energy (Sahnow, 2014). However, a pattern of lines was produced through spectroscopic experiments. Bohr thought these two questions were related to each other, which meant there should be a connection between spectral lines and atomic structure. So, he began to concentrate upon this issue intensively.

Bohr's Theory

Niels Bohr developed the classical atomic structure using quantum principles. Bohr Model was proposed in 1915, which contained the most important properties of atomic and molecular structure (Lerner, 2007).

Approach. To figure out the relationship between spectral lines and atom structure, Bohr decided to focus on a research begun by Johann Balmer. Balmer is a German physicist who discovered mathematical formula of a hydrogen spectrum in the 1880s, which dealt with contents about line frequencies on the spectrum (Sahnow, 2014). Even though the formula had the precise values, Balmer could not find what it meant. When Bohr connected the formula of the hydrogen spectrum to the problem of the atomic structure, however, he could easily know the meaning of the formula. He asserted that contrary to the classical theory, an electron of an atom was static within a certain orbit without radiating energy. An atom had several permitted orbits, and an electron released or absorbed energy when it was moving from one orbit to another. So, Bohr said the value calculated by the formula meant not only the frequency of spectral lines but also the amount of the energy released or absorbed when electrons changed the orbit (Sahnow, 2014). This hypothesis became the first important point of Bohr's atom theory.

Bohr Model. According to Bohr Model, electrons are existed in a certain circular orbit around a nucleus in a hydrogen atom as shown in figure 3. Each orbital shell has certain energy value. Lerner says the quantized energy levels have a quantum number: the innermost orbit that contains the lowest energy level has a quantum number of 1 (n=1). Additional orbital shells are assigned quantum numbers of 2, 3, 4, and so on (n=2, n=3, n=4, …) (2014). The closer an electron is from the center, the smaller radius the orbital shell has, and the less energy the electron has. The maximum number of electrons that an orbital shell can accept is $2n^2$ (Lerner, 2014). For example, the first shell (n=1) can have 2 electrons while the second one (n=2) holds 8 electrons. For an element, electrons start to fill the closest shell to the nucleus. In case of a sodium atom as figure 4, the third shell (n=3) holds the last electron after the other electrons are accepted by the first and second orbital shells (n=1, n=2).

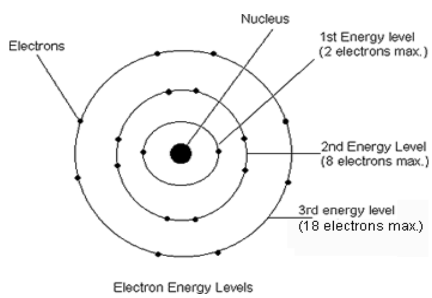

Figure 3. Atomic structure of Bohr Model ("Atomic Structure", n.d.)

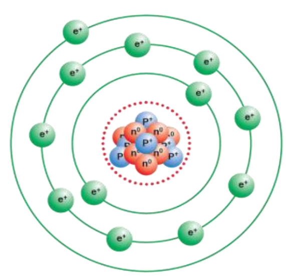

Figure 4. A model of a sodium atom (Gundersen, n.d.)

Like figure 5, an electron can shift from an orbital shell to another. If the electron moves farther from the center, it would get more energy, which is called "potential energy". The more potential energy an electron has, the less stable it becomes. When electrons of an atom are in the lowest energy state, the atom is in a “ground state”. But it sometimes acquires energy, which excites electrons. The atom with electrons at the higher energy orbits is called “excited state”. The maximum energy that excites electrons of the atom is called “ionization potential energy”. The ionization potential energy level forms a continuum. In case of a hydrogen atom, it starts at 13.6 eV (Lerner, 2014).

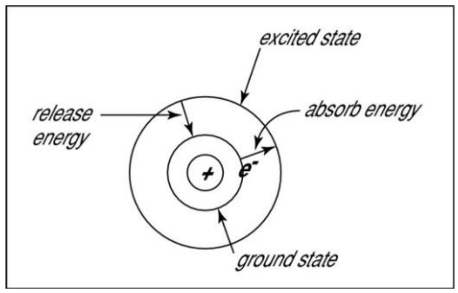

Figure 5. Energy movement ("Atomic Structure: The Bohr Model", n.d.)

