CHEMICAL PROPERTIES OF THE NEUTRON MATTER AND ITS PLACE IN THE PERIODIC SYSTEM OF ELEMENTS

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Today, the neutron matter and neutron stars are already substantially rooted in the nuclear and astrophysics, and it is logical to have their consideration of them in terms of chemical properties and principles of general chemistry.

The paper deals with the formation of neutron matter and, in addition to the gravitational neutronization, considers other mechanisms, such as condensation of ultracold neutrons (UCN) and neutronization by critical increasing of atomic number of elements in the Periodic System (PS). Thus the question of the "end" of System is raised, but if we start from the Mendeleev's original representations of PS, the neutron matter must be inevitably considered in the group of noble gases and at the "beginning" of the System. Also,the possibility of chemical interaction of UCN with molecules of substances with an odd number of electrons is considered. The possible plan of the experiment on "chemistry" of UCN is discussed. The extension of PS beyond classic chemicals and their coverage of much wider matter of the Universe, based on the forgotten ideas of D.I. Mendeleev, is proposed. Moreover, the PS is begun with the neutron and its isotopes (dineutron, tetraneutron et al) and ended with a neutron stellar material.

Keywords: Neutron, Neutron matter,Noble gases, Periodic system of elements, Neutronization, Zero period.

Neutron matter, from the point of view of General Chemistry, can be formally attributed to chemically simple (i.e., it cannot be decomposed further into simplerby chemical means), then inevitably the question arises about the Element, it corresponds to, and its place in the Periodic System (PS). Based on the logic of the Periodic Law (PL) - (atomic number = electric charge) - atomic number of neutron matter will correspond to zero, which brings to mind the Dmitri Ivanovich Mendeleev's idea of the zero group and period. D.I. Mendeleev assumed the existenceelements X and Y that should go before the Hydrogen. The element X (Mendeleev called it "Newtonium") got its place in the periodic table –in the zero period and the zero group as an analog of the lightest noble gas. In addition, Mendeleev admitted the existence of another element lighter than the Hydrogen - an element Y, «Coronium (Crownium)» [1,2].

The problem of "zero group and period" becomes clear, if we extend the concept of "atom" - not only as the sum of electrical charges but also other types of charge (baryon and lepton). Then, a positronium (a pair of electron-positron) is found its place before the Hydrogen in the PS, which has long been regarded as the atomic system, as well as Mendeleev's Newtonium as its isotopes: neutronium (neutron and antineutron) and neutrinium (neutrino-antineutrino) [2].

It should be noted that issue of "zero" elements repeatedly raised after D.I. Mendeleev's works, for example, Ernest Rutherford in 1920 [2, 4] and Andreas von Antropov (Andreas von Antropoff) in 1926 (before the discovery of the neutron itself) postulated them as a designation for a hypothetical element with the atomic number zero, which was placed in the top of the periodic table [3]. The term "neutronium" was first proposed by A. Antropov, but he meant by this term the neutron, which had not been discovered yet but was expected. Today, the dineutron and tetraneutron can claim this place in the PS, which have already appeared in the literature [5,6] and which can be formally considered as neutron isotopes. It is not difficult to see that the matter of neutron stars itself, which was predicted in 1937 by L.D. Landau and was opened in 1968 by astronomers from Cambridge, can be considered from the point of view of isotopy of Neutronium element. Thus, its zero position in the PS corresponds to the representation of it as a "singular point", which is an association of micro- and mega-World, which has been repeatedly said by philosophers and scientists.

The process of conversion of ordinary matter into the neutron matter under the influence of gravitational forces in the evolution of some stars is called Neutronization. In the final stages of the evolution of some stars the density of matter is greatly increased, and the electron gas becomes degenerate. The energy of degenerate electrons reaches such a magnitude that they can overcome the energy barrier and be captured by atomic nuclei. The processes of so-called inverse beta decay begin to take place, through which protons are converted inside the atomic nucleus into neutrons. It is this process of multiple electron capture by nuclei, which is accompanied by the emission of neutrinos and the formation of theneutron matter, is called Neutronization.

