The Bohr Model of the Atom

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CONCEPT 1 The Bohr Model of the Atom

Lesson Objectives

The student will:

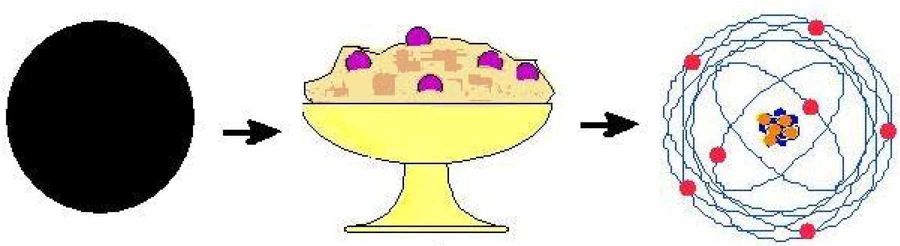
- describe an electron cloud containing Bohr's energy levels.
- describe how the Bohr model of the atom explains the existence of atomic spectra.
- explain the limitations of the Bohr model and why it had to be replaced.

Vocabulary

- energy level

Introduction

By 1913, our concept of the atom had evolved from Dalton's idea of indivisible spheres to Thomson's plum-pudding model and then to Rutherford's nuclear atom theory.



Rutherford, in addition to carrying out the experiment that demonstrated the presence of the atomic nucleus, proposed that the electrons circled the nucleus in a planetary-like motion. The planetary model of the atom was attractive to scientists because it was similar to something with which they were already familiar, namely the solar system. Unfortunately, there was a serious flaw in the planetary model. At that time, it was already known that when a charged particle moves in a curved path, the particle emits some form of light or radio waves and loses energy in doing so. If the electron circling the nucleus in an atom loses energy, it would necessarily have to move closer to the nucleus (because of the loss of potential energy) and would eventually crash into the nucleus. Scientists, however, saw no evidence that electrons were constantly emitting energy or crashing into the nucleus. These difficulties cast a shadow on the planetary model and indicated that it would eventually be replaced.

The replacement model came in 1913 when the Danish physicist Niels Bohr (pictured in **Figure** 1.1) proposed an electron cloud model where the electrons orbit the nucleus but did not have to lose energy.

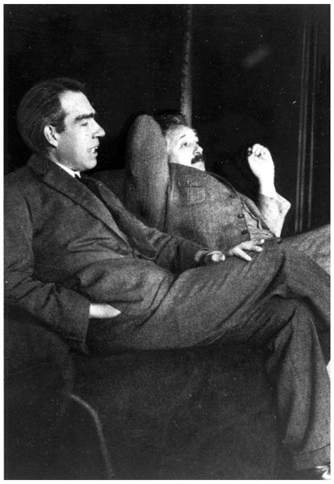
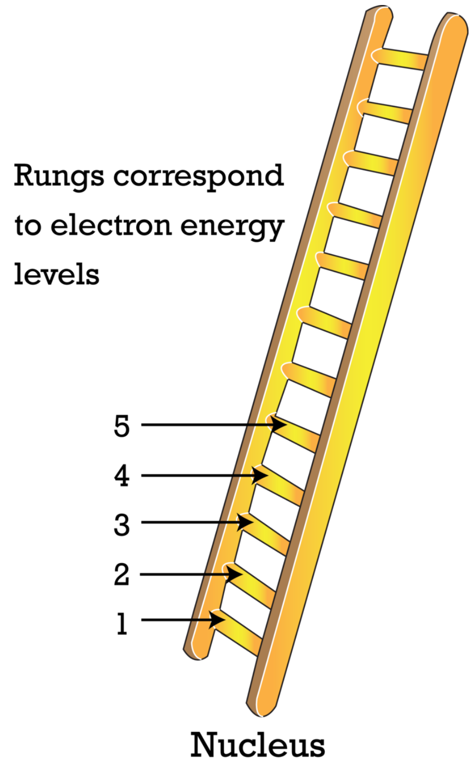


FIGURE 1.1
Niels Bohr and Albert Einstein in 1925.

