Bulletin of National University of Uzbekistan: Mathematics and Natural Sciences

Volume 2 | Issue 2 Article 2

6-6-2019

Periodic table of elements, Mendeleev's periodic table: history, achievements and problems

Boris Oksengendler
National University of Uzbekistan, Center for Nanotechnology Development NUUz, oksengendlerbl@yandex.ru

Kamil Mukimov
National University of Uzbekistan, Center for Nanotechnology Development NUUz, kmukimov@mail.ru

Renat Letfullin
Rose-Hulman Institute of Technology, letfulli@rose-hulman.edu

Nigora Turaeva
Webster University, nigoraturaeva82@webster.edu

Gulmurza Abdurakhmanov
National University of Uzbekistan, Center for Nanotechnology Development NUUz, Scientific and Technical Center of AG Uzbekenergo, gulmirzo@mail.ru

Recommended Citation

Oksengendler, Boris; Mukimov, Kamil; Letfullin, Renat; Turaeva, Nigora; Abdurakhmanov, Gulmurza; and Yuldashev, Shavkat (2019) "Periodic table of elements, Mendeleev's periodic table: history, achievements and problems," *Bulletin of National University of Uzbekistan: Mathematics and Natural Sciences*: Vol. 2 : Iss. 2 , Article 2.
Available at: https://uzjournals.edu.uz/mns_nuu/vol2/iss2/2

Periodic table of elements, Mendeleev's periodic table: history, achievements and problems

Authors

Boris Oksengendler, Kamil Mukimov, Renat Letfullin, Nigora Turaeva, Gulmurza Abdurakhmanov, and Shavkat Yuldashev

This article is available in Bulletin of National University of Uzbekistan: Mathematics and Natural Sciences: https://uzjournals.edu.uz/mns_nuu/vol2/iss2/2

Volume 2, Issue 2 (2019)

To the 150-anniversary of periodic table of elements by D. Mendeleev

PERIODIC TABLE OF ELEMENTS, MENDELEEV'S PERIODIC TABLE: HISTORY, ACHIEVEMENTS AND PROBLEMS

Oksengendler B.[1,2], Mukimov K.[1,2], Letfullin R.[3], Turaeva N.[4],
Abdurakhmanov G.[1,2,5], Yuldashev Sh.[6]
[1]*National University of Uzbekistan, Tashkent, Uzbekistan*
[2]*Center for Nanotechnology Development NUUz, Tashkent, Uzbekistan*
[3]*Rose-Hulman Institute of Technology, Terre Haute, USA*
[4]*Webster University, St. Louis, USA*
[5]*Scientific and Technical Center of AG Uzbekenergo, Tashkent, Uzbekistan*
[6]*Nano-Information Technology Academy (NITA), Dongguk University, Seoul, Republic of Korea*
e-mail: `oksengendlerbl@yandex.ru`, `kmukimov@mail.ru`,
`letfulli@rose-hulman.edu`, `nigoraturaeva82@webster.edu`,
`gulmirzo@mail.ru`, `shavkaty@yahoo.com`

Abstract

This paper, devoted to the yubilee of Mendeleev's table, deals with a set of historical and physico-chemical problems related it. Basing on the evolutional approach to the development of the concept of "elements and structure" and up to the appearance of the notion "complexity" we discuss the applicability of Mendeleev's table to the understanding of modern aspects of science such as "nano", "fractals", "synergetics" and "hirality". The problems which are open for further research are revealed and the particular importance of their development for the condensed matter science of living and nonliving matter is pointed out.

Keywords: periodic table of elements, history, nanoelectronics, nanomedicine, mu-catalysis, chemistry, radiation physics, Au-nanocatalysis, intermediate valency, synergetics, chirality.

Physics and Astronomy Classification Scheme: 05.65.+b, 36.10Gv, 61.46.+w, 73.63.-b, 81.07.Wx, 82.65.+r, 87.23.Kg

1 History of the problem "Elements and Structure"

The history of science knows and pays tribute to the profound maxims formulated by major thinkers. One of them is the idea put forward by the leading French mathematician Henri Poincaré (1854-1912), who wrote that no set of important particular results can replace a deep generalizing idea which determines the transition to a new level of knowledge.

Undoubtedly, precisely such a large concept is the idea of "elements and structures", manifested by maximum efficiency in periodic table of D.I. Mendeleev, published 150 years ago.

The idea of "a small number of elements on which all structures are built" oneself appeared in ancient times, apparently, from the time of Empedocles (483-423 BC). In those days, this idea of elements was a Natural minimum, i.e. a reachability limit below which an object already lost its properties. Then it was believed that there are four types of elements: water, air, earth, fire. However, Democritus (460-370 BC) and Aristotle (384-322 BC) soon came up with the ideas of atoms (always the same for all objects, which served as the building material for these objects). In parallel, the idea of a certain duality of properties was discussed: hot/cold, wet/dry, so such a system was considered sufficient for a full description.

These positions migrated to the Middle Ages, where they were used in the natural philosophy of Islam and Christianity. The basic position of that time was the concept of "sulfur-mercury" (Arab scientists-alchemists, who introduced these concepts into the Latin world). In those centuries, representations of cold/wet were associated with sulfur, and hot/dry with mercury. Subsequently, Paracelsus (1493-1541) supplemented the concept of sulfur/mercury by adding a third element – salt, which made it possible to sharply expand various objects for analysis. In those days, this "triad" surprisingly harmonized with the concept of the Trinity (father, son, and holy spirit), which strengthened the belief in the reliability of such a general approach. The next important step belonged to the French: the priest Pierre Gassendi (1592-1655) and the mathematician and natural philosopher Rene Descartes (1596-1650), combining the ancient ideas of atomism with rapidly developing ideas of mechanics (it was about "contacts between elements"). Such principle was very successfully adapted by the physician and mystic Jan Baptist van Helmont (1580-1644), who applied it to the phenomena of solubility. An exceptionally important further step belonged to the physicist and theologian Robert Boyle (1627-1691) (monograph "The Skeptic Chemist", 1661), who introduced the idea of corpuscles.

These ideas on the element-structure problem were masterfully applied by many chemists and physicians, which gradually brought the ideas of atomism to the most advanced positions of the science. An enormous role was further played by a whole group of scientists: the Bernoulli Brothers (1655-1705, 1667-1748), Amedeo Avogadro (1776-1856), Antoine (1743-1794). Lavoisier has fully accepted Boyle's doctrine of the elements, but knew how to isolate them from chemical compounds; he was apparently the first to compile a table containing about thirty elements (Fig. 1). Over the next hundred years, the work of many chemists replenished the Lavoisier table.