The reaction of electron capture by atomic nuclei (A, Z) (where A isthe mass number, Z – the atomic number of the element) has the form:

$$(A, Z) + e^{-} \rightarrow (A, Z-1) + \nu \quad (1)$$

Since the energy threshold of the reaction (1) is large, the electrons energy can exceed the critical threshold value of neutronization only for matter at high densities, which is characteristic of the final stages of stellar evolution.

Gravitational neutronization was widely described and discussed in detail, but other mechanisms of neutron matter formation, such as condensation of ultracold neutrons (UCN) and neutronization by critical increasing of the atomic number of elements,are also possible.

Since now the question of "the beginning" and "end" of the PS is raised, let us consider neutronization by means of the critical increase of atomic number of the elements. The problem of stability of superheavy atoms has been described rather thoroughly by Ya.B. Zeldovich and V.S. Popov in 1971 [7]. The electronic structure of the atom in a supercritical nuclear charge ($Z>170$) is a great theoretical interest. *"The quantum theory of electrons, positrons, and the electromagnetic field cannot be considered as complete as long as the clarity in this matter is not achieved"* - the authors believed.

Even Paul Dirac showed in 1928 [8] that the solution of electron state in the electric field of a point charge Z_e becomes singular at $Z = 137$. Taking into account the finite size of the nucleus, I.J. Pomeranchuk and J.A. Smorodinskii [9] in 1945 showed that the accurate calculation leads to a critical charge (Z_c=170). S.S. Gerstein and Ya.B. Zeldovich [10] in 1969suggested that bare nucleus Z spontaneously emits positrons at $Z>Z_c$. The atom with the filled K-level with increasing nuclear charge $Z>Z_c$ (the electron levels continue to drop with the growth of Z, and the size of the nuclei continues to grow) transforms directly into a supercritical state without emitting positrons, butby capturing the electrons by atomic nucleus.

The authors also consider the possible contribution of the vacuum polarization effects and the appearance of pairs of particles and antiparticles in the field of critical nuclei.

However, a few critical remarks cannot be avoided to make:

1. Despite the unconditional heuristic value of Zeldovich’s and Popov’s article, they did not go further–they did not makethe direct conclusion of the almost complete neutronization of supercritical nuclei, although they laid the preconditions for this.

2. Their conclusion (the forth one on p.410. [7]) that the properties of the outer shells of atoms (that determine, in particular, the Mendeleev’s periodicity of chemical properties) continue naturally into the transcritical region- is in doubt.

3. They underestimated the role of the vacuum polarization. Although there were studies [11] thatpostulated the polarization of the vacuum increases indefinitely when Z>Zc. This was contrary to their conclusions, but in our opinion, it is closer to the truth and that is what leads to the inevitable and almost complete neutronization of supercritical nuclei.

The gradual neutronization of nuclei is observed long before reaching the critical values of Z that is presented in Table 1.

Table 1

№№ periods of the periodic table						
1	2	3	4	5	6	7
~0.5	0.94	1.03	1.15	1.28	1.48	1.53
The average (through the period) ratio of the neutrons to protons in the nucleus of the chemical elements						

Qualitatively, the growth of neutronization degree of nuclei can be well observed on the extrapolation of the curve inthe protons - neutrons diagram (Fig.1).

