

On the extreme variants of nuclear fusion realization

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The canonic reaction of helium synthesis as a result of deuterium and tritium interaction can take place both in high-temperature and low-temperature variants. In both cases, the nuclei draw together so closely that Coulomb's barrier becomes enough transparent for tunneling. In the case of high-temperature synthesis the energy of chaotic thermal motion is needed to overcome the energy of electrostatic repulsion of «bare» nuclei. As a contrary, in the low-temperature variant, when deuterium and tritium nuclei replace protons in partially ionized hydrogen molecule, and negatively charged μ -meson replaces the only electron, electromagnetic interaction of nuclei with μ -meson provides nuclei approach each other to the critical distance of $R_c \approx 5 \cdot 10^{-13}$ m. A hypothesis on appearance of intermedium quasi-molecular states (IQS) when negatively charged ions collide is formulated. It is supposed that in such states the nuclei can draw together due to effective attraction to the group of negatively charged electrons having higher mass and charge as compared with individual electron. The value $R_c \approx 5 \cdot 10^{-13}$ m guarantees the tunneling only for light nuclei; therefore, the focus is made on ions' collision with α -clustered nuclei (having compositions divisible to α -particles compositions). It is expected that the new nuclei synthesis will take place in the presence of oncoming tunneling of relatively weakly connected α -particles from α -clustered nuclei. For IQS formation, the energy acquired by colliding ions in external fields has to be comparable with the energy of their entire ionization. It was shown that the energies (not exceeding 1 keV) of oxygen ions in experiments with electrolysis of water, were accompanied by appearance of mainly carbon, silicon and iron, which meet this condition. These facts testify for the existence of IQS that have to be considered as one of the necessary conditions of low-energy nuclear reactions. In the Conclusion the program of further research is briefly stated.

Keywords: quasimolecular state, α -clustered nuclei, nuclear fusion.

1. Introduction. The hypothesis on the mechanism of low-energy synthesis of elements with α -clustered nuclei

Nowadays, helium synthesis as a result of deuterium and tritium interaction is a generally recognized canonic example of nuclear fusion. It is principally important that the named synthesis can take place both in high-temperature and low-temperature variants. The general condition is close approach of positively charged nuclei (up to distances $\sim 10^{-13}$ m) providing enough transparency of Coulomb's barriers for tunneling of nuclei with subsequent stabilization of helium nuclei due to short-range attraction forces.

The ways of approach are, however, principally different. In the high-temperature variant ($T \approx 10^8$ K), for drawing «naked» nuclei together, high energy of the chaotic thermal motion is spent on partial compensation of the electrostatic repulsion energy. On the contrary, when in low-temperature variant deuterium and tritium nuclei in partially ionized hydrogen molecule replace protons, and a negatively charged muon replaces the only electron, the electromagnetic interaction of nuclei with muon makes it possible for nuclei to approach each other to the critical distance of $R_c \approx 5 \cdot 10^{-13}$ m [1].

Thus, somewhat generalizing the idea of muon catalysis, one can state that the possibility of a low-temperature start of nuclear reactions is connected with using such states of molecular type at which the electromagnetic interaction of opposite charges maximally promotes the nuclei approachment. Such statement is natural as there is no alternative for electromagnetic interaction on atomic scale. It's appropriate to note that the typical diapason of atomic scales is prescribed by the values of radii R_{bs} of atoms' basic states that can be evaluated using the formula for radii of basic state of hydrogen-like ions:

$$R_{bs} = R_B/Z, \quad R_B \approx 5 \cdot 10^{-11} \text{ m.} \quad (1)$$

In (1) Z is the charge number equal to the atomic number of a chemical element in Mendeleev's table, and R_B is the radius of the first electronic orbit in Bohr's model for hydrogen atom. The most massive nuclei are characterized by charge numbers $Z \approx 100$. Therefore, the lower bound of the diapason of atomic scales $(R_{bs})_{\min}$, according to (1), corresponds to value $\approx 5 \cdot 10^{-13}$ m, i.e. to orders of magnitude less than R_B . Obviously, the equality of $(R_{bs})_{\min}$ with R_c in this case is achieved owing to high value of Z . At the same time, for ionized muonic hydrogen molecule the achievement of R_c is conditioned by

high mass of muon, practically 200 times exceeding the mass of an electron.