So, one can note the figure of the "king of chemists" Jens Jakob Berzelius (1779-1848), who discovered selenium, thorium, lithium, vanadium, and some rare earth elements; He also owns the modern designations of chemical elements (based on Latin and Greek). In the XIX century, when it became clear that the number of elements was more than 60, attempts were made to classify them. In this regard, it is necessary to note the attempts of Döbereiner (1817), Pettenkoffer (1850), Gladstone (1853), Odling (1857), de Chancourtois (1863), Newlands (1865) and, especially Lothar Meyer (1830-1895). Their activity was connected with the search for a set of properties that would pass from element to element, and at first there was clearly not enough "number", for, as Immanuel Kant later wrote: "Only number can lead to science”.

And such two numbers were distinguished: the atomic weight of the element and its valency (the latter was understood as the number of bonds of each element with others). The honor of introducing the most important number - “atomic weight” fell to John Dalton (1766-1844), who deeply and diversely studied the concept of an element, which he defined as “a substance consisting of atoms of one species” (1804-1808 - namely in the last year of this creative period, his famous book, The New System of Chemical Philosophy, was published). The concept of the molecule and its difference from the atom was enshrined in a special resolution of September 4, 1860 (Stanislao Cannizzaro). It is interesting to note that the creative credo of all the aforementioned scientists was to a certain extent contrary to Newton’s ideology (“I do not make hypotheses” - and they did!). They thought up a whole system of knowledge about atoms, which themselves at that time were super-hypothetical. Here it is: brilliant collective thought! Using these two numbers and a huge database of chemical properties and transformations, a number of scientists, inclined to deep generalizations, set about building a common system of elements.

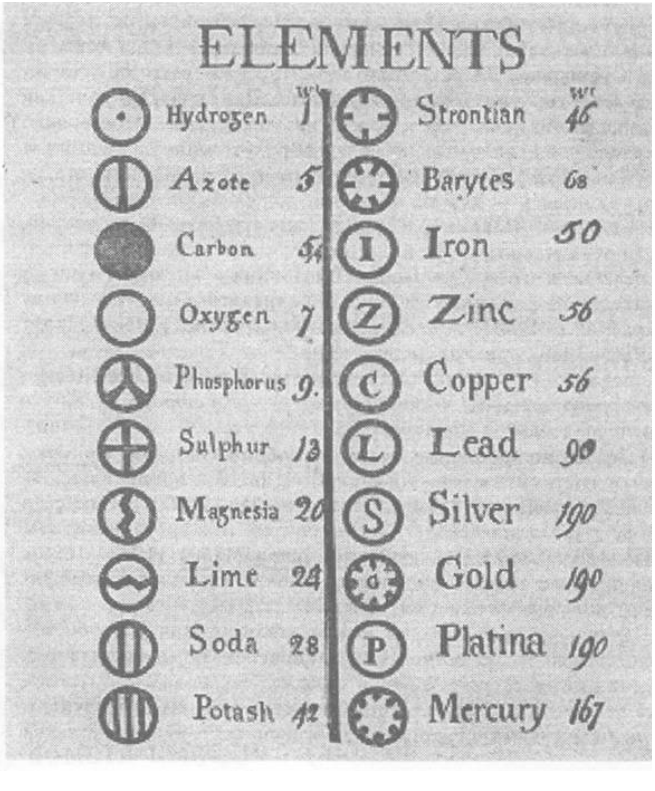

Fig. 1

Among this galaxy, the most important role was assigned to the Russian scientist physicist-chemist D.I. Mendeleev (1834-1907) and the German physician Lothar Meyer (1830-1895); both by that time were already known for their tremendous achievements in the sciences of matter. In fantastic competition, through titanic efforts, both of these people decided, as it is now customary to say, an “incorrect task" - for their purposes, however, there was clearly not enough data on a number of elements, moreover, they simply were not open! And in 1869 such a table (or rather, one of its most successful versions) was published by D.I. Mendeleev.

Let us plunge into the past and borrow a few lines from Google: "On February 17 (March 1), the manuscript of the article containing a table entitled "Experience in a system of elements based on their atomic weight and chemical similarity" was completed and put in print with notes for typesetters and with the date "February 17, 1869". The report on the discovery of Mendeleev was made by the editor of the Russian Chemical Society, Professor N. A. Menshutkin at a meeting of the company on February 22 (March 6), 1869. Mendeleev himself was not present at the meeting, because at that time, on the instructions of the Free Economic Society, he examined the cheese dairies of the Tver and Novgorod provinces." We will not dwell on its structure - people now know this, starting from high school, but it must be said that the missing empty cells in the periodic table were very soon filled with newly discovered chemical elements. In terms of "signs of the theory's correctness", developed later by Albert Einstein in letters with his friend Moris Solovin (May 7, 1952 onwards), the periodic table demonstrated the so-called Einstein's "external justification", but another theory requirement ("internal perfection") came much later - only after the creation of quantum mechanics (N. Bohr, V. Heisenberg, E. Schrēdinger, P.M. Dirac, and others (1925-1927)), which explained the structure of atoms and molecules. It became clear how deeply the periodic table anticipated the foundations of the structure of matter.

Currently, the periodic table is recognized as the unshakable foundation of the structure and transformations of matter of both inanimate and living Nature: physics, chemistry, biology, medicine. Despite this, people armed with a history of the development of scientific ideas sometimes doubt creep in - is the periodic table with its colossal number of applications unshakable everywhere and forever? This question is all the more important to answer, because, starting from about the last third of the twentieth century, areas began to emerge very rapidly as the crossroads of various sciences. Could we not expect at these crossroads surprises associated with the omnipotence of the periodic system of Mendeleev? Below we will offer and discuss a number of examples, where, as it seems to us, this omnipotence raises suspicion and even doubt, and indicates that these ideas are open to development.

2 Chemical phenomena and nuclear physics

There was nothing known in the time of D.I. Mendeleev about the existence of the nucleus, of course, and therefore all chemistry was reduced to a certain general atomic substance. Discovery of electron by J.J. Thomson (1897), nucleus by Ernest Rutherford (1911), and after them - the formation of all nuclear physics, including nuclear fusion reactions, could be considered completely separate from all that associated with valence electrons, i.e., in framework of ordinary chemistry, but a wide range of elementary particles, obtained by the middle of the 20th century, opened up completely new opportunities for chemical processes.