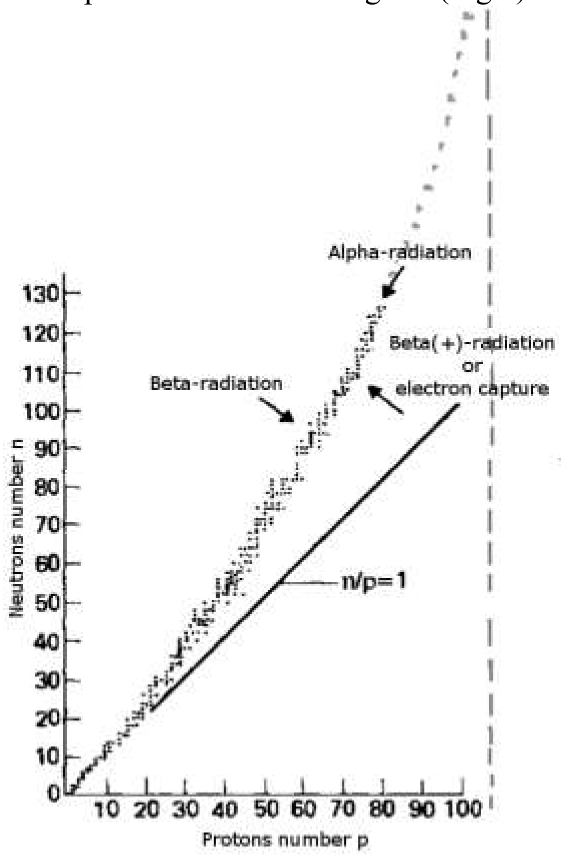

Fig.1. The protons - neutrons diagram.

It is quite clear, that for the quantitative conclusions from the extrapolation of the diagram, the thorough statistical treatment of p - n curve (Fig.1) for a very wide range of nuclides must be conducted.

Additional information can be obtained from the dependence of the specific energy of the nucleons in the nucleus of atoms from their atomic mass A (Fig. 2), which is well described by Weizsäcker equation (2).

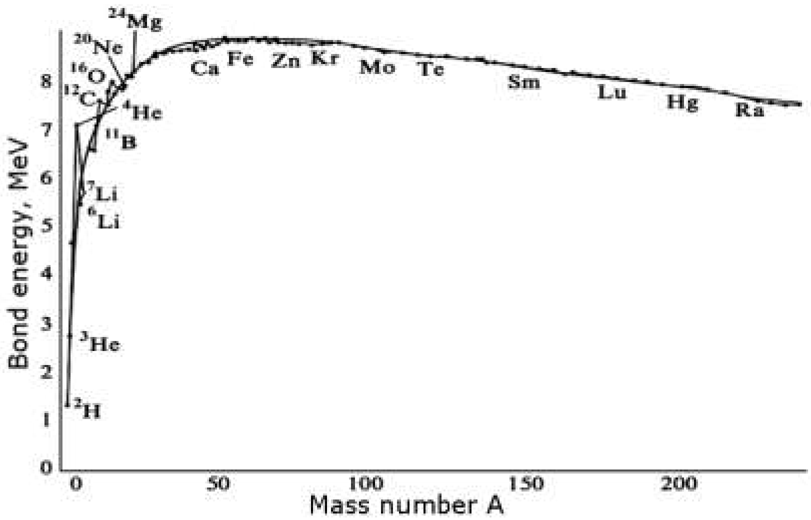

Fig. 2. The dependence of the specific binding energy of the nucleus in atoms on their atomic mass.

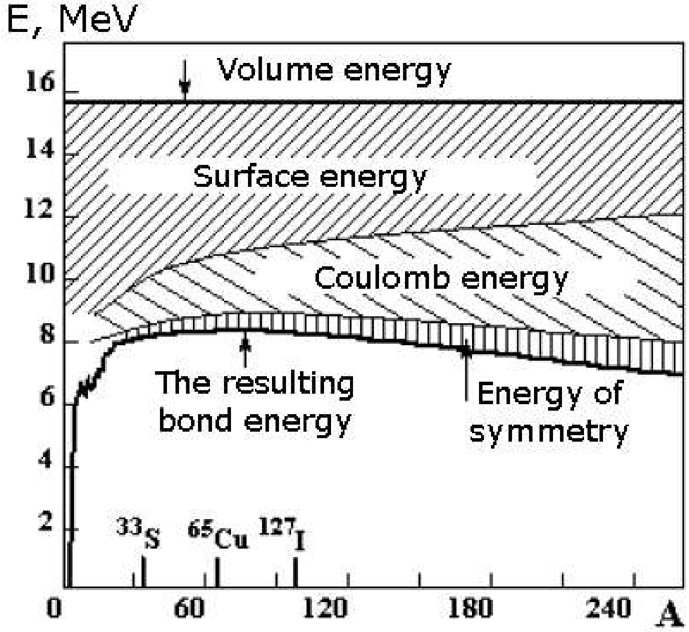

Fig. 3. Contribution of different energy in the Weizsäcker's dependence.

