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Misconceptions about Atomic Models Amongst the Chemistry Students

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Abstract

Bohr's model is a semi-classical model which involves both classical and quantum principles. Although more sophisticated Schrödinger model has been presented to students, the residual picture in their minds persists to consider Bohr's model to be the closest to the physical reality. We included few questions about Bohr's model in tests to assess the students' understandings of realistic atomic models in general-chemistry courses offered for freshmen in two universities in the Middle-East (namely, Yarmouk University at Irbid, Jordan, and the United Arab Emirates University at Al-Ain, UAE, from both a statistical sample of 687 students was collected). The results reveal the existence of huge misconceptions amongst a large portion of the students' sample (i.e., ≥ 85%). Alternative solutions are discussed and suggested to draw a strategy to better dissimilate the knowledge in order to overcome the existing learning difficulties.

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1. Introduction

Atoms are the building blocks of matter and the understanding of their structures and properties is very fundamental for everything in life ranging from building blocks of nature to advanced nanotechnology. Historically, the discovery of atom and its structure passed through efforts of generations of talented scientists, starting from the Russian chemist Dmitri Mendeleev's discovery of the periodic table of elements in 1869 [1]. Yet, the breakthrough in discovering the structure of an atom occurred after the appearance of modern physics, in 1913, by a Danish physicist Niels Bohr together with Ernest Rutherford who depicted the atom and gave a model for the simplest atom of hydrogen [2-3]. Such a discovery has insighted all mankind and Bohr deserved, indeed, a Nobel prize in physics in year 1922.

Thereafter, three historical models of the hydrogen atom were developed, as been originally proposed by Niels Bohr [2], Louis de Broglie [4] and Erwin Schrödinger [5]. In the Bohr's model, electrons are point particles that move around the nucleus in circular orbits at fixed radii. In the de Broglie's model, electrons are standing waves on rings with the same radii as in the Bohr's model. In the Schrödinger's model, electrons are clouds of probability whose density is given by the solutions to the three-dimensional Schrödinger's equation for the Coulomb potential that the electron feels from the nucleus. In all these preceding three models the knowledge of quantum mechanics is essential. Here occurs a great debate. Basically, some educators favor the postponement of teaching Bohr's model until the college level as they see that the quantum mechanics would not be appropriate at secondary level. The work of Fischler and Lichtfeld [6] has been cited in the physics education research (PER) community and beyond as evidence that it is preferable to avoid teaching Bohr's model entirely [7-9] and their claims have been incorporated into curriculum design [7]. Another group of educators [10-11] stood against such claims and saw that Fischler and Lichtfed did not provide convincing evidence that teaching Bohr's model would prevent students from learning the Schrödinger's model. In particular, Petri and Niedderer [11] viewed a Bohr-like model as a necessary step in the learning pathway of a student and should rather be an important historical step in understanding atoms.

According to the US-National Research Council (US-NRC)'s report [12], science is defined to be "both a body of knowledge and an evidence-based, model building enterprise that continually extends, refines, and revises knowledge". In the perspectives of atomic models, the US-National Science Education Standards state that "each atom has a positively charged nucleus surrounded by negatively charged electrons"; but do not describe the properties of those electrons [13]. Thus, it seems that both national and district standards are silent on the question of which model(s) should be used to describe atoms for secondary-level (i.e., high-school) students.

In our view, the reports by Fischeler-Lichtfeld and US-NRC do not provide convincing evidence to avoid teaching Bohr's model in high-school, as they claim that that prevents students from learning Schrödinger's model. We stand with the fact that students need to study both introduction to modern physics and general chemistry since high school. They need to get familiar with the periodic table of elements, where shell-structure of electrons in an atom is ultimately needed. So, in the present investigation, we have included two conceptual multiple-choice questions about Bohr's model and more advanced atomic models and given them in a test to undergraduate students taking general chemistry course after the topic of atomic structure been covered. The same questions were proposed in tests for students in two different universities (namely, Yarmouk University at Irbid, Jordan, and UAE University at Al-Ain, UAE). The results reveal fascinating facts about the interests of students and their ability of grasping the existing atomic models of an atom. In next section, the results will be discussed.