Mu catalysis. In 1936, K. Anderson discovered the μ-meson, which is a particle having a mass 200 times greater than the mass of an electron, but with the same negative charge. By this time, the quantum problem of complex systems consisting of light and heavy particles (the Born-Oppenheimer theorem) had already been studied, i.e. theorists understood how the geometric and electronic structures depend on the mass ratio of light and heavy particles. Niels Bohr and then Schrëdinger calculated the radius of an electron in the first orbital as it moves around the proton $r_1 \sim 1/m_e$. This radius is about 0.53 Åfor electron rotating around a proton; if the electron is replaced by a μ -meson, then the radius is about 1/100 Å. These numbers mean that the Coulomb field of the hydrogen atom with electron and with the muon is felt as 1/100 at a distance from the nucleus. This simple thought led the prominent American theorist F. Frank (1884-1966) to an interesting thought about a special way of carrying out the synthesis of helium atoms from hydrogen isotopes, which should be accompanied by a huge surge of energy (for example, by the reaction D + T -> He^4 + n + 17.6 MeV; other synthesis reactions are possible with the release of lower energy). If we follow the generally accepted path of thermonuclear fusion, it turns out that the mechanism of fusion of the deuterium and tritium nuclei is the so-called quantum tunneling through the barrier, which is reduced by preliminary heating to a temperature of 10^8 K (Fig. 2).

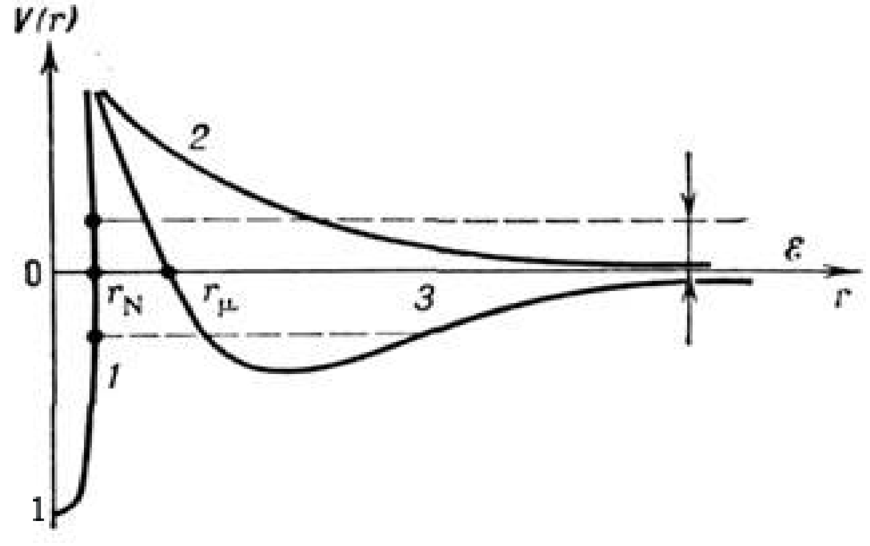

Fig. 2. Schematic representation of the potential energy V of the interaction of nuclei depending on the distance r between them: 1 - strong attraction at small distances $\sim r_N$; 2 - Coulomb repulsion at large distances; 3 - interaction of nuclei in a muon molecule; there is an attraction region $V(r) < 0$ for $r > r_m \gg r_N$.

3 Radiation physics and Mendeleev's table

Another feature of the time in which Mendeleev created was ignorance of the existence of electrons and their distribution over electron shells, i.e., in the classical understanding of chemistry, all chemical processes were associated with the outermost valence electron shell. But what about the other deeper shells? What brings their participation into chemistry (when it is possible)? It turned out that the excitation of these deep electron shells by external radiation is an extremely strong factor in modifying the totality of chemical processes.

The paradox of the elemental composition of living matter. Many years ago, biologists were struck by the fact that the elemental composition of a living matter can be clearly divided into "leaders and outsiders." The former understood elements such as hydrogen (H), carbon (C), nitrogen (N) and oxygen (O). They were the overwhelming participants in the structure of living systems; the remaining representatives of the periodic table were in an undoubtedly smaller proportion. What is the nature of such a filter? This circumstance, which even received the status of a paradox, was especially pronounced for elements C and Si. Indeed, in fact, all life turned out to be carbon, and this despite the almost complete closeness of the chemical parameters of C and Si, the latter being found in nature three hundred times more often. The first productive solution to this paradox was proposed by the Moscow biophysicist G. Ivanitsky (2012), who believed that such a filter was water, which selected carbon for living systems of long molecules using hydrolysis reactions, effectively breaking long silicon-based molecules and weakly acting on carbon base long molecules. Despite the elegance of this idea, it did not become a unified solution to the problem of "leaders and outsiders" (indeed, hydrolysis was especially effective only for C and Si). Another idea – a "radiation filter" – was put forward by Tashkent scientists (2017), who focused on the fact that all "leaders" were elements of the second period of the periodic table, and "outsiders" were of more distant periods (third and further). The quantum theory of atoms immediately indicated the difference between the second and higher periods (the latter had extra subshells). What factor that has been active throughout the entire evolutionary period was sensitive to the number of subshells? Well, of course, radiation, which was "always"! And through the so-called Auger effect, it strongly separated chemical processes involving valence electrons of elements of the second period and elements of more distant periods. Indeed (Fig. 3), it can be seen that after ionization of the deepest K-shell of carbon and silicon, the entire external structure of the electron shells "falls through" differently into the formed empty states (the so-called holes in orbits): in carbon, as a result of such a process, it breaks one chemical bond, while silicon breaks both chemical bonds. The living system does not tolerate unnecessary participants and throws them out of itself. Thus, silicon chains break systematically, while carbon chains are easily restored. It is interesting to note that this so-called Auger effect or Auger cascade, named after the physicist Pierre Auger, who discovered this phenomenon, is the standard systematic reaction that occurs in all people undergoing X-ray irradiation in clinics. Moreover, these phenomena of the "collapse" of electron shells into holes formed in deep electronic orbits are terrifyingly called "Rare Disasters". It is clear from this how unacceptable that these rare catastrophes occurred often with an overabundance of X-ray research.