Carl Friedrich von Weizsäcker obtained the semi-empirical equation for the binding energy:

$$E_{BIND} = \alpha A - \beta A^{2/3} - \gamma Z^2 A^{-1/3} - \xi (N-Z)^2/A + \delta A^{-3/4}, \quad (2)$$

where, α = 15.75 MeV; β = 17.8 MeV; γ = 0.71 MeV; ξ = 22 MeV; δ = + 34 MeV for even-even, δ = 0 MeV for odd, δ = –34 Mev for odd-odd, A – atomic weight.

It can be seen (Fig. 3) that with increasing of the atomic weight, the largest contribution to the decrease of the binding energy of the protons is madeby electric repulsion energy. The contribution of the surface energy is reduced, and the symmetry energy is not decisive.

Let's try to extrapolate the Weizsäcker's dependence to supercritical nucleus (Fig. 4).

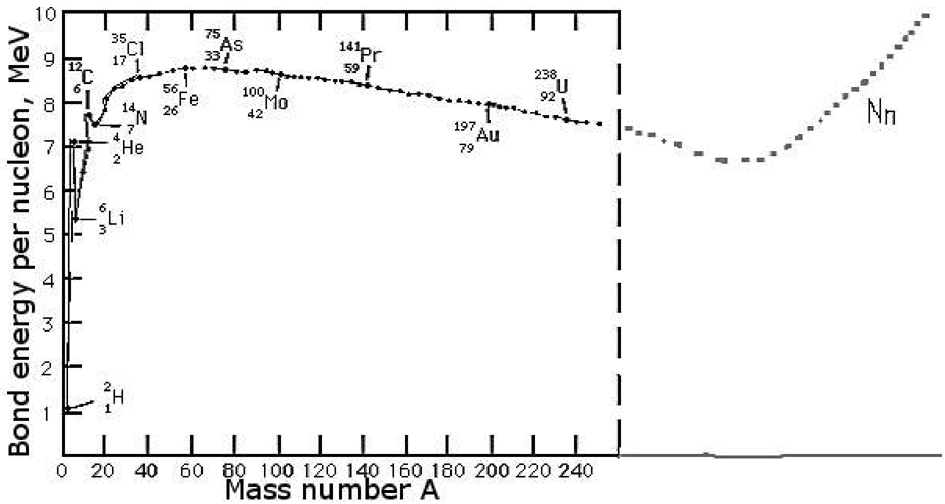

Fig. 4. The extrapolation of Weizsäcker's dependence to supercritical nuclei (where Nn is neutron matter).

Due to almost complete neutronization, the contribution of the surface energy for supercritical nuclei will be leveled, and the electric repulsion will stop to increase when the supercritical state is reached. This will lead to stabilization of the neutron matter and reduce the likelihood of its decay on a particular mechanism (nuclear fission, α -, β (+) - decay). It is necessary to consider more thoroughlythe β (-) – decay, which seems to be dominant in such an "overloading" of neutrons. However, the paradox of neutron matter leads to the fact that starting from a certain critical mass and size (when the path of β-electron in a neutron matter becomes smaller than the size of the matter), β (-) - decayfrom the destabilizing factor becomes a significant factor of stability.

There is always some residual content of the protonmatterin the neutron matter, and beta-electron emitted by decayed neutronis not able to leave the neutron matter of sufficient size (larger than the path of beta-electron in it). The emitted electron is absorbed by the remaining protons, which in turn are converted into neutrons, thus the dynamic equilibrium of the system is maintained. In fact, it corresponds to the theory of Tamm [12], which he put forward in his time (1934) to explain the mechanism of nuclear forces for ordinary nuclei. It should be noted that his theory was not consistent for ordinary atoms (Tamm appreciated his "unsuccessful" theory of nuclear forces more than his Nobel work on Cherenkov radiation), but it can be realized for the neutron matter of appropriate scale (200-300 fm and more femtometers), giving it additional stability.