A photon is a quantum packet of light energy. An electron can absorb or emit energy as the photon as shown in figure 6 (Doan, 2017). If an electron absorbs energy and becomes excited, it is called “atomic excitation”, which means the atom gains the photon. But if the excited electron emits energy and becomes stable, it is called “atomic de-excitation”, which means the atom release the photon (Lerner, 2014). When the electron shifts from an orbit to another one, the amount of energy released or absorbed equals to the energy difference between two orbital shells. In other words, only certain energy of light can move through orbital shells. Lerner underlines the amount of the energy carried by the photon (E) is inversely proportional to wavelength of the absorbed or emitted light (λ). This energy can be calculated by an equation $E = {hc}/{\lambda}$ (h= the product of the Planck constant, c= the speed of light) (2014). As a frequency (ν) is in inverse proportion to the wavelength (λ), the more energy is carried, the greater frequency of the light is ($E \propto \frac{1}{\lambda} \propto \nu$).

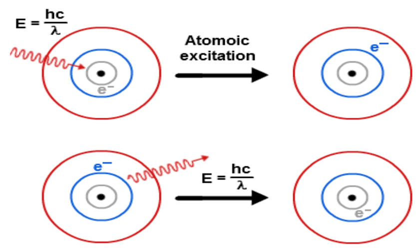

Figure 6. Atomic Excitation and De-excitation ("Niels Bohr Atomic Theory", n.d.)

Criticism

A criticism is highly important because analytical thinking about something leads to advanced interpretation about not only what has been developed well but also what should be more improved in the future. Bohr atomic model helped the classical physics to be improved and opened the door toward quantum mechanics by suggesting a new structure of the atom. However, there are several things that are not precise so that they should be supplemented.

Limitation. The first drawback is that Bohr Model only applies to a hydrogen atom. Bohr could not explain existence of electron orbital shells of larger atoms other than hydrogen (Lerner, 2014). So, Bohr's theory only works for atoms that have a single electron. In addition, he claimed that electrons were stationary unless they move from an orbital shell to another one even though the classical electromagnetism insisted an electron and a nucleus could not remain the space apart due to the electric charge. Bohr's opinion was exactly correct, but it was impossible to demonstrate it by showing obvious evidence at that time. The other one is that in his theory, the particles move in a circular motion. In nature, yet, this motion cannot be existed in wave-like movement (Doan, 2017)

Influence. Despite of the limitation, there are several important points that are still applied to modern atomic model: electrons are stationary in certain orbital shells, and when they move from one energy level to another, energy in the form of a photon is released or absorbed (Doan, 2017).

After Bohr proposed his atomic theory, as Narins says, he founded the University of Copenhagen's Institute for Theoretical Physics (2008). Since Bohr Model had both features of the classical physics and modern physics, numerous scientists including Bohr were interested in how to view a new physics world between two other issues. Bohr's Institute provided a lot of helps to young physicists to investigate this field in the mid-20th. Finally, they found two principles: the principle of correspondence and the principle of complementarity (Narins, 2008). These two theories helped to resolve the contradiction between the classical and modern physics.

Furthermore, Bohr's theory contributed to nuclear physics. After Bohr discovered the characteristics of electrons, he started to focus on the atomic nucleus. Then he demonstrated the liquid-drop model, which said that a nucleus looked like a drop of liquid due to its internal forces (Narins, 2008). Deepening this knowledge, other scientists found the process of nuclear fission, which was the first step to develop nuclear physics. Likewise, Bohr's efforts made nuclear technology enhanced, and the first atomic bombs were created, but it was not only thing that he did. He also encouraged uses of atomic weapons peacefully. According to Aaserud, CERN (European Center for Nuclear Research) and Nordita (Nordic Institute for Theoretical Atomic Physics) which were built in order to discourage the military to control atomic weapons were founded by Bohr. Due to the positive influence on nuclear physics, he received the first Atoms for Peace Award given by the Ford Foundation (2017).

Conclusion

Niels Bohr, a Danish physicist who had been raised by best family to use his talent, set a new milestone for both classical and modern physics. Bohr Model had great explanation about electrons in certain energy levels, which also explained energy movement in an atom. Though his theory had some drawbacks, it is evident that it greatly contributed to the progress of physics.

Moreover, the study of the quantum mechanics started from that point. Bohr continued to work for his study at his institute until his death on November 18, 1962.

If this research project is extended, the further research should deal with the subject of the quantum mechanical model of the atom such as Erwin Schrodinger's theory. It would efficiently show how modern physics was proceeded as an extension of Bohr Model.

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