In this connection it's obvious that, in general case, a multiplicative combination of the influence of mass and charge factors is possible. In this respect intermediate states of quasi-molecular type appearing when negatively charged ions collide seem to be perspective for study. Indeed, the positive nuclei can draw together due to effective attraction to the collective of negatively charged electrons characterized by high masses and charges as compared with an individual electron, possessing elementary charge e and mass m . Certainly, the experimentally determined value $R_c \approx 5 \cdot 10^{-13}$ m guarantees the efficacy of tunneling only for light nuclei, therefore, being guided by values of R_c , one should firstly pay attention to collision of ions whose nuclei can be attributed to α -clustered type. In this case the nuclei compositions are divisible (with multiplicity k) to the composition of α -particles, i.e. helium ${}_2\text{He}^4$ nuclei. Then it may be expected that the synthesis of new nuclei will take place along with oncoming tunneling of relatively weakly connected α -particles from α -clustered nuclei. In the framework of delineated physical conceptions, it is clear that the threshold energies of the start of low-temperature nuclei fusion should not be too high, because the conservation (to maximum possible extent) of all electrons present before the collision provides conditions for the nuclei rapprochement in an intermediate quasi-molecular state. At the same time the energy of colliding ions should be enough for a reorganization of their electronic structure into the structure of an intermediate state. It means that the energy acquired by colliding ions in external fields has to be comparable with the energy of their entire ionizing. Let us determine the energy of entire ionizing of an atom $E_{\text{bs}(i)}$, as energy of ionization of hydrogen-like ion:

$$E_{\text{bs}(i)}(Z) = E_{\text{B}(i)} Z^2, \quad E_{\text{B}(i)} \approx 13.6 \text{ eV}, \quad (2)$$

where $E_{\text{B}(i)}$ is the energy of hydrogen atom ionizing. From (2) it is obvious that even at $Z = Z_{\text{max}} \approx 100$, the value $(E_{\text{bs}(i)})_{\text{max}} \sim 0.1$ MeV is 10 times less than the lower bound of energies $E_n \sim 1$ MeV typical for nuclear reactions. At the same time, at $Z=10$ the energy $E_{\text{bs}(i)}$ makes ~ 1 keV, i.e. is three orders lower than E_n . Within the limits of the verbalized hypothesis postulating existence of an intermediate state one could expect, for instance, that at $Z \sim 10$ and mass of the electron collective ~ 10 m, close rapprochement of the nuclei (distances $R \sim R_c$) at energies of ion colliding ~ 1 keV is quite possible. Let us note, for comparison, that rapprochement of «naked» nuclei with charge numbers $Z \sim 10$ till distances near R_c in the variant of high-temperature fusion would need temperatures $T \approx 10^{10}$ K, by two orders exceeding the values $T \approx 10^8$ K at $Z=1$ (as the energy of Coulomb's repulsion $\sim Z^2$). Let us remind that $E_n \sim 1$ MeV corresponds to temperature $T \approx 10^{10}$ K on energetic temperature scale. The stated comparison shows that development of a concept of intermediate quasi-molecular states is advisable as very actual for realization of low-energetic element fusion.

The purpose of this work is to demonstrate that there are experimental data bearing evidence to the existence of intermediate states favorable for synthesis of chemical elements with α -clustered nuclei, and to develop the program of further study.

2. Elements with α -clustered nuclei and their fixing in experiments with electric current impact on distilled water

The experimental data testify to the possibility of synthesis of chemical elements with rather broad assortment of Z values as a result of affecting substance by electric current pulses, electro-magnetic fields and shock waves (see, for example, [2–5]). All these data are naturally divided into two groups by the type of nuclear transformations accompanying elements' synthesis. The first group includes variants of transforming of the nominal nucleus ${}_Z X^A$ of element X with mass number A and charge number Z restricted only to Z value change. The second group includes variants of transforming related with obligatory change of A values. The transformations in the first group can be interpreted as a consequence of weak interactions leading to change of $\Delta Z = \pm 1$ (a cascade of such decays is possible). In the present work attention is focused on the appearance of elements having α -clustered nuclei. Let us remind, for the readers' ease, that beside ${}_2\text{He}^4$ ($k=1$), isotopes with multiplicities $3 \leq k \leq 10$ (${}_6\text{C}^{12}$, ${}_8\text{O}^{16}$, ${}_{10}\text{Ne}^{20}$, ${}_{12}\text{Mg}^{24}$, ${}_{14}\text{Si}^{28}$, ${}_{16}\text{S}^{32}$, ${}_{18}\text{Ar}^{36}$, ${}_{20}\text{Ca}^{40}$) are stable, and those unstable at $11 \leq k \leq 25$ begin with the isotope ${}_{22}\text{Ti}^{44}$ and end with the isotope ${}_{50}\text{Sn}^{100}$.