2. Results and discussion

In both concerned universities, the general-chemistry-1 course [14] consists basically of the following topics: Matter and measurement; Basic concepts of chemical bonding and molecular structures; Chemical stoichiometry; Acids-bases and oxidation-reduction reactions; the atomic structure; and other related topics. In the chapter of atomic structure, several subjects are discussed in a sequence; namely as: the electromagnetic radiation, the photoelectric effect, the duality aspects of light, the atomic spectrum of Hydrogen atom, Bohr's model, the quantum numbers, the periodic table of elements, respectively. Actually, these topics overlap with those taught in a Modern-Physics course [15] to Physics students. The subject of Bohr's model appears as essential amongst all these topics and to warrant its concept to be grasped by students is a very important matter. This model, of course, should consist a basic stone to further more sophisticated models fully based on quantum mechanics, such as Schrödinger's model. Usually tests like midterm and final exams are composed of two parts: (i) Multiple-choice questions (MCQs); and (ii) Solving problems. Here in this investigation, we will discuss the results of two MCQs proposed about Bohr's model to assess students about which model should be more realistic. The number of students participated in the test is 389 from Yarmouk University (YU) and 298 from UAE University (UAEU), which makes a total of 687 students. In MCQ # 1, students were tested whether they can recognize the

Table-1: Statistics of students answering MCQ#1 in two universities

	(a)	(b)	(c)	(d)	Total
# in YU	49	173	96	71	**389**
# in UAEU	36	172	60	30	**298**
Total	**85**	**345**	**156**	**101**	**687**

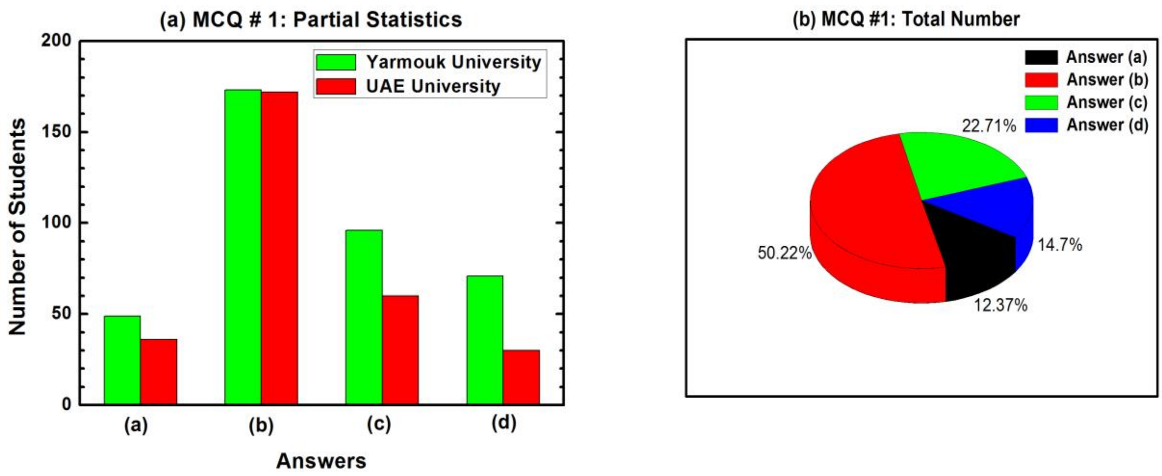

Figure-1: Statistics of students' answering question #1, which is about Bohr model in: (a) YU and UAEU Universities; and (b) Total. Note that the correct answer is (d).

name of the model or not. Namely, MCQ # 1 focuses on which model to use to best describe atom: (a) Thomson model; (b) Bohr model; (c) Rutherford model; or (d) None of those. Table-1 shows the results in number, while Figure 1 displays them in chart and pie diagrams. Figure 1a shows that the two universities (Yarmouk and UAEU universities) have about the same trends of results. While Figure 1b shows the total number of students choosing various answers. It is amazing to discover that only 15% of the total number got the correct answer (d), and among the 85% who got the wrong answers, 50% have chosen answer (b), which is wrong of course. More specifically, in UAEU, 10% got the correct answer (d), and among the

90% who got the wrong answers, 58% have chosen the wrong answer (b). Whereas, in YU, 18% got the correct answer (d), and among 82% who got the wrong answers, 44% have chosen the wrong answer (b). Answer (b) seems like a strange attractor to students. The trends between the two universities are similar and worth a serious investigation to analyze and to seek the reasons behind these shortcomings.

