Mendeleev’s law and Chicherin’s atomic nucleus

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Abstract. The XVII International Conference and the School of Young Scientists "Physical and Chemical Processes in Atomic Systems" were dedicated to the 150th anniversary of the Mendeleev Periodic Table of Chemical Elements. Here we want to draw attention to the influence of Mendeleev's discovery on the development of the first model of the atom, assuming the existence of a nucleus in it. Historically, atomic models were developed on the basis of modern experimental data. W. Thomson's model (1902) uses the discovery of electrons by J.J. Thomson. Nagaoka's (1904) model derives the finite size of atomic nuclei from optical spectra, and Rutherford's (1911) model finds the actual size of nuclei from experimental alpha scattering data. In this work, we recall that it was Boris Nikolaevich Chicherin who proposed the earliest model that assumed the existence of an atomic nucleus. This model was published in a series of articles in the journal of the Russian physio-chemical society in 1887-1892. The model was based on a complex mathematical analysis of Mendeleev's law, specifically on the periodicity of experimental data associated with atomic specific volumes, and made it possible to predict the existence of a central positively charged nucleus and a negatively charged periphery of an atom. We must pay tribute to Chicherin and recognize his model as the earliest model of the atom, assuming the presence of an atomic nucleus in it.

Dmitry Ivanovich Mendeleev published his first version of the periodic table of chemical elements 150 years ago, in 1869, in the article "Relationship of properties with the atomic weight of elements" [1]. He suggested that the properties of elements depended on their masses. The modern interpretation of the periodic table of chemical elements (Periodic Table) establishes the dependence of the properties of elements on the charges of the atomic nucleus. The discovery of the periodic law by Mendeleev was a breakthrough in chemistry, which made it possible not only to order the known chemical elements, but also to predict the existence of new elements and their properties. Less well-known is the fact that the periodic law was used in the 19th century to predict the complexity of the structure of atoms, in particular the existence of a positively charged nucleus and negatively charged shells. The authors of world textbooks on atomic and nuclear physics attribute the first ideas about the modern structure of atoms to the works of Hantaro Nagaoka, published in 1904 [2], and Ernest Rutherford, published in 1911 [3]. In a monograph on the history of atomic models in the context of quantum physics [4] - Hentschel calls Nagaoka's "Saturnian Model" "the earliest published quasi-planetary model of the atom." Later, Inamura [5] argued that the models of Nagaoka and Rutherford are in fact identical, and discussed the issues of the correct presentation of the history of an atomic structure study in physics textbooks. Nagaoka and Rutherford developed their models using experimental data. Nagaoka based his model on observing the
structure of the optical spectra of atoms, while Rutherford in his model explained the results of scattering of alpha particles by the existence of a "central positive charge" less than $10^{-12}$ cm in size. It is curious that the terms "atomic nucleus" and "planetary model of the atom" appeared not in Rutherford's article, but in a very competent review of this article. Soviet and Russian physics textbooks follow the same tradition. However, in several sources (for example, [6,7]), as well as, what is remarkable, in the physics history course and textbook by Boris Ivanovich Spassky [8] (which was taught for many decades to students of the Physics Faculty of the Lomonosov Moscow State University) a model is mentioned for an atom containing a nucleus that was proposed in 1887 by one of the most famous Russian intellectuals Boris Nikolaevich Chicherin [9]. This earliest planetary model of the atom, assuming the existence of an atomic nucleus, was proposed and substantiated in a series of articles published in 1887-1892 in the journal of the Russian physico-chemical society, the leading natural science journal of the Russian Empire [10].

Chicherin's model of the atom had also been based on a mathematical analysis of experimental data on the periodicity of specific volumes of atoms from the periodic table, which made it possible to predict the existence of a "central positively charged massive nucleus" and a "negatively charged compressible periphery" ("circles") of the atom. This model was highly appreciated by Mendeleev, as well as by the famous Russian physicist Alexander Grigorievich Stoletov. On Mendeleev's recommendation, Chicherin was elected an honorary member of the Russian physico-chemical society. Chicherin was also elected a member of the physics department of the Society of natural science amateurs, which was headed by Stoletov. Subsequently, Chicherin's contribution to the study of the structure of the atom did not receive a proper assessment by physicists, but was repeatedly noted in publications on chemistry in the USSR.

Investigating the decrease in the specific volume of alkali metal atoms, Chicherin came to the conclusion about the inhomogeneity of the distribution of matter over atoms and for the first time made a conclusion about the existence of an atomic nucleus [9]. When constructing the model, Chicherin carefully studied the course of theoretical physics written by William Thomson (Lord Kelvin) and Peter Tait [11] (in fact, its translation into the German maid by Hermann von Helmholtz and G. Wertheim), and linked his considerations with the description of the displacement of the ocean surface on the Earth's surface due to the influence of the Moon. Chicherin made further conclusions on the basis of careful calculations using the formula for this displacement, which depends on two masses - the central core (Earth) - probably Chicherin simply used the term core from the book by Thomson and Tait - and remote object (the Moon corresponds to the shell). Studying the complete periodic table and comparing the position of elements in the table with their mass density led Chicherin to the conclusion that "all the difference between atoms depends on the amount and distribution of the substance in them ... The starting point of the study is the obvious fact that in each row … of the periodic system ... with increasing weight and volume, the density also increases, that is, the volume of each unit of matter that is part of the atom decreases ... to separate from the center "([10], Chapter VII, pp. 232-233). In another place he writes: ",... the mass on the circle does not merge with the central nucleus, but is at some distance from it ..."
Figure 1. Fragment from the paper by Chicherin [9] with the citation from the book by Thomson and Tait [11].

