The Bohr Atom

PHYS 1301 F99
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Introduction

In this week's computer simulation, we will examine the behavior of a *simplified* model of the hydrogen atom. This model, the "Bohr model," is a useful picture of how a hydrogen atom works although the model is wrong in some important details of how a genuine hydrogen atom works. (For example, it incorrectly predicts that for all electronic orbits about the proton, the orbits are perfect circles. Most of the orbits of a real hydrogen atom do not resemble circles but are more complicated patterns.) This model does correctly account for the facts that electronic orbits are discrete; that spectral lines are observed with a specific pattern for the wavelengths; that these patterns depend on the number of protons in the nucleus of the atom in a very specific way; and that the size of a hydrogen-like atom (an atom with only one electron orbiting a nucleus containing an arbitrary number of protons) depends on the number of protons in the nucleus.

Neils Bohr invented this model of the workings of the hydrogen atom around 1913. The model incorporates quantum mechanics and is probably the first semi-realistic description of a real physical system that does incorporate quantum mechanics. This is important because quantum mechanics is necessary to explain the stability of a hydrogen atom. So-called "classical" physics, the physics of Isaac Newton, Charles Coulomb, James Clerk Maxwell, and many others, predicts that the hydrogen atom would spontaneously decay. Without the physics of quantum mechanics a hydrogen atom would not be stable, there would be no water and you and I would not be here discussing this matter.

Today's simulation will **not** prove that a real hydrogen atom acts the way it is portrayed in the software. We will assume that the simulation is correct and try to guess for ourselves, using numbers calculated by the software, what are the simple algebraic relations that relate the energy levels of the hydrogen atom, the size of the atom, and the number of protons in the nucleus. I also want you to understand what happens to the size of an atom when it either absorbs or emits a photon.

Our simplified model of the hydrogen atom assumes that there is a single electron orbiting in a perfect circle about the nucleus. We can label each of these orbits with a single integer n ($n=1,2.3…$) and we will refer to n as the *principal* quantum number of the hydrogen atom. A real hydrogen atom has other quantum numbers but n remains the most important.

Procedure

1. Start the PEARLS program by double clicking on the PEARLS icon. I will help you to find this icon. Click on the Modern Physics category and then click on the menu item "Bohr Atom". You may have to scroll a bit to find these items. Inform me if you get stuck and cannot find either.

2. If you are successful, you should see a screen showing a set of circles concentric with a colored dot. The circles represent the circular orbits of the electrons in the Bohr model and the dot represents the hydrogen atom nucleus. To the left of this image you will see a control panel that will allow you to change various features of the model hydrogen atom like the number of orbits displayed and the mass of the electron. You should also see a graph at the bottom of the screen displaying the energy of the electron. (This number will be negative and measured in the units called "electron volts". The energy of an electron in your television set is about 10,000 electron volts just before it crashes into the back of the TV screen.)

3. There are two important numbers that the program displays. The first is the electron energy shown at the bottom of the screen and the other is the orbit radius of the electron. As the electron changes its orbit, both of these numbers will change.

4. Push the "RUN" button under the *Simulation* menu. Observe what happens. Push the "STOP" button and then the "RESET" button. Change some of the settings (like the quantum number and the atomic number) on the control panel on the left hand side of the screen and observe their effect when you click the "RUN button again. While the electron is orbiting, push the ABSORB and EMIT buttons a few times. Play a bit so that you become familiar with the controls.

5. Stop and reset the simulation. Click the REVERT button in the *Simulation* menu. This will set all values to their defaults. Put the electron in the orbit corresponding to quantum number $n=1$. What do you see? (You do not have to "START" the simulation.) What is the value of the electron's orbit radius? This value is what we mean by the "size" of the atom, the orbit radius of the outermost or "valence" electrons. **Fill out the first 3 columns in table 1** below by changing the electron's orbit radius from quantum number $n=1$ through $n=6$ and observing the electron's orbit radius. From these three columns, you should be able to guess a simple relationship between the electron's radius r' in any orbit, the principal quantum number of that orbit and the radius of the smallest possible electron orbit. **Question 1.** Write down a simple algebraic relationship between the principal quantum number n, the radius of the electron's orbit r' and the value of the smallest orbit radius a_0 (corresponding to $n=1$). Your formula should be of the form: $r'=\ldots$