Table-2: Statistics of students answering MCQ#2 in two universities

	(a)	(b)	(c)	Total
# in YU	31	302	56	**389**
# in UAEU	21	244	33	**298**
Total	**52**	**546**	**89**	**687**

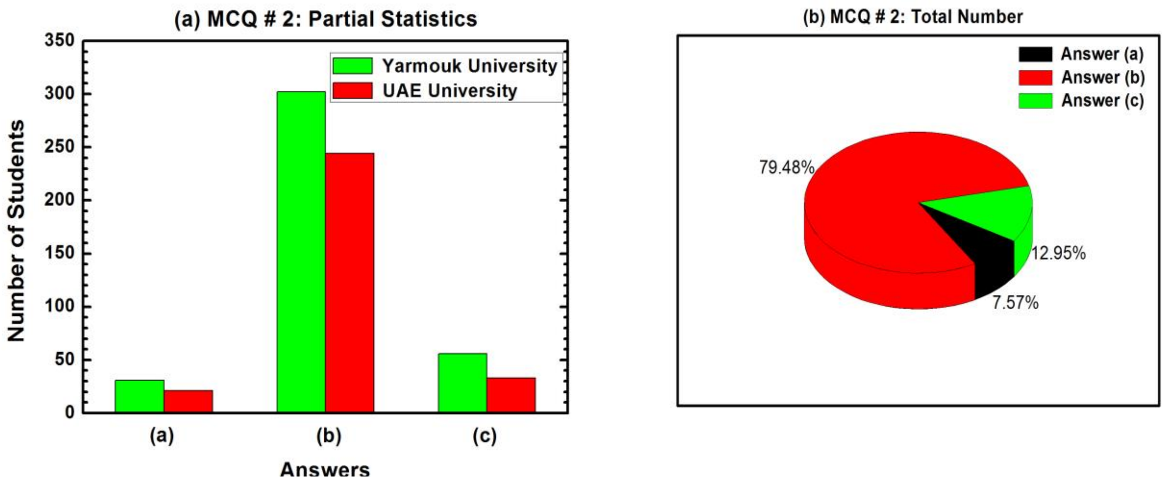

Figure-2: Statistics of students' answering question #2, which is about Bohr model in: (a) YU and UAEU Universities; and (b) Total. Note that the correct answer is (c)

Question # 2 deals with the behavior of electrons in an atom. Students were given 3 choices: (a) Electrons in atom to be immersed in a soup of positive charge; or (b) Electrons to act as particles moving around the nucleus in circular orbits at fixed radii; or (c) Electrons not to be confined to orbits but exist everywhere with a certain probability distribution. Table-2 shows the statistics of number of students answering various question in both YU and UAEU universities. The question is very conceptual and relies on visualization and students might have seen similar picture in logos such as the one of "International Atomic Energy Agency" (IAEA). Here as well, it is amazing that overall only 13% got the correct answer (c), and among the 87% who got the wrong answers, 75% have chosen the wrong answer (b). More specifically, in UAEU, only 11% got the correct answer (c), and among the 89% who got wrong answers, 82% have chosen the wrong answer (b). In YU, only 14% got the correct answer (c), and among the 86% who got wrong answers, 78% have chosen the wrong answer (b). So, the wrong answer (b) acts as false attractor to students in both universities. This reveals that students think that Bohr's model is the one closest to the reality of behavior of electrons in an atom. It is worth mentioning that the

study was conducted on several sections (taught by different instructors) at each university. The purpose of this study was to investigate the students comprehension of the ultimate atomic model and not to compare the performance of students in the two different universities. However, we showed the results of both universities in order to display the very similar trends in both institutions. This indicates that the ideas that the students possess about the Bohr's model is not connected with a particular institute or instructor. It is important to investigate the possible factors that contribute to this alarming misachievment of students in a basic concept of modern physics. We believe that the method of teaching practiced at the two different universities may play a major role. To our knowledge the conventional lecture practice where students act as passive receptors and where the instructor act as an authority of knowledge is practiced at both universities and in many other parts of the middle east region. Students are not the center of the learning process but rather it is the instructor who controls the stage. This conventional practice disconnects the students from their learning process and attributes to the shortcoming of their acheivment. This conclusion has been pointed out by many researchers who have investigated ineffectivness of the conventional method of teaching [16-17]. Another possible factor could be related to students' attitudes toward learning, their expectations, and the lack of motivation. Such factors plays a major role in the students's detachment of their learning process, as investigated by few researches [18]. Lack of critical thinking among students could also play an important role. According to some researchers, low achievement of students could be related to teachers' beliefs and attitudes in shaping education and students experience [19]. In our case of study, the above mentioned factors should be investigated further to identify the ones that play major role in the students' misconceptions about the Bohr model and the atomic structure in general.