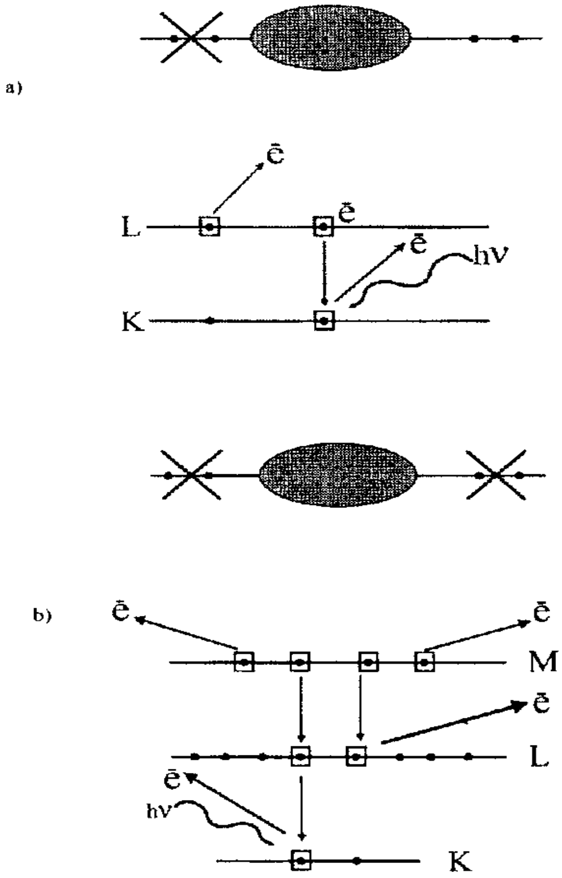

Fig. 3. The effect of X-ray radiation on C (*a*) and Si (*b*)

4 Nanotechnology and the Mendeleev's table

Fractal Au nanocatalysis. In the last quarter of the 20th century, after the epochal speech of the great American physicist Richard Feynman, regarding the secrets of Nature, lurking in the field of substance sizes from 5 to 500 nanometers, studies of living and inanimate matter began to gain great scope, where some discoveries after others just famously appeared, and where chemistry and molecular physics dominated strikingly. This whole area, called "nanotechnology", began to "speak" in a new language, where the terms such as "nanoscale", "fractals", "low-dimensional systems", "chiral symmetry", "non-linearity", "instability", "attractors", "synergetics" were most often repeated. It was found that the symbiosis of these properties and experimental conditions almost guaranteed a lot of paradoxical phenomena. Specialists began to call this area of astonishing condensation of sciences with one term - "complexity". The events in nanocatalysis turned out to be surprisingly indicative.

So, in 1985, the Japanese physicist-chemist Haruto, by some strange influx, decided to check the super-established thesis – is gold really noble, even if its piece is reduced and reduced to nanoscale. Haruto tested this thesis for the possibility of catalyzing a chemical reaction of complete oxidation ($CO+O_2 = CO_2$). It turned out that with a decrease in the size of a piece of gold to 7 nanometers, it completely lost its “nobility” and turned into a fantastically strong catalyst. These studies were picked up by many experts, but the Irishman Hudchings (2002) was significantly successful, having sharply expanded the range of catalyzed reactions - a new, extremely fruitful direction appeared – nanocatalysis. It is not surprising that many theoretical teams rushed to explain this paradox (indeed, why the gold over 7 nanometers obeys the rules of the periodic table, and less than 7 nanometers suddenly stops doing this?), including a group of Professor Norskoff, our fellow countrymen from the Institute of Polymers, as well as a former employee of this Institute, Doctor of Sci. N. Turaeva (from the USA). However, despite the tremendous computational capabilities, Norskoff failed to explain the main test of the effect (increase in catalytic activity with a decrease in the size of a piece of gold in the cube), but the group of our fellow countrymen was more fortunate, and it’s believed (so far?!) that the combination of explanation by B. Oksengendler, N. Turaeva and colleagues are far more acceptable. At the same time, one very important circumstance turned out to be characteristic here – when solving a serious problem, “along the way” there are always a lot of new results, maybe without direct hits. And this, first of all, should be attributed to the Norskoff group, which succeeded in virtually all of nanocatalysis, unfortunately, except (alas) the mechanism of gold nanocatalysis. In this regard, there is another important circumstance: a group of Tashkent citizens thought, in addition to reducing a piece of gold, to discuss the role of the corrugation of its surface – the so-called fractality. The theory showed a significant increase in the effect (Fig. 4), so now this direction has become known as “fractal aurumnanocatalysis”. Moreover, in fact, it was from these studies that a new nano-field, which was called “nanofractals”, was generally developed (it is very pleasant that our fellow countrymen have an absolute and recognized priority here).

Intermediate valency. The valency of chemical elements is defined as a positive integer reflecting the number of chemical bonds with which a given atom is connected to other atoms [1]. It follows from the construction of the periodic table that the valency of the atoms of the elements corresponds to the group in which they are located. Therefore, valency cannot be zero or greater than eight. For example, in a water molecule H_2O, the hydrogen atom is monovalent, and the oxygen atom has a valency equal to 2. However, when studying the compounds of rare-earth metals and actinides with uncompleted 4f and 5f shells, it was found that formally their valency is fractional. Examples are compounds UBe_{13} (formally according to this formula the uranium valency should be equal 26), $CeAl_3$ (cerium valency is 9), $LaAl_3$, $GdAl_3$, UCd_{11}, U_2Zn_{17} (lanthanum, gadolinium and uranium valency is equal to $5\frac{2}{7}3$) and many others [2]. Such a discrepancy between the apparent valency and position of these atoms in the periodic table is due to the crystal structure of the compounds: in UBe_{13}, uranium atoms form [3] a cubic lattice (Fig. 5a), in the center of which there is an icosahedron of 12 Be atoms, and the thirteenth Be atom is walled in the center of the icosahedron. Truly, “there is an egg in a chest, and a needle in an egg”! However, it is not clear how the 12 divalent beryllium atoms are related to each other and how the thirteenth is related to them.

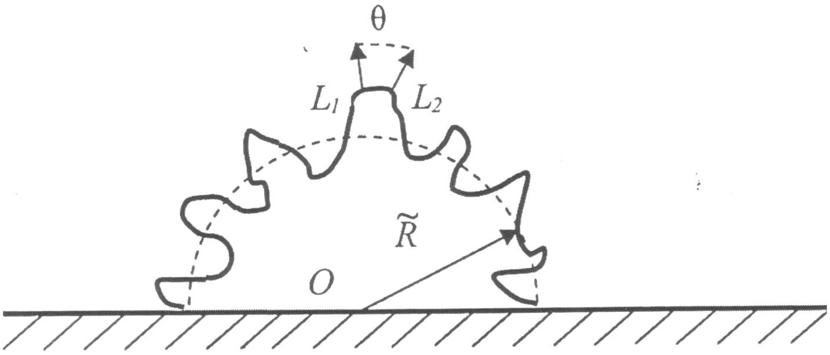

Fig. 4. Fractal Au nanocatalysis. The effect is due to a sharp increase in reactivity due to extended electronic orbitals on the fractal surface

In $CeAl_3$ [4] with a hexagonal structure, cerium atoms are surrounded on three sides by aluminum atoms (Fig. 5b) and have one bond with each of the aluminum atoms. But the miracles of these compounds are not completed with valency. It turns out that almost all of them are compounds with heavy fermions [2] – the effective mass of electrons in them is up to 1000 times (!) more than the mass of a free electron. It turns out that the electrons in them are free with fetters on their feet - they are not tied to anywhere, but they can’t run! Such a combination of properties together with nanostructuring is very interesting for developing of new thermoelectric materials.