6. Now we will observe what happens to the energy of the electron when it changes its orbit around the nucleus. Put the electron back into the *n=1* orbit. What is the electron's energy? **Fill out the last two columns in table 1.** You should now be able to guess at a simple relationship between the electron's energy in any given orbit *E'*, the principal quantum number of that orbit, and the energy of the electron when it is in the *n=1* orbit. **Question 2.** Write down a simple algebraic relationship between the principal quantum number *n*, the electron's energy *E'* when it is in an arbitrary orbit and the smallest possible value of the electron's energy E_0 (corresponding to *n=1*). Your formula should be of the form: $E'_0 = \ldots$

7. Now we will examine the behavior of *hydrogenic* atoms. These are atoms that, like hydrogen, only have a single electron orbiting the nucleus. Unlike hydrogen though, they have more than 1 proton in their nucleus. A helium atom with only one electron is an example of a hydrogenic atom. We want to see now how the electronic energy levels and the orbit radii change when the number of protons ion the nucleus changes. Change the number of protons *Z* in the nucleus from *Z=1* through *Z=4* and notice what happens to the orbit radius and the electron energy level. Remember, the electron is supposed to be in the *n=1* orbit all the time. This will make the pattern I want you to see easier to observe. **Complete table 2.**

8. From examining the entries in table 2, you should be able to guess the algebraic relationship that relates the size of an atom's *smallest* orbit when it has *Z* protons in its nucleus to its smallest size when it has only 1 proton in its nucleus. **Question 3.** What is this relationship? Let *Z* be the number of protons, r'_0 be the smallest possible orbit radius for an atom with *Z* protons and let a_0 be the corresponding radius when the atom is hydrogen (*Z=1*). Your formula should be of the form: $r'_0 = \ldots$ Similarly, you should be able also to guess the relationship between the smallest possible energy level of a multi-proton atom E'_0, the number of protons in the nucleus *Z* and the smallest energy level for a hydrogen atom E_0. **Question 4.** What is this algebraic relationship? Your formula should be of the form $E'_0 = \ldots$

9. The immediately preceding relationships were just for the *n=1* orbits. Now I want you to generalize these relationships based on what you observed in table 1. **Question 5.** Write down an algebraic relationship for the size of the orbit radius *r* of an atom in terms of the principal quantum number *n* of the orbit, the number of protons *Z* in the atom's nucleus, and the size of the smallest possible orbit for a hydrogen atom a_0. **Question 6.** Now write down an algebraic relationship for the energy level of an electron *E*. This relation should include terms for the principal quantum number *n* of the orbit the electron is occupying, the number of protons *Z* in the atom's nucleus, and the size of the electron's smallest possible energy level in a hydrogen atom E_0.

10. Finally, observe what happens when the atom either emits or absorbs a photon. Notice how its size changes. Reset the simulation and click the yellow arrow at the top of the display to return the simulation to its default settings. Run the simulation and push the ABSORB button. What do you see? Does the size of the atom decrease or increase? Click the button several more times. Is this pattern repeated? Bow push the EMIT button. What do you see? Does the size of the atom increase or decrease? What happens to the energy level of the electron when photons are absorbed or emitted? Recall that two weeks ago you witnessed photons being emitted from a glass tube containing hydrogen. You saw different colors. Assuming the Bohr model is reasonably correct, what does this imply about the kinds of transitions the electrons in those hydrogen atoms were making? For example, were all the electrons starting from or ending in the same orbits?

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Abstract

Data

Table 1.

Quantum number n	Orbit radius r(n)	r(n)/r(n=1)	E(n)	$E(n=1)/E(n)$
N=1				
N=2				
N=3				
N=4				
N=5				
N=6				

Table 2.

Z	$r(Z,n=1)$	$r(Z=1,n=1)/r(Z,n=1)$	$E(n=1)$	$E(Z,n=1)/E(Z=1,n=1)$
1				
2				
3				
4				

Question 1.

Question 2.

Question 3.

Question 4.

Question 5.

Question 6.

Conclusion