The larger the central core, the more particles are attracted to the center, and the more, due to the approach, the volume of each unit decreases, that is, the more compression occurs. On the contrary, the greater the mass of the circle (shell), the more particles are repelled from the center and the more they diverge, that is, the stronger the rarefaction is. Calculating the “volume loss” of atoms, he comes to the conclusion:

"An atom consists of four components: 1) the central nucleus; 2) a circle (shell); 3) the distance between them, which determines its volume; 4) and the neutral belt, later inserted into this intermediate space. The main factors, without which there is no atom, are the nucleus and the circle; the distance between them represents their formal relationship; the neutral belt is formed as a result of their interaction" ([10], Chapter IV, p. 164).

Analyzing the change in the density of chemical elements in the periodic table and their chemical properties, Chicherin comes to the conclusion that in the atom "... the central elements are electrically positive, and the peripheral ones are electronegative ...". That is, "... an atom with its central core and bodies revolving around it is an analogy with the solar system" ([10], Chapter IV, p. 170). He also concluded that the shells are negatively charged and the nucleus of the atom carries a positive electrical charge, based on an analysis of two forms of corona discharge, in which a metal tip was connected to either the cathode or the anode of electrophoretic machine. As a result, he makes a generalization:

"So, in the construction of the solar system we find a complete analogy with the system of chemical elements. ... The atom is a microcosm, the universe in a small form."

And that was written at a time when nothing was known about either the electron or the proton (finally discovered by J.J. Thomson in Cambridge in 1897 and 1906, respectively), or the neutron (discovered by D. Chadwick in 1932).

With the help of his model, Chicherin was able to numerically describe the densities of all chemical elements known at that time. It is important to note that Chicherin, like Mendeleev, assumed that the properties of an atom can only be described on the basis of its atomic weight. In Chicherin's model, not
only the nucleus was massive, but also the atomic shells. Chicherin also considered lithium to be the nucleus of sodium, potassium and cesium. However, he also came to the conclusion about the complex structure of the shells, for example, Chicherin presented the lithium atom as containing a positively charged nucleus and three negatively charged shell elements.

What is more remarkable that the very nucleus of the atom was considered by Chicherin as a complex object [10]:

“If the core formed a continuous homogeneous mass, then the rarefaction, naturally, would consist in expansion in all directions. But it is composed of separate, albeit connected together, elements”.

Thus, Chicherin's model was the first model in which an atom is represented by a complex structure with a compound positively charged nucleus and negative shell elements. Once again, we note that the subsequent nuclear models of the atom, proposed by Nagaoka, Rutherford and Bohr, were built, like the Chicherin model of the atom, on the basis of experimental data - the structure of the optical spectra of atoms and the results of alpha radiation scattering particles. The discovery of the electron by Joseph Thomson in 1897 and the determination of its insignificant mass ruled out the idea of the massiveness of the atom negative shells in Chicherin's model, but retained the idea of their existence.

It should be emphasized that Chicherin was not a physicist. However, his elaborate not speculative model anticipated further discoveries of the structure of the atom. Such events in the history of physics and chemistry have met before - one of the creators of the energy conservation law was the doctor Julius von Mayer. Describing the method of his research, Chicherin writes:

“And this harmony belongs to her [model] not by virtue of any theoretical or artificial construction. The impartial reader could be convinced that in the previous study we did not start from any preconceived thoughts and even less from any metaphysical principles. We didn't even make any hypothesis; trying to reveal mathematical relations between experimental data, we simply asked questions, and calculations gave us answers to these questions” [10].

Logic, according to Chicherin, is "the first and basic science that gives law to everyone else." Not forgetting about the "shoulders of giants", Chicherin concludes the penultimate chapter with the following words [10]:

![Figure 2. Portrait of Chicherin (V.O.Shervud).](image-url)
“It is impossible not to end this chapter with the words of Mendeleev: “as the world of celestial bodies with its suns, planets and satellites, animated by the eternal living force of motion, forming particles, as celestial bodies form systems similar to the solar system”, and are indivisible only relatively, since the planets of the solar system are indivisible, and stable and strong, as the system is strong in the world.”

In these Mendeleev’s words, the influence on Chicherin's work is obvious.

In conclusion, there are a few more words about the author of the discovery of the planetary model of the atom. Boris Nikolaevich Chicherin went down in history as a lawyer, historian, philosopher, sociologist, i.e. scientist-encyclopedist; as an honorary member of the St. Petersburg Academy of Sciences, head of the Moscow circle of Westernizers, the founder of the state school in Russian historiography, a supporter of the constitutional monarchy, the author of works on the history of state and law, political doctrine, which are a model of scientific and social thought.

Chicherin was the first Russian scientist to develop the basic principles of political science, that is, politics as a science. He defines it as “the science of achieving state goals”, substantiates the decisive role of the state in the history of Russia.

After being removed from the post of head of Moscow for a speech during the coronation of Tsar Alexander III, in which the authorities saw a call for the introduction of a constitution, he retired to his estate near Tambov and devoted the last 20 years of his life to science. Chicherin died in 1904 when Nagaoka wrote about the nucleus of the atom in his work.

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