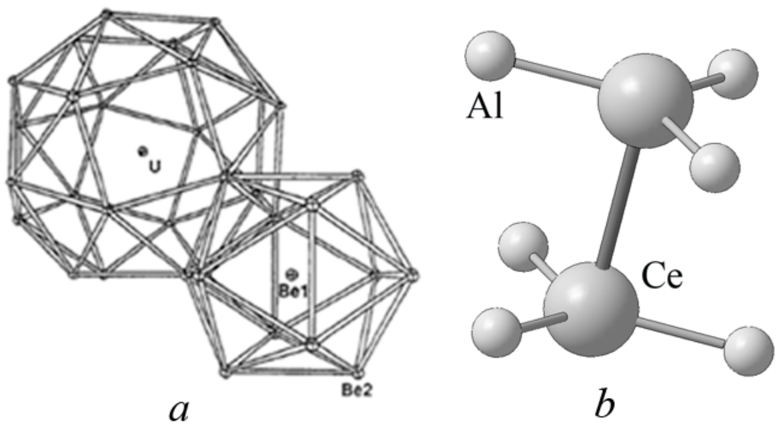

Fig. 5. (a) Structure of the UBe_{13} compound (only one U atom located at the top of the cube is shown) [3]. (b) Structure of the $CeAl_3$ compound [4]

Here we should also mention the record holder for a variety of valencies – a noble metal of ruthenium, which, in addition to eight valencies in different compounds, also exhibits a forbidden zero valency in $Ru(CO)_5$ [5],[6]. So believe nobleness of noble after that!

Another example where valency is not observed is silicate glass [7]: the absence of a crystal lattice (symmetry requirements in the arrangement of atoms and molecules) in which the hands of atoms and molecules are untied. So, SiO_2 and PbO form a homogeneous, transparent and colorless glass (Fig. 7) at any PbO content up to 90% by weight. What are the valence ratios!

Fig. 6. Silicate glass sample of composition $2SiO_2 \bullet PbO$

Nanoelectronics. Currently, a new word – nanoelectronics – has become popular and widely used. What is it and how does it differ from conventional electronics? The term “electronics” is associated with an electric current, which is a stream of electrons under the influence of, for example, an external voltage applied to the device. Why then do you need the prefix “nano”? The term nanoelectronics is associated with the use of nanotechnology in the manufacture of electronic components. These components are several nanometers in size. Nanoelectronics are a field of knowledge that covers, among others, subsections such as spintronics, topological insulators, and electronics based on low-dimensional carbon (carbon nanotubes, graphene).

We also know that electrons, like other fundamental particles, obey the laws of quantum mechanics. However, in the case of conventional electronics, there is no urgent need to take quantum effects into account, apart from the fact that the electrons obey the Fermi-Dirac distribution. The transport and dynamics of such electrons can be adequately described using semiclassical equations of drift and diffusion, which depend on macroscopic properties such as mobility and conductivity. Indeed, in micron-sized devices such as conventional metal oxide semiconductor (MOS) field-effect transistors, the Fermi-Dirac distribution, and the semiclassical diffusion-drift model are all that is needed to describe the physics of electron transport under the applied voltage, while nanoelectronics needs the use of quantum physics in instruments and electronic devices.

In nanoscale systems, quantum-size effects become noticeable, leading to the appearance of electronic subbands and the tunneling effect. For example, quantization of electron energy and the absence of continuous states at a zero-dimensional quantum dot lead to new transport properties where the electron flux is no longer described by the usual current-voltage characteristic, corresponding to Ohm's law.

Many new band structures or subbands arising due to geometric modification or size reduction lead to a change in the spin-orbit interaction, which in turn leads to topological properties in electron transport (quantum Hall effect, quantum spin-Hall effect, etc.).

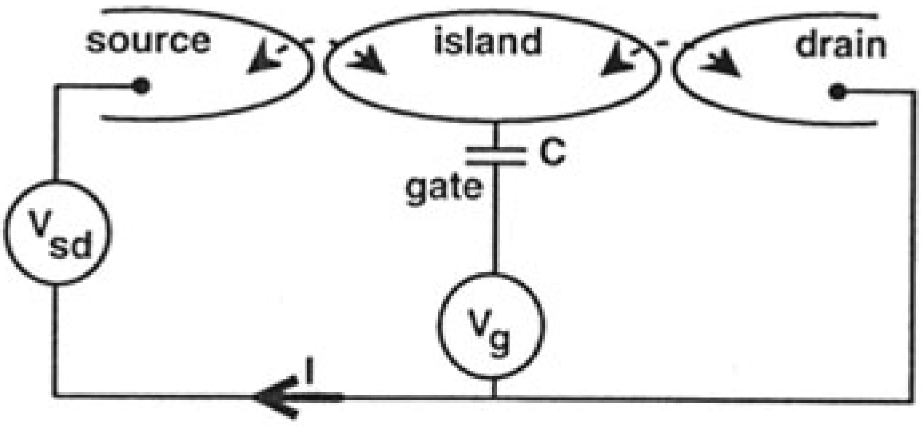

Fig. 7. Schematic illustration of a single-electron transistor

Due to the size reduction of the devices, the tunneling current through the oxide barrier, which is a purely quantum-mechanical phenomenon, can no longer be ignored. As the size of the instruments decreases, it becomes possible for electrons to flow through the device without scattering. Ballistic transport becomes important and the motion of electrons can be described in terms of the wave function or non-interacting Green function.

The reader may ask how all of the above can be connected with the periodic table, and what is nanoelectronics here? The fact is that properties of metal and semiconductor nanoparticles (quantum dots) are similar to atoms, which is why they are often called “artificial atoms”.

In Fig. 7 schematically represented a single-electron transistor [8] based on a metal quantum dot, two current electrodes: a source and drain, as well as a potential gate electrode. Current electrodes are separated from the quantum dot by metal oxide potential barriers.

When electrons tunnel from the source to the quantum dot and then to the drain, the electric current changes discretely due to the discrete nature of the charge. When relatively high energy barriers separate the quantum dot from the source and drain electrodes, tunneling through the quantum dot is weak and the number N of electrons in the quantum dot will be well defined by an integer. The electric current flowing through the tunneling of single electrons through a quantum dot will cause a change in the number of electrons in the quantum dot per unit. The Coulomb repulsion between electrons in a quantum dot results in a significant expenditure of energy to add an additional electron charge. Therefore, additional energy is required, and the current will not flow until an increase in voltage provides this energy. This phenomenon is known as the Coulomb blockade.