Let us note also that some of the elements synthesized may be considered genetically connected with α -clustered elements. For example, six stable isotopes (${}_{20}\text{Ca}^{44}$, ${}_{22}\text{Ti}^{48}$, ${}_{24}\text{Cr}^{52}$, ${}_{26}\text{Fe}^{56}$, ${}_{28}\text{Ni}^{60}$, ${}_{30}\text{Zn}^{64}$) have their mass numbers divisible to 4 ($A=4k$, at $11 \leq k \leq 16$) but charge numbers $Z=2k-2$. Such isotopes of elements can be naturally considered genetically connected with α -clustered unstable isotopes having undergone a couple of β -decays, i. e. reactions from the first group. If we postulate four β -decays, then eight more isotopes with charge numbers $Z=2k-4$ ($A=4k$, at $17 \leq k \leq 24$) may be attributed to those genetically connected with α -clustered nuclei: ${}_{30}\text{Zn}^{68}$, ${}_{32}\text{Ge}^{72}$, ${}_{34}\text{Se}^{76}$, ${}_{36}\text{Kr}^{80}$, ${}_{36}\text{Sr}^{84}$, ${}_{40}\text{Zr}^{88}$, ${}_{42}\text{Mo}^{92}$, ${}_{44}\text{Ru}^{96}$. And, finally, isotope ${}_{44}\text{Ru}^{100}$ (stable after six β -decays) may be juxtaposed to unstable ${}_{50}\text{Sn}^{100}$.

For the present work it would be enough to regard brief information on elements' fusion in the course of treatment of water (see chapter 4 in [3], further reference [3] applies to this only chapter). According to [3], at realization of one of the schemes of water electrolysis (analyzed in detail in the next section of the article), origination of chemical elements (with maximum yield of C , Si , Fe) was fixed. Though the isotope composition of elements was not studied in [3], we can note that carbon and silicon, as mentioned above, possess isotopes with α -clustered nuclei, and iron has an isotope that can be naturally considered to be genetically bound with α -clustered nuclei ${}_{28}\text{Ni}^{56}$ ($k=14$) having undergone a double β -decay. Hence the oxygen included in water molecules (as a rule, ${}_8\text{O}^{16}$ isotope) belongs to elements with α -clustered nuclei ($k=4$), it's naturally to think that it is oxygen that plays part of the basic element for synthesis of α -clustered nuclei when electric current is conducted by water. Therefore, it can be expected that energies accumulated by oxygen ions, according to (2), at $Z=8$ would be comparable with $E_{\text{bs}(i)}(8) = 870.4$ eV.

3. Evaluation of the energies of oxygen ions obtained from external fields, for two variants of electrolyzes

For clarity, a scheme of active part (the reactor) of the setup used in [3] is shown in Fig. 1.

Let us remind that in [3] the triggering pulse (between electrodes 6 in Fig. 1) is connected with potential of 220 V, and the support of a stabilization current (between electrodes 2 and 3 in Fig. 1) is carried out from an alternating current circuit with a voltage 380 V either through a rectifier with a potential difference up to 500 V. The typical value of current is 20–40 A. Besides, the zone of reaction is placed in magnetic field of the solenoid (cross-cuts of solenoid's coils are marked by 5 in Fig. 1). As a result, the discharge area (plasmoid) — a film up to 50 μ thick appears between tubular electrodes. The form of plasmoid resembles hyperboloid of rotation that clearly manifests itself by fluorescence in optic diapason.

Oxygen as the basic element for reactions of fusion in the form of O^{2-} ion either belongs to the neutral polar molecule of water, or is a part of OH^- ion, or turns to free state during the treatment of water. Presence of protons in water molecules, OH^- ions, or in a complex with polar water molecule (conventionally specified as H_2OH^+) allows, evidently, to diversify the isotope composition. That leads to appearance of elements differing from pure α -clustered ones.

