***● Учебно съдържание, планове и програми ●***
***● Curriculum Matters ●***

# 137: A BOHR'S THEORY PREDICTION OF THE UPPER LIMIT FOR THE NUMBER OF CHEMICAL ELEMENTS

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***Abstract**. The semi-classical Bohr´s model, although it is an incomplete and old theory, is one of the first approximations to the one electron atom that students learn. In this paper an answer is given using this model to a question that can often arise in introductory chemistry or atomic physics courses when dealing with the subject of the periodical table, namely if there is an upper limit for the number of chemical elements. It is hoped that the manuscript could be useful to teachers and students to learn about this question since the very first physics and chemistry courses.*

***Keywords**: periodic table, Bohr's model, atom, chemical elements*

There are today 112 known chemical elements if we consider a synthetic radioactive Copernicium (symbol Cn, its nucleus contains Z=112 protons) as the highest numbered element officially recognized by the International Union of Pure and Applied Chemistry (IUPAC) [1] (see Fig. 1). How many other elements could exist is a question that can often arise in physics and chemistry courses at different levels and a theme that to the best of the author´s knowledge has not been considered yet in current text books. We will demonstrate briefly here how the ancient Bohr´s theory for the one electron atom could be helpful to explain in introductory courses that there must be an upper limit for the number of chemical elements. This approach could be useful, for example, when students have their first approaches to the periodic table of chemical elements in undergraduate courses and are not yet familiar with the basic concepts of quantum mechanics and therefore with more advanced atom models.

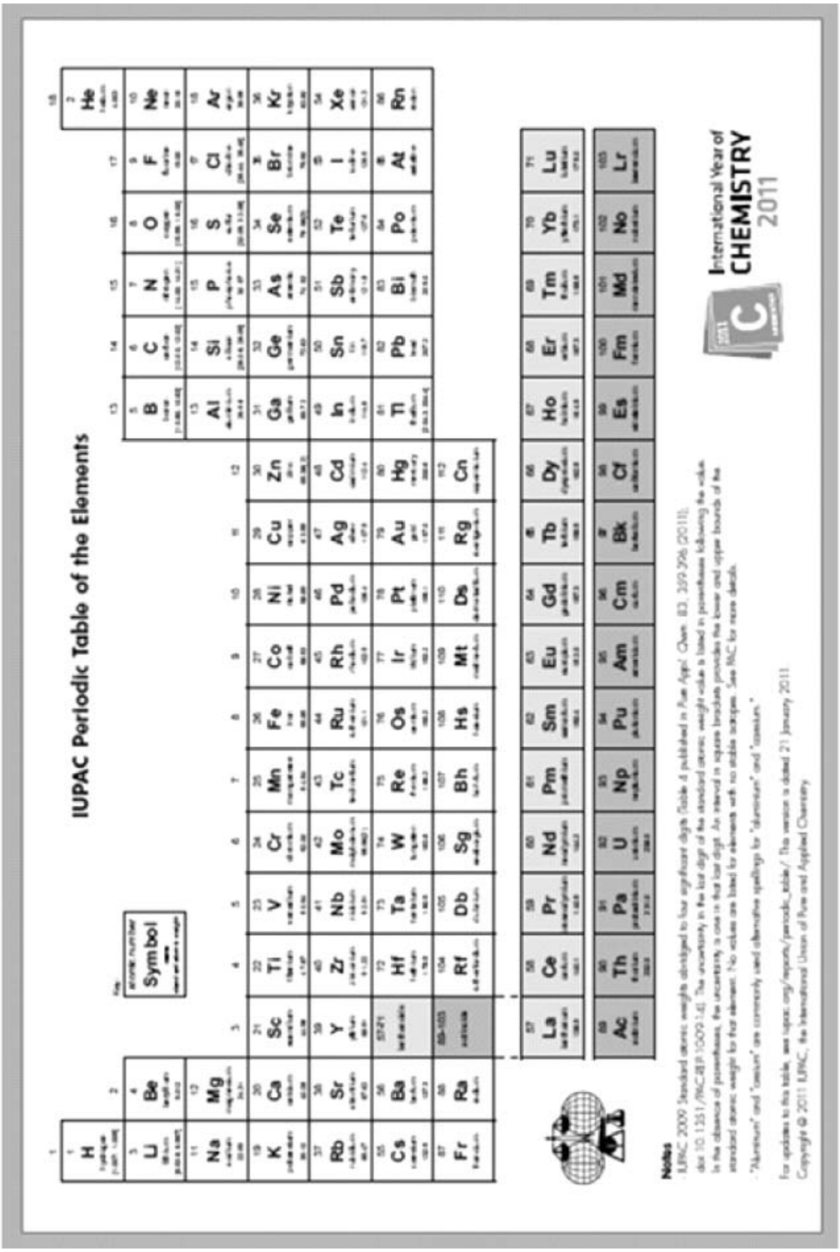


Fig. 1.The 2011 periodic table of the elements1)

That there is a maximum to the number of stable elements that can exist could be an obvious conclusion if we imagine an atomic nucleus containing Z positively charged particles (protons) that can repel each other by Coulomb forces increasing with the numbers of protons, making the nucleus no longer stable above certain Z values. But we must remember that there exists a competing force, much stronger than the Coulomb ones, that is called the strong nuclear force that holds the protons and neutrons together inside the nucleus. Thus one must also look outside the nucleus where the Coulomb force governs its interaction with the atom electrons.