Bohr's Energy Levels

The key idea in the Bohr model of the atom is that electrons occupy definite orbits that require the electron to have a specific amount of energy. In order for an electron to be in the electron cloud of an atom, it must be in one of the allowable orbits and have the precise energy required for that orbit. Orbits closer to the nucleus would require the electrons to have a smaller amount of energy, and orbits farther from the nucleus would require the electrons to have a greater amount of energy. The possible orbits are known as **energy levels**.

Bohr hypothesized that the only way electrons could gain or lose energy would be to move from one energy level to another, thus gaining or losing precise amounts of energy. It would be like a ladder that had rungs at certain heights (see image below). The only way you can be on that ladder is to be on one of the rungs, and the only way you could move up or down is to move to one of the other rungs. Other rules for the ladder are that only one person can be on a given rung and that the ladder occupants must be on the lowest rung available. Suppose we had such a ladder with 10 rungs. If the ladder had five people on it, they would be on the lowest five rungs. In this situation, no person could move down because all the lower rungs are full. Bohr worked out the rules for the maximum number of electrons that could be in each energy level in his model. In its normal state (ground state), this would require the atom to have all of its electrons in the lowest energy levels available. Under these circumstances, no electron could lose energy because no electron could move down to a lower energy level. In this way, the Bohr model explained why electrons circling the nucleus did not emit energy and spiral into the nucleus.



Bohr Model and Atomic Spectra

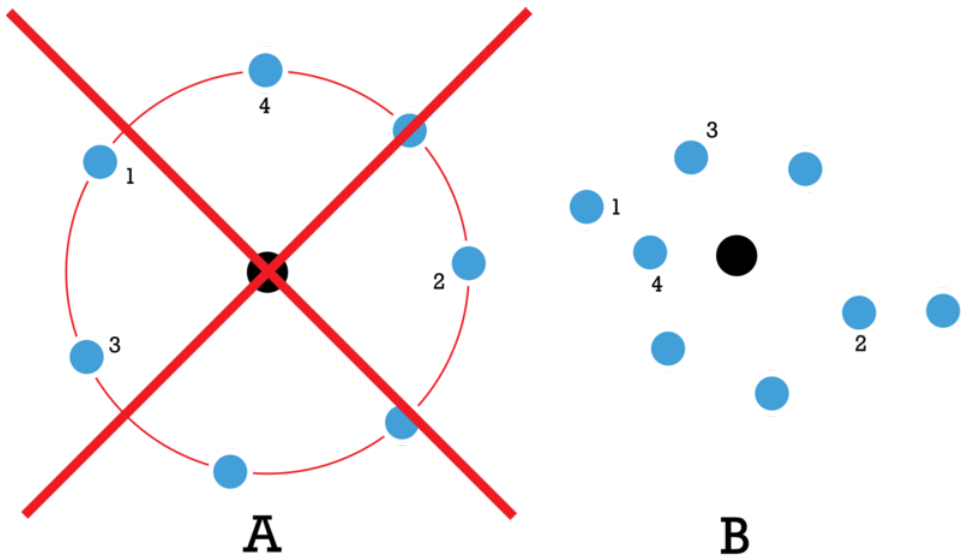
The evidence used to support the Bohr model came from the atomic spectra. Bohr suggested that an atomic spectrum is created when the electrons in an atom move between energy levels. The electrons typically have the lowest energy possible, but upon absorbing energy, the electrons would jump to a higher energy level, producing an excited and unstable state. The electrons would then immediately fall back to a lower energy level and re-emit the absorbed energy. The energy emitted during these electron "step downs" would be emitted as light and would correspond with a specific line in the atomic emission spectrum. Bohr was able to mathematically produce a set of energy levels for the hydrogen atom. In his calculations, the differences between the energy levels were the exact same energies of the frequencies of light emitted in the hydrogen spectrum. One of the most convincing aspects of the Bohr model was that it predicted that the hydrogen atom would emit some electromagnetic radiation outside the visible range. When scientists looked for these emissions in the infrared region, they were able to find them at the exact frequencies predicted by the Bohr model. Bohr's theory was rapidly accepted and he received the Nobel Prize for physics in 1922.