There is a lot of virtual particles in the strongly interacting systems and all kinds of interactions permitted by considerations of invariance are carried out. Academicians V.L. Ginzburg and E.L. Feinberg wrote well in their preface to I.E. Tamm'swork [12]*: "Already in the hisfirst report (1934), I.E. Tamm has writtenhis equation for the capacity of interaction that occurs between the nucleons, and showed that this interaction is very small compared* *with the actually existing nuclear forces. Consequently, although* ***the beta-forces, of course, exist****, they do not provide the stability to nuclei. However, starting fromthis work, Yukawa soon showed that nuclear forces may be due to the exchange of particles, if the particles are much heavier than the electron. Based on this, the mesons, which interact strongly in thenucleus, had been predicted and then discovered. The I.E. Tamm's work served as a prototype and the basis of the meson theory of nuclear forces and other similar studies, all of which were built in general on the same theoretical scheme as a theory of beta-forces created by Igor Evgenievich. This work belongs to his best achievements and he appreciated her more than all his works."*

So, in our opinion, I.E. Tamm's "original" theory of exchangeable β-nuclear forces (e - exchange of nucleons), and not only its modification made by Hideki Yukawa (π-exchange of nucleons), is still awaiting its acceptance (since except as meson cloud around a nucleon, there are certainly other particles) and "dominates" in the neutron matter of the Universe, providing its stability and a wide cosmicspreading.

Another factor of additional stability of the neutron matter during the significant increase of its mass (up to a macro scale) will be the ever-increasing contribution to the gravitational interaction. Thus, we obtain a modified Weizsäcker equation for the neutron matter, which describes the main factors of its stability and the real existence in the Universe:

$$E_{BIND}=\alpha A-\beta A^{2/3}+\tau A^{t}+\lambda A^{l}, \quad (3)$$

where, α = 15.75 MeV; β = 17.8 MeV; τ – Tamm - interaction; λ – the gravitational interaction.

It is namely Tamm interaction, due to nuclear β - force, confers resistance to neutron substance already on the micro-level, not just at the macro-level due to the gravitational interaction, as it is now considered to be in astrophysics!

The parameters of equation 3 (τ, λ, t, l) need to be clarified in the course of further research in this area.

It's time to come down from the Space to the Earth and see where you can find here the neutron matter? Usually we are dealing with neutron radiation of different energy, but not with the neutron matter. It was not until 1968, when at the Laboratory of Neutron Physics, under the supervisingof corresponding memberof the Academy of Sciences of the USSR Fyodor L. Shapiro [13,14],the experiment was performed in which the phenomenon of retention of very slow neutrons in the vessels was first observed. It should be noted that this phenomenon was predicted by Academician Ya.B. Zeldovich. The behavior of neutrons, which are retained in evacuated vessels, is similar to the behavior of highly rarefied gas in the vessel. These neutrons are called ultracold neutrons (UCNs).

Only for such slow moving neutrons, their size, which is determined by the de Broglie wavelength, becomes macroscopic with the values from 0.1 to 1 micron, i.e. a thousand times greater than the dimensions of the atoms. For this reason, during the collision of such a "big" neutron with the surface, it interacts directly with tens of thousands of the atomic nuclei of the material surface layer. The resulting chaotic thermal motion of the individual atoms of matter, which have the energy of hundreds of thousands of times the energy of neutron falling to the surface, is averaged over an area corresponding to the size of a neutron.

Therefore, the neutrons that have kinetic energy corresponding to the temperature of about 0.001 K, are almost perfectly elastically reflected from the wall material, which has a room temperature of about 300K. Such an "insulation" of very "cold" neutron from a very "hot" wall allows the neutrons, which are collided a lot with the wall, to be kept in a closed evacuated vessel for quite a long time (about 10 minutes). And this time, in principle, is limited only by the decay of the neutron itself. The retention of UCN in vessels attracts the researchers by the opportunity to observe for longer time this elementary particle in the experimental installation (as compared with a single flying of neutrons through anexperimental volume), which gives a significant increase in sensitivity and accuracy of experiments on the interaction of neutrons with the matter and fields.