One of the simplest models that have been accepted to describe the basic properties of atoms is that due to Bohr. The Bohr´s Theory of the Atom [2-4] has been outlined in several textbooks and scientific papers (see for example Ref. [5] and references cited herein) and it is still used in physics and chemistry courses as one of the first approximations for the description of atoms, especially in the context of its development post-Rutherford and the ad-hoc invocation of quantization. This model predicts, for example, some properties of the emission spectrum of the Hydrogen and Deuterium atoms. But it can be useful as well in more advanced courses, for example to estimate the energy of electrons states in extrinsic semiconductors and that of excitonic states in these materials [6].

Starting from some basic assumptions (see for example Ref. [7]), Bohr's was capable to deduce the equations that allow the calculation of the radius of the (semi-classical) allowed orbits, and the velocity and the energy of the electron in each of them (the last being consistent with that predicted by the non-relativistic quantum mechanical model). In particular for the speed of an electron in the n-th orbit of a hydrogen-like atom (namely any atom with one electron and a nucleus with Z protons and therefore with a nuclear charge *Ze*, where e is the electron elementary charge) Bohr´s theory leads to the following result:

$$v_n = Z\alpha c/ n \qquad 1)$$

where $\alpha = 2\pi ke^2/hc \sim 1/137$ is the dimensionless fine structure constant [8], h is the Planck's constant, $c$ the speed of light in vacuum, $k=1/4\pi\varepsilon_0$ is the electrostatic force constant, with $\varepsilon_0$ as the electrical permittivity of vacuum, and $n$ is called the principal quantum number, that can take integer values starting from 1, the value corresponding to the electron´s ground state. The same result is also obtained when relativistic corrections are made to the model [9]. Note that $v$ does not depend on the electron mass since the nucleus of our hypothetical atom is much heavier than the electron.

Hydrogen and its isotopes are the only electrical neutral one-electron atoms. The other one-electron atoms are positively charged ions. In particular the elements with $Z > 94$ are all artificial radioactive. Scientists have "observed" their nuclei created for very short time intervals as the result of certain nuclear reactions and nuclear decay processes. They are very heavy nuclei that could only have existed naturally at early states of the universe, or that can be created in some cosmic explosions that could be the source of the kinds of events necessary to produce them.

Suppose a bounded system of such a nucleus and one electron, i.e. suppose that we have a heavy positive ion with atomic number $Z$ and with a unique electron orbiting it in its lower energy state of $n$=1. According to Eq. (1) this electron will then moves with a speed given by

$$v_1 = Zc/137 \qquad (2)$$

Thus, for atomic numbers greater than 137 this electron will move faster than $c$. This is an obviously contradicting result and from it we can conclude that the Bohr´s atom theory predicts 137 as the maximal allowed atomic number and therefore for the number of the chemical elements.

It is worth to be noticed that the start point of the demonstration given here is the Eq. (1), which can be deduced without the need of introducing relativistic corrections, as stated elsewhere [10]. Note also that a more realistic calculation must be realized in the context of a more advanced theory, namely quantum mechanics, and it has to take into account both the nuclear and the electrons charge distribution in a many electrons atom, the electrons magnetic moments interactions such as spin-orbit couplings, nuclear effects, among others. Taking some of these and other effects into account a critical $Z$ of about 172 has been proposed recently [10], but the demonstration is far behind the scope of introductory physics courses and thus of the presentwork.

We hope that this brief article should be helpful to conclude that, although it contains several rough approximations to the physical reality, the Bohr´s model can be useful to show in a first approach that there are physical rules that limit the number of chemical elements that can be synthesized by nature or by man. During the last three centuries, a new element has been discovered on average every three years. Undoubtedly, more will be found and time and research will say the last word about this fascinating subject.

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NOTES

1. http://old.iupac.org/reports/periodic_table/IUPAC_Periodic_Table-21Jan11.pdf

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# ГОРНА ГРАНИЦА НА БРОЯ НА ХИМИЧНИТЕ ЕЛЕМЕНТИ ПО БОР

**E. Marín**

***Резюме***. *Съгласно класическата теория на Бор (1913 г.), броят на химическите елементи в периодичната таблица не може да бъде по-голям от 137. За атомни числа, по-големи от 137, електронът ще се движи със скорост над скоростта на светлината, което е невъзможно.*

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