Due to the Coulomb blockade, a current can flow only when the electrons on the electrodes have energy enough to occupy the lowest possible energy state for $N + 1$ electrons at a quantum dot. By changing the voltage at the gate, the ladder of energy states in the quantum dot shifts through the Fermi levels on the electrodes. This leads to a series of sharp peaks of the measured current (Fig. 8a).

Fig. 8b shows the allowed orbits of electrons in a quantum dot. The orbit with the smallest radius corresponds to the lowest energy state. This state corresponds to an angular momentum equal to zero, and as in the case of the s-state in an atom, it can include two electrons with opposite spins. Additional energy ΔE is required in order to add a third electron, since this electron must go to the next energy level. The electrons in this new orbit have an angular momentum of ± 1 and two spin states, so this second level can contain 4 electrons. Thus, such filling of energy levels can be represented in the form of a periodic table similar to the Mendeleev's table (Fig. 8c).

"Artificial atoms" created using nanotechnology, allow you to simulate the behavior of real atoms when super-strong magnetic and electric fields are applied, which are difficult to achieve for real atoms. The quantum nature of electronic states in nanostructures can be used to create quantum computers that possess properties unattainable with conventional computers.

Nanomedicine. It can be argued that chemistry represents the most commonly shared branch of science and engineering among the various disciplines, including physics, biology, materials, spectroscopy and lasers/optics – hence its descriptor of centrality. To fully understand and appreciate any field of science (pure and applied), being grounded in Mendeleev Periodic System of Elopements is essential.

Chemistry is often the glue that connects various fields in an interdisciplinary manner, and gaining an understanding of the principles of chemistry helps with learning and defining principles in other areas. An example is the role of energy, where descriptions of spectroscopic processes in molecules and chemicals are similar to those in solid-state physics, but associated with different energy regimes: transition energies in chemistry typically fall on the electron volt (eV) scale, whereas they fall on the meV scale in solid-state physics. What are called the highest-occupied and lowest-unoccupied molecular orbitals in a molecule corresponds, respectively, to valence and conduction bands in solid-state physics, with the Fermi level occurring in both cases. Analogously, the transitions occur on different time scales, where the time decreases as the transition energy increases. An interesting and fun book to read along these lines was published three decades ago by 1981 Chemistry Nobel Laureate Roald Hoffmann [9], where he draws analogies between surface physics and chemistry.

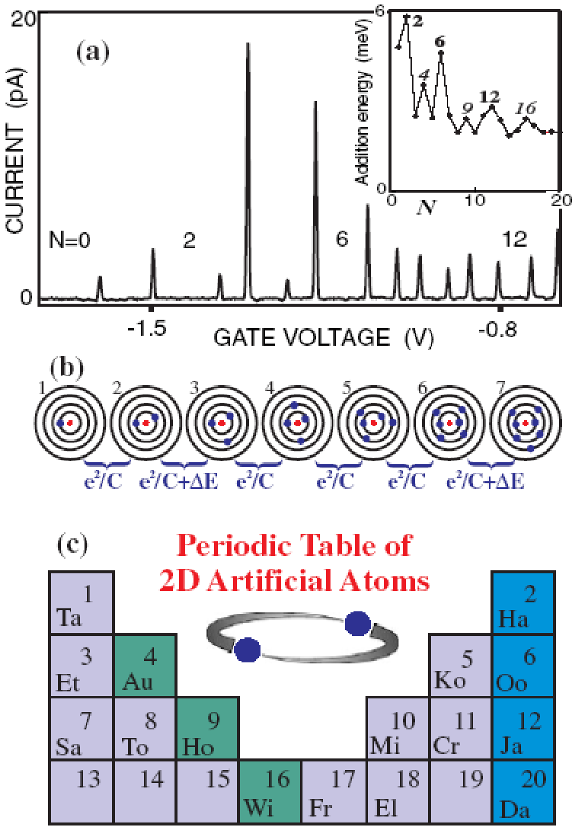

Fig. 8. (*a*) Electric current flowing through a two-dimensional circular quantum dot at different gate voltages. The first peak corresponds to the electric voltage, where one electron enters the quantum dot and the number of electrons N in the quantum dot increases by one electron. (*b*) Schematically shows the addition of electrons to the circular orbits of a quantum dot. (*c*) The electronic properties of the obtained "artificial atoms" can be presented in the form of a periodic table of two-dimensional elements. (Elements are named after the members of the scientific group who took part in this study [8]).

Let us touch on one area of science where chemistry provides the foundation – nanomedicine. In nanoscience, the concept of pseudoatoms or quantum dots or superatoms for nanocrystals with quantized energy states of electrons and holes is often used. And this is no coincidence. Experiments and theories support this concept because of the analogies of the behavior of the ionization potential and electron affinity of a number of metal clusters and real atoms from the periodic table. Both real atoms and pseudoatoms have filled shells with 8, 20, and 34 electrons. If electrons in real atoms are considered in Coulomb potential wells, then in pseudoatoms the potential wells are rectangular in shape, which opens up a completely new chemistry of pseudoatoms as new elements that can be combined with other atoms or even molecules. Such pseudoatoms are widely used in nanomedicine. Quantum dots are an example of inorganic nanoparticles that are used to improve images in medicine. These quantum dots can be prepared with atomic accuracy in order to have a very specific spectrum of light emission, which allows discriminate the arrangement of points on cancer cells from healthy cells. Quantum dot barcodes can be used to label different disease markers, such as different sections of cancer cell DNA, to recognize mutations that cause this type of cancer. In addition, tiny iron oxide nanoparticles, ferromagnetic in nature, as can be clearly seen from the periodic table, become superparamagnets with sizes of 10-15 nm, which are widely used in medicine to deliver drugs to infected cells using an external constant magnetic field or hyperthermia of cancer cells via alternating magnetic field.

In conclusion, nanomedicine is revolutionizing the way we treat the patients. We have discussed here only a few current and potential applications of nanomedicine recently published in the book by Letfullin & George [10]. Rapid detection and treatment at the cellular level are very important to many life threatening diseases. For cancer, early detection would cure the cancer and save lives instead of just extending the patient's life. As seen in this paper, nanodevices/nanoparticles will play a very large role in the future of medicine, taking part in many new advances in the fields of diagnostics and treatment of diseases.

Nanoparticles can provide very good solutions for some medical problems we face and improve currently used methods. Nanorobots and nanomachines as discussed here are the new molecular technologies that have gradually developed over the years, creating robots or machines made up of parts that are at or close to the scale of nanometers.