For example, the using of UCNshas allowed lowering significantly the limit of the existence of the electric dipole moment of the neutron, necessary to verify the law of conservation of time parity; more precisely measuring the lifetime of a free neutron until β-decay. The main feature of the UCNs is that they do not behaveas raysbut as the substance and they can be handled asthe substance similar to the rarefied noble gas. Moreover, it is possible to study its both physical and chemical properties. Physical properties are already studied, but the question about the chemistry of UCNs seems to not be even raised, because by default, it seems clear that they should behave like noble gases. This seems to be true, but in fact we know now that the noble gases, albeit with difficulty, enter into chemical reactions and form, even not stable, but chemical compounds. Could the similar thing take place with UCNs?

Assuming that the chemistry is only the interaction of the electron shells of atoms, as many people believe, it should result in categorically negative answer. But, if by the Chemistry we start to understand, more widely, the ability of micro-objects (nano-, pico- or femto-) to interact and to form relatively stable compounds, why not? It is true, that neutrons do not have the electric charge and free electrons, so all ideas about possible classical chemical bonds (ionic, covalent, and others) at once uniquely disappear. But, the neutron does have the magnetic moment and, possibly, electrical dipole moment. Can it serve as the ability to interact with other objects to form, if not stable, but observable compounds? For example, for neutrons it is possible to interact with the molecules of substance with an odd number of electrons. A scheme of one of the experiments on the proof of such interaction can even be proposed.

Scheme on the "neutron chemistry" experiment:

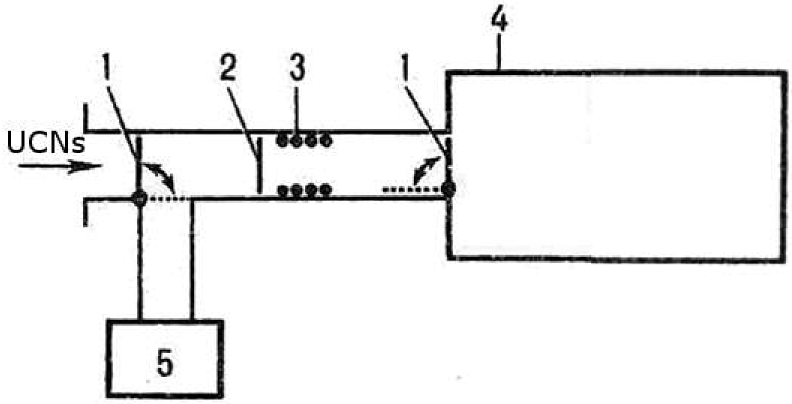

Fig. 5. The experimental scheme of the chemical interaction of the neutron with molecules with unpaired electrons: 1- neutrons intake and exhaust valves; 2 - polarizer; 3 - contour of the spin rotator; 4- storage chamber of ultracold neutrons with matter with unpaired electrons; 5-detector [15].

This scheme is almost completely similar to experiments of determination of the electric dipole moment (EDM) [15] of the neutron, only storage chamber (4) with UCNs is not exposed to magnetic and electric fields, butthe control experiment is conducted on the inlet and outlet of UCNs and their detection by the detector. Then, the same with minor additions (approximately equal to the concentration of UCNs) of, for example, NO_2 (or any other gas with an odd number of electrons), and then the same with CO_2 (an even number of electrons) and the count rate at the detector is compared in all these cases. In the absence of interaction of CO_2 with neutron, the count rate will be as in the control experiment. In the presence of interaction (NO_2), the count rate should be less since for {neutron*NO_2} complex, the polarizer is impermeable, but if there is no interaction, the count rate is as in control experiment. All this should be carried out at low temperatures (liquid nitrogen) or extremely low (liquid helium) temperatures, because the {neutron*NO_2} complex ({Nn*NO_2} or {Nn*$(NO_2)_x$}) is, of course, not stable; where, a neutron –Nn.

If there is a magnetic interaction (nuclear magneton - Bohr magneton interaction or magneton – magneton interaction (MMI)) and the existence of a complex with nitrogen dioxide, the detector count rate will be much lower than in the case of carbon dioxide, and a control experiment. Yes, it's not exactly like a classical chemical interaction, and to calm the conservative chemists (and such chemists do exist, as follows from the discussion on this issue) these interactions and connections are suggested to call as quasichemical. This suggestion is because conventional chemical interactions really have the electronic nature, but here we have the magneton – magneton interaction.

And it not depends on how they are named, but it is obvious that it is necessary to study and to put such experiments in close collaboration of chemists and physicists.