3. Conclusion

The Bohr's model of hydrogen atom is one of the fundamental topics that should be considered a prerequisite concept necessary for the understanding of atomic structure using quantum mechanics. A large sample of general-chemistry students were exposed to two basic questions about Bohr's model at two different universities (YU and UAEU). For the first question, we notice that more than 85% of the students got wrong answers while a large percentage of students agree to select the same wrong answer, indicating the Bohr's model is the correct model of describing the atom. Similarly, for the second question, when students were asked about the behavior of electrons in an atom, only 13% got the correct answer, while a large percentage of students agree to select the same wrong answer, indicating that the reality of electronic behavior in an atom follows Bohr's model. We notice that the results of study display very similar trends in both institutions where the course is delivered for multi-sections and by different instructors. This indicates that the concepts the students possess about the Bohr's model are not connected with a particular institute or instructor.

The low performance of students in the topic of Bohr's model could be traced to several factors. For example, the conventional method of teaching practiced at the two different universities may play a major role. In the conventional method of teaching, students act as passive receptors and instructor act as an authority of knowledge. Students are not the center of the learning process but rather it is the instructor who controls the stage. This practice disconnects the students from their learning process and attributes to the shortcoming of their acheivement. Another possible factor could be related to students' attitudes toward learning, their expectations, and the lack of motivation. These factors play a major role in the students's detachment of their learning process. Lack of critical thinking among students could also play an important role. In addition, low achievement of students could be related to teachers' beliefs and attitudes in shaping education and students experience.

We suggest few possible practices to elevate students' misconceptions. Instructors are encouraged to deviate from the traditional method of teaching and focus on students as major player in the learning process. Students should be involved in the content discussion and problem-solving practice in class. Students should be encouraged to actively participate in the course progress and encouraged to be independent thinkers. Finally, we believe it is essential for students to appreciate and be aware of the importance of the topic in modern science.

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Appendix: The Multiple-Choice Questions

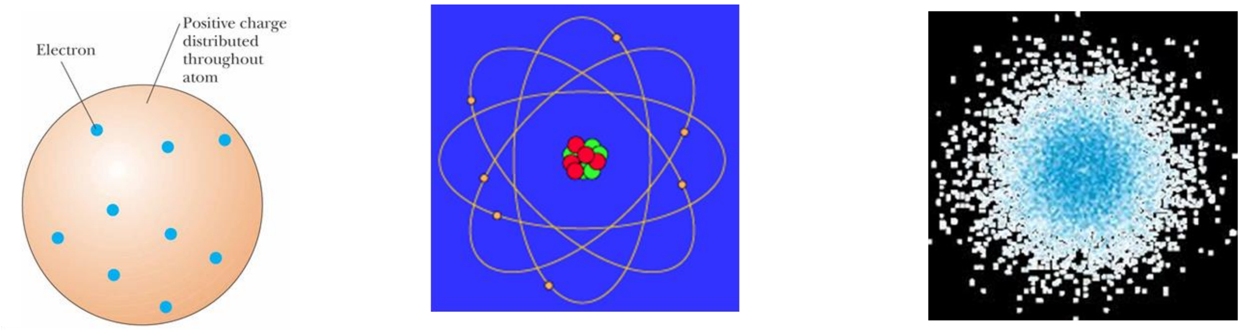
Chose the correct answer for the following questions:

Question #1: An accurate understanding of atoms is provided by

(a) Thomson Model
(b) Bohr Model
(c) Rutherford Model
(d) None of the above

Note: The correct answer is (d).

Question #2: The most accurate image that reflects the current understanding of electrons in atoms is:



(a)
Electrons in the atom are immersed in a soup of positive charge

(b)
Electrons are point particles that move around the nucleus in circular orbits at fixed radii.

(c)
electrons are not confined to orbits, but exist everywhere according to a probability distribution.

Figure-3: Various atomic models. The images were obtained from several websites.
Note: The correct answer is (c).

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