Let us propose that the main role at initial stages of elements' formation is played by collisions of the O^{2-} ions that are effectively accelerated in external electric field up to the energy levels sufficient for the formation of an intermediate quasi-molecular state that is able to initiate the beginning of nuclear fusion process. As it was already mentioned, this level has to be comparable with the energy of atoms' ionization, as the electron structure should be reconstructed without loss of negative charges.

Let us discuss the scheme of ion motion in the reactor (see Fig. 1) in order to evaluate the energy of accelerated oxygen ions. The process is initiated in the medial part of the reactor.

Positive and negative ions get in this area oppositely directed transverse velocity components and specific (per one elementary charge) kinetic energies up to 220 eV.

The action of magnetic component of Lorentz force leads to rotation of the ions in one direction (as both charge signs and velocity directions of ions are opposite). The ions move from the central area along broadening helices (owing to mutual repulsion), but in different directions — towards unlike tubular electrodes, acquiring additional energy up to 250 eV (per elementary charge). Hence, the univalent ions can obtain energies up to 470 eV in active zone. Correspondingly, bivalent oxygen ions can get energies up to 940 eV, that exceed the entire energy of oxygen atom ionization $E_{bs(i)}(8) = 870.4$ keV only by 69.6 eV. Naturally, total ionizing is not needed and does not take place, as the energy is spent for restructuration of electronic shells but not for a single electron detachment. It's obvious as well that only the ions that did not undergo collisions all the way up to the tubular electrodes vicinity, can accumulate the maximum energy. It should be noticed

in this connection that the area of plasmoid appears to be rather a vaporous interlayer with ion motion in one direction, characterized by longer times of free ion path as compared with the liquid phase. Therefore, the experimental data [3] correspond with the expected, according to (2), energy scale for intermedium quasi-molecular state formation.

It should be noted that in the independent experiments on the electrolysis of water (see, for example, [6]) formation of new elements was also observed, whereas the electric diagram of electrolyser shown in Fig. 2 allows the performance of oncoming collision of identical accelerated ions.

As a result, in case the electric potential difference makes 220 V, the maximum energy of colliding for O^{2-} ions can reach 880 eV. This value testifies for the conclusions stated above when the conditions for element fusion initiation in the reactor of electrolyser (scheme shown in Fig. 1) were analyzed.

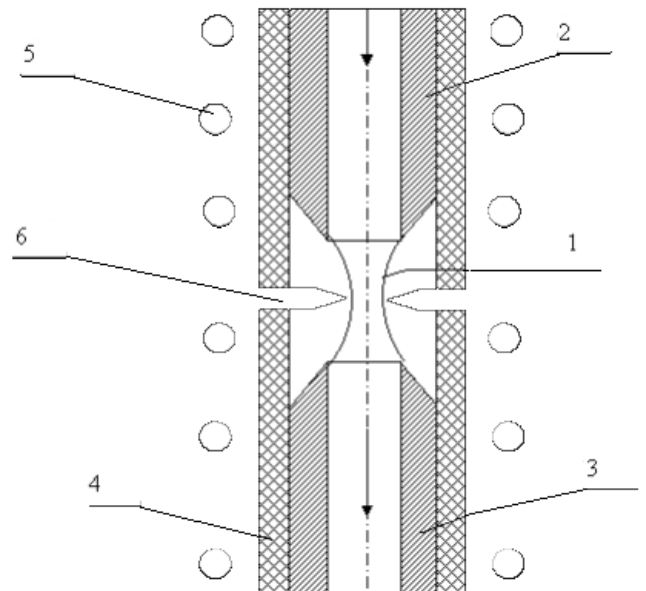


Fig. 1. Scheme of the reactor: 1 — the discharge area; 2 — upper tubular electrode; 3 — lower tubular electrode; 4 — the reactor vessel; 5 — solenoid (the inductor); 6 — pulse electrodes, arrows indicate the direction of water flow [3].

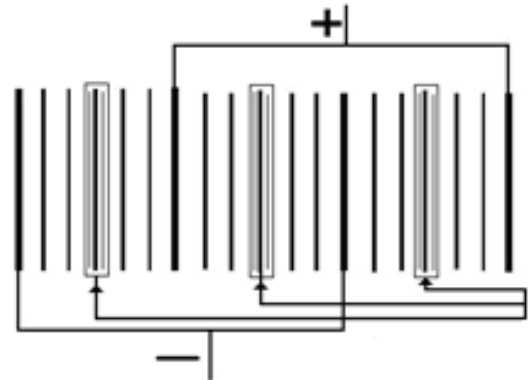


Fig. 2. The electric scheme of water electrolysis [6]

4. The final notes

The fact of formation of new chemical elements in the experiments with values of oxygen ions' energies not exceeding 1 keV, testifies (most likely without any alternative) for initiation of intermediate quasi-molecular states (IQS) in accordance with hypothetic qualitative scheme presented in the first part of this work. In this connection it seems to be important to realize at least the following program of theoretical study.