All over the world, the researches to develop new sources of ultracold neutrons are actively conducted, some of them are based on the use of solid deuterium at the temperature of 4.5 K (LANL, USA; PSI, Switzerland), and others - on the accumulation of UCNs in superfluid helium (KEK-RCNP-TRIUMF, Japan-Canada; ILL, France). Similar work is carried out in Russia: in the Frank Laboratory of Neutron Physics at the Joint Institute for Nuclear Research (Dubna), at the St. Petersburg Institute of Nuclear Physics (PINP). In Gatchina (PINP) the work on the creation of high-intensity UCN source is carried out. By using it, the data, which will give answers to the major questions of modern physics, is hoped to be obtained.

The projected source will allow obtaining a stream of ultracold neutrons (UCNs) with a density of 10^4 cm^{-3}, which is many times greater than the maximum density achieved today [16]. This task –of getting the intense UCNs flow –is now considered to be one of the priorities in the neutron physics. The increase of the UCNs density will inevitably lead to the formulation of the question about their possible condensation and production of condensed neutron matter,similar to the Space neutron matter,in the laboratory conditions. It should be noted that the idea of obtaining and using of the neutron matter as the technical material (neutrid or neutronid) has long been debated in the Internet [19], scientific, popular [17] and sci-fi literature [18], but only now we came to the scientific substantiation of ways to produce it on the Earth. Not so long ago,the decisive breakthrough was made in the new field: creation of radically new form of matter, the so-called Bose condensates of atoms of the substance.

Is it possible for neutron condensates to exist? To exist the condensates, whose density and strength are comparable with density and strength of the atomic nuclei. In other words, how close we came today to thefrontier of the creation of cosmic neutron matter in the laboratory?The Nobel Prize in Physics was awarded in 2001to researchers Eric A. Cornell, Wolfgang Ketterleand Carl E. Wieman for the obtaining and investigation of the properties of the fifth state of matter: Bose-Einstein condensate [20]. They were able to get the first Bose condensate and this was done with the help of the developed shortly before methods of particles supercooling by laser beams and magnetic field.

Bose condensate of atoms was obtained in a form convenient for research and laboratory analysis. Soon after that, the reports of Bose condensates of various atoms appeared everywhere. The scientists'activities were facilitated greatly by the fact that the installation for production of Bose condensates was relatively inexpensive - experiments were carried out in many countries. Soon the methods for Bose condensates of half-integer spin particles - fermions (a class which includes and neutrons) - were found. The particles inside them are connected in pairs that then results inthe Bose condensate formation. The neutrons in many properties are close to the lightest atoms. For example, the mass of the neutron is almost equal to the mass of a hydrogen atom, a Bose condensate of which was obtained by Ketterle in 1997. But, unlike atomic Bose condensates, whose natural compression during Bose condensation is restricted irresistibly by their electronic shell, the compression of neutron Bose condensates does not interfere with anything. With such a condensation gas formed neutron pairs, when the critical density and temperature itself will shrink to nearly the nuclear density, when the matter will take nuclear forces, forming a stable state - a condensed neutron matter.

CONCLUSION

Thus, the neutron matter in our time is quite concrete physical reality, which strongly demands its rightful place in the PS and to be studied from point of view of not only its physical but also chemical, and possibly in the near future, technical properties.

The Periodic System of elements begins (zero period) with the neutron matter, or rather with the Element it corresponds to, and finishes (supercritical atoms) by it. The neutron matter is conferred resistance already at the micro-level by means of Tamm interaction, not just at the macro-level due to the gravitational interaction, as it is now considered to be in astrophysics. The possibility of neutronization is not only due to the gravitational interaction, but also due to other mechanisms (supercritical increase the atomic number of elements and UCNs condensation), so there is a principal possibility of the neutron matter obtaining in the Earth conditions. The neutron matter is necessary link connecting (inducing a bridge) the micro-, the macro- and mega-World, from the free neutron to the neutron stars and the black holes. **The neutron matter consistently fits into the original concept of the Periodic Law and the System proposed by Dmitry Ivanovich Mendeleyev** [1, 2, 21, 22, 23].

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