These new technology fields have evolved through several developmental stages and are still under research and development. These small devices have opened a new world of discoveries and feasibilities in nanomedicine.

5 Synergetics and the Mendeleev's table

In the middle of the last century, a young scientist Boris Belousov studied the seemingly unremarkable chemical reaction at the Faculty of Biology of Moscow State University, in which cerium sulfate, molonic acid and potassium bromide dissolved in sulfuric acid participated. But the association was such that there was an excess of Ce^{3+} ions (it was red) in one vessel, and Ce^{4+} (blue) in the other vessel. Their merger (as B. Belousov expected) should have given a certain brown solution. However, depending on the experimental conditions (especially temperature), the young scientist received astonishingly different results. There were mainly two of them: sometimes the whole solution turned blue, then spontaneously turned red, then back, showing a real chemical clock with an oscillation time of about 3 minutes; sometimes stationary, time-independent, alternating layers were formed - red, blue, etc. colors (Fig. 9).

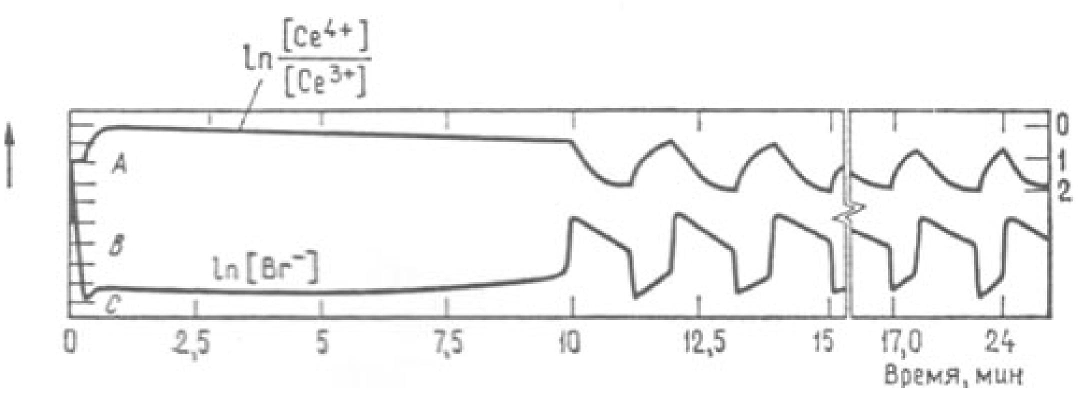

Fig. 9. Time dependence of $\ln[\mathrm{Br}^-]$ and $\ln([\mathrm{Ce}^{4+}]/[\mathrm{Ce}^{3+}])$, taken by the potentiometric method during the Belousov-Zhabotinsky reaction. Initial concentrations: $CH_2(COOH)_2 = 0.032M$, $KBrO_3 = 0.063M$, $Ce(NH_4)_2(NO_3)_5 = 0.01M$, $H_2SO_4 = 0.8M$ and $KBr = 1.5 \bullet 10^{-5}M$.

So, there was either temporary or spatial self-organization of a huge number of ions - the fantasy of this result was a complete refutation of the second law of thermodynamics (as pillars of physics and chemistry of that time), associated with the concept of entropy. Naturally, all attempts to publish these results by Belousov fought off in all editions like a tennis ball (as rumor goes, accompanied by not-so-flattering words addressed to researchers). And these results were laid in the table.

A considerable time passed, and the young theorist Eduard Shnol appeared at this department of Moscow State University, who did not see gross violations of the laws of nature in Belousov's research, and at his insistence B. Belousov sent small abstracts (2/3 pages to a minor non-core conference). "By misunderstanding" theses were published. These results, subsequently deepened by a student of Belousov Jabotinsky, became the cornerstone of an absolutely fantastic new science and even a worldview called synergetics.

So, now synergetics is a tremendous scientific knowledge about the phenomena of spontaneous self-organization: in addition to chemistry, biology, biomedicine, physics, materials science, meteorology, the principles of this science, it is better to say the sciences, are deeply embedded in cybernetics and in many humanities (economics, linguistics, geography, history. . .). The number of scientists - experimenters and theorists who are creating in this field is incredibly large. And, of course, it has its founders: the Belgian Prigozhin (1977 Nobel laureate), the German German Haken, a whole galaxy of once-Soviet theoretical physicists, to whom the world community also pays tribute. Sometimes the emphasis in a new generation of synergetics is placed on the emergence of hierarchical structures and dynamic chaos. And here there are already new heroes (Thuring, Ruelle, Tankens, Pumo, Monneville, Sinai, Nikolis, Babloyans, E. Lorenz, Mandelbrot and others). And everyone clearly indicates that the origins of synergetics (self-organization, etc.) lie in chemistry.

6 Chirality and the periodic table

Going out the periodic table is also observed in our daily lives, in food and in medicines. One example is glucose and fructose, as well as ordinary sugar [11], which provide our body with energy. In diabetes mellitus, the human body cannot process sugar and glucose, which got into the blood from food, as a result of which the body loses energy supply, the person weakens. And fructose can be absorbed and provide the energy needs of the body. It is surprising that all three sugars consist of the same chemical elements - carbon, hydrogen and oxygen: sugar has the chemical formula $C_{12}H_{22}O_{11}$, glucose (grape sugar, dextrose) and fructose (levulose, fruit sugar) - $C_6H_{12}O_6$. What is so striking for our body that sugar, glucose and fructose differ with the same chemical composition? It turns out that the whole point here is the structure of their molecules (Fig. 10). Regular sugar (sucrose, Fig. 10a) consists of two molecules - α -glucose (Fig. 10b) and β -fructose (Fig. 10c) [12].