1. To develop physical models of the variants of IQS initiated owing to collisions of ions (possessing α -clustered nuclei) with energies comparable with the energy of ionization and providing rapprochement of nuclei until distance $R \sim 10^{-13}$ m.

2. To carry out the analysis of possibilities of α -particles' tunneling in the conditions of IQS. Obviously, the essential role should be given in this case to the control of quantum fluctuations, as according to [7], the state of α -clustered nucleus matter is sensitive to infinitesimal change of the locality degree of nucleon-nucleon interaction, so that quantum fluctuations can initiate an analogue of phase transition «liquid–gase». It's useful to note that adequate variants of description of tunneling have appeared also for solid state [8]; it is accompanied by sharp increase of the barrier transparency, capable to explain low-energy nuclear reactions with hydrogen isotopes participation.

3. To write down the possible variants of new elements' nuclei formation reactions considering not only pair collisions of ions, but also more complicated variants, as clusters of two or three water molecules can play the role of targets for accelerated ions. The participation of the products of preceding reactions in the chain of processes of new elements fusion should be considered as well.

4. To perform a selection of the most probable exothermic reactions that can provide self-sustaining mechanism of elements synthesis.

Besides, to obtain a more complete database, it is desirable to carry out experiments on electrolyzers of different types with precise analysis of isotope chemical composition of reaction products in gaseous, liquid and solid-state phases, with simultaneous measurement of radiation typical for the nuclear reactions.

The authors hope that in the course of this program realization, some additional possible technology solutions will be revealed as well; they will concern energy supply by means of low-temperature reactions, acceptable both from economic and ecological standpoints.

Certainly, none of the potentially perspective directions of problem solution should not be ignored. Particularly, the commercial use of canonic reaction of helium synthesis

requires solution of the problem of the lack of tritium. In this connection, successful synthesis of tritium from deuterium nuclei in the conditions of cold synthesis [9], realized with reliable reproducibility at saturation of titanium powder with deuterium, should not be ignored.

5. Conclusions

The offered hypothesis on existence of IQS as a necessary condition of implementation of the low-energy reactions of new elements formation is constructive, according to the authors' opinion, because it demands neither cardinal refusal [6] of the well-established concepts of quantum mechanics, nor qualitative assumption on nuclei refinement until deuteron level [3]. It is also obvious that the idea of intermediate quasi-molecular states, where substantial nuclei rapprochement is possible, has a broad physical meaning, not limited to the consideration of synthesis of elements with α -clustered nuclei.

References

1. S.S. Gershtein, Yu.V. Petrov, L.I. Ponomarev. *Sov. Phys. Usp.* 33 (8), 591–615 (1990). DOI: 10.1070/PU1990v033n08ABEH002619
2. V.V. Krymskiy, and V.F. Balakirev. *Doklady Physical Chemistry.* 385(4–6), 197–198 (2002). DOI: 10.1023/A:1019919424464
3. V.F. Balakirev, V.V. Krymskiy, B.V. Bolotov et al. *Interconversion of chemical elements.* Ekaterinburg, UB RAS. (2003) 97 p. (in Russian) [В.Ф. Балакирев, В. Крымский, Б.В. Болотов и др. *Взаимопревращения химических элементов.* Екатеринбург, УрО РАН. (2003) 97 с.]
4. V.V. Krymskiy, V.F. Balakirev, E.V. Litvinova, E.A. Ibragimova, M.K. Kuzmina. *J. Chem. Chem. Eng.* 7, 529–532 (2013).
5. V.V. Krymskiy, V.F. Balakirev, N.V. Plotnikova. *J. Chem. Chem. Eng.* 9, 211–217 (2015). DOI: 10.1265/1934-7375/2015.03.007
6. F.M. Kanarev. *Monograph of the microcosm.* (2015) 628p. (in Russian) [Ф.М. Канарев. *Монография микромира.* (2015) 628 с.]
7. Elhatisari S. et