Shortcomings of the Bohr Model

The development of the Bohr model is a good example of applying the scientific method. It shows how the observations of the atomic spectra led to the creation of a hypothesis about the nature of electron clouds. The hypothesis also made predictions about emissions that had not yet been observed (the infrared light emissions). Predicted observations such as these provide an opportunity to test the hypothesis through experimentation. When these predictions were found to be correct, they provided evidence in support of the theory. Of course, further observations can also provide insupportable evidence that will cause the theory to be rejected or modified. In the case of the Bohr model of the atom, it was determined that the energy levels in atoms with more than one electron could not be successfully calculated. Bohr's system was only successful for atoms that have a single electron, which meant that the Bohr model did not accurately reflect the behaviors of most atoms.

Another problem with Bohr's theory was that the Bohr model did not explain why certain energy levels existed. As mentioned earlier in this lesson, at the time it was already known that charged particles emit some form of light or radio waves when moving in a curved path. Scientists have used this principle to create radio signals since 1895. This was the serious flaw in Rutherford's planetary model of the atom, which Bohr attempted to deal with by suggesting his electron cloud model. Although his calculated energy levels for the hydrogen were supported by hydrogen's emission spectrum, Bohr did not, however, explain why only the exact energy levels he calculated were present.

Yet another problem with the Bohr model was the predicted positions of the electrons in the electron cloud. If Bohr's model were correct, the electron in the hydrogen atom in ground state would always be the same distance from the nucleus. Although the actual path that the electron followed could not be determined, scientists were able to determine the positions of the electron at various times. If the electron circled the nucleus as suggested by the Bohr model, the electron positions would always be the same distance from the nucleus. In reality, the electron is found at many different distances from the nucleus. In the figure below, the left side of the image (labeled as A) shows the random positions an electron would occupy as predicted by the Bohr model, while the right side (labeled as B) shows some actual positions of an electron.

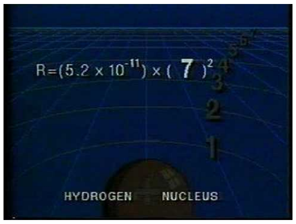


The Bohr model was not, however, a complete failure. It provided valuable insights that triggered the next step in the development of the modern concept of the atom.

Lesson Summary

- The Bohr model suggests each atom has a set of unchangeable energy levels, and electrons in the electron cloud of that atom must be in one of those energy levels.
- The Bohr model suggests that the atomic spectra of atoms is produced by electrons gaining energy from some source, jumping up to a higher energy level, then immediately dropping back to a lower energy level and emitting the energy difference between the two energy levels.
- The existence of the atomic spectra is support for the Bohr model of the atom.
- The Bohr model was only successful in calculating energy levels for the hydrogen atom.

This video provides a summary of the Bohr atomic model and how the Bohr model improved upon Rutheford's model **(1i; 1g IE, 1k IE)**: http://www.youtube.com/watch?v=bDUxygs7Za8 (9:08).



MEDIA

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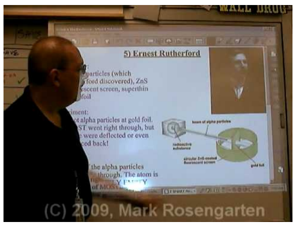
This video describes the important contributions of many scientists to the modern model of the atom. It also explains Rutherford's gold foil experiment **(1g IE)**: http://www.youtube.com/watch?v=6773jO6fMnM (9:08).



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Further Reading / Supplemental Links

These various videos examine the components of the Bohr model of the atom.

- http://www.youtube.com/watch?v=QI50GBUJ48s&feature=related
- http://www.youtube.com/watch?v=hpKhjKrBn9s
- http://www.youtube.com/watch?v=-YYBCNQnYNM&feature=related

Review Questions

1. What is the key concept in the Bohr model of the atom?
2. What is the general relationship between the amount of energy of an electron energy level and its distance from the nucleus?
3. According to Bohr's theory, how can an electron gain or lose energy?
4. What happens when an electron in an excited atom returns to its ground level?
5. What concept in Bohr's theory makes it impossible for an electron in the ground state to give up energy?
6. Use the Bohr model to explain how an atom emits a specific set of frequencies of light when it is heated or has electric current passed through it.
7. How do scientists know that the sun contains helium atoms when no one has even taken a sample of material from the sun?

References

1. . BohrandEinstein. Public domain