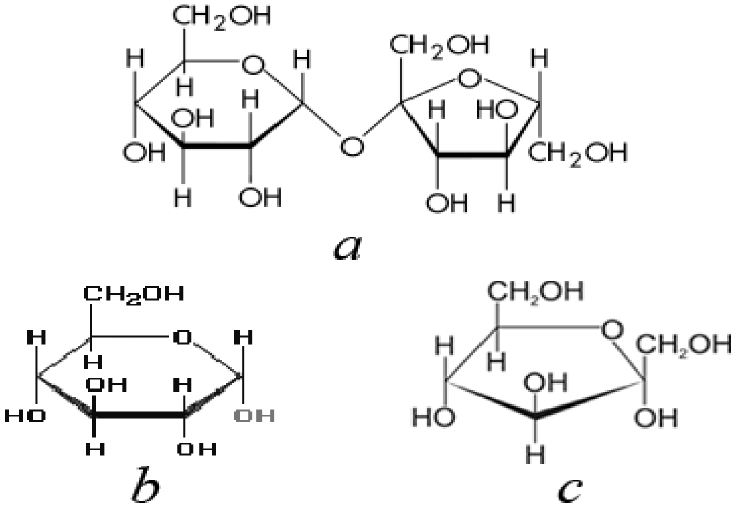

Fig. 10. The structure of the molecules of sucrose (a), α -glucose (b) and α -fructose (c). Fructose is an isomer of glucose. Carbon atoms located at the tops of the rings are not shown. Isomers of glucose and fructose are in the form of six-link (b) and five-link (c) rings (furanose and pyranose, respectively)

Coming with food, sugar in the intestines is broken down into glucose and fructose, which enter the liver through the blood and turn into pyruvate, but with the help of various enzymes. The enzymes hexokinase (glucokinase) and phosphofructokinase that work with glucose stop working when a certain level of pyruvate is reached, which protects us from obesity and diabetes mellitus-2. The enzyme fructokinase (ketohexokinase), which works with fructose, does not have such a brake, and therefore excessive consumption of fructose leads to obesity and the epidemic of diabetes mellitus-2, characteristic of developed countries.

Molecules of sugar, glucose and fructose are optically active (chiral) - they rotate the plane of polarization of optical radiation, but in different ways: sugar and glucose - to the right, fructose - to the left.

They differ in taste as well - glucose is two times less sweet than sugar, and fructose is two times sweeter, which is also important in the confectionery business - with the same sweetness, products with fructose are half as high in calories as with sugar.

The latter indicates the presence of asymmetric agents in biological processes and is associated with the specific and yet unsatisfactory explained property of wildlife to construct proteins from the left optical isomers of amino acids - 19 of the 20 vital amino acids are optically active. It is also interesting [10] that the difference in the structure of sugar molecules is used to determine the source of sugar production: sugar beet has a C3 mechanism of absorption of carbon dioxide (through phosphoglyceric acid) and preferably absorbs the ^{12}C isotope; Sugarcane has a C4 mechanism for absorbing carbon dioxide (via oxaloacetic acid) and preferably absorbs the ^{13}C isotope.

An amazing phenomenon of the predominant role of only one of the forms of optical isomers in biological processes can be of fundamental importance for elucidating the ways of origin and evolution of life on Earth [13].

Based on the above and some other considerations, in this anniversary year for the periodic table, all scientists are absolutely united in the fact that these results are in no way connected with the periodic table.

Conclusion

It seems to us, that a short sketch that we could afford here, once again suggests that no matter how brilliant a discovery in nature is, it is less than nature itself. At the same time, we already understand that the study of the table of the periodic law itself is not as complete a page as it seems: there are attempts (and here it is necessary to note the special persistence shown by theorists Rumer and Fet from Russia) in the search for special additional principles of symmetry in the periodic system elements. Apparently, that two-dimensional table to which we are accustomed and in which two numbers dominate (atomic weight and valency) is only a certain section in a multidimensional space, the axes of which are at least synergetic indicators, nanoscale indicators and... But to see this “cross-section” under conditions of a clear lack of information, even for a two-dimensional system, atomic weight-valency is the genius of a person – D. Mendeleev, before whom we and future generations take off their hats.

References

[1] Alvarez L.W., Bradner H., Crawford F.S., Jr., Crawford J.A., Falk-Vairant P., Good M.L., Gow J.D., Rosenfeld A.H., Solmitz F., Stevenson M.L., Ticho H.K., Tripp R.D. Catalysis of Nuclear Reactions by μ Mesons. Phys. Rev., Vol. 105, Issue 3, 1127–1128 (1957).

[2] Tiras Kh.P., Skavulyak A.N., Aslanidi K.B., Ivanitsky G.R. Why effects of the weak combined magnetic fields on biosystems are not always reproduced? Doklady Biochemistry and Biophysics, Vol. 443, No. 1, 127–129 (2012). DOI: 10.1134/S1607672912020172.

[3] Hutchings G.J. Gold catalysis in chemical processing. Catalysis Today, Vol. 72, Issue 1–2, 11–17 (2002). DOI: 10.1016/S0920-5861(01)00473-4.

[4] Oksengendler B.L., Askarov B., Nurgaliyev I.N., Maksimov S.E., Nikiforov V.N. Nanocatalysis: hypothesis on the action mechanism of gold. Nanosystems: Physics, Chemistry, Mathematics, Vol. 6, No. 2, 249–261 (2015).

[5] Ugay Ya.A. Obshaya ximiya (In Russian; General Chemistry). High School Publishers, Moscow, (1984). – 440 pp.

[6] Khomskii D.I. Neobichnie elektroni v metallax (In Russian; Unusual Electrons in Metals). Znanie Publishers, Moscow, (1987).

[7] McElfresh M.W. et al. (1990). Structure of the Heavy-Fermion Superconductor UBe_{13}. Acta Crystallographica Section C, Vol. 46, Part 9, 1579–1580 (1990).

[8] CeAl3 Crystal Structure: Datasheet from "PAULING FILE Multinaries Edition – 2012" in SpringerMaterials (https://materials.springer.com/isp/crystallographic/docs/sd_0533921), Springer-Verlag Berlin Heidelberg & Material Phases Data System (MPDS), Switzerland & National Institute for Materials Science (NIMS), Japan, (2016).

[9] Zvyagintsev O. E. et al. Khimiya ruteniya (In Russian; Ruthenium Chemistry). Nauka Publishers, Moscow, (1964).

[10] Seddon E.A. The Chemistry of Ruthenium. Elsevier, New York, (2013).

[11] Appen A.A. Ximiya stekla (In Russian; Glass Chemistry). Khimiya Publishers, Leningrad, (1974).

[12] Kouwenhoven L.P., Austingand D.G., Tarucha S. Few-electron quantum dots. Reports on Progress in Physics, Vol. 64, No. 6, 701–736 (2001).

[13] Hoffmann R. Solids and Surfaces: A Chemist's View of Bonding in Extended Structures. Wiley-VCH, (1988).

[14] Letfullin R.R., George T.F. Computational Nanomedicine and Nanotechnology: Lectures with Computer Practicums. Springer, Switzerland, (2016).

[15] Mathlouthi M., Reiser P. Sucrose: Properties and Applications. Springer, (2012).

[16] Kochetkov N.K. et al. Khimiya uglevodov (In Russian; Chemistry of Carbohydrates). Khimiya, Moscow, (1967).

[17] Lustig R., Schmidt L.A., Brindis C. The toxic truth about sugar. Nature, Vol. 482, No. 7383, 27–29 (2012). DOI: 10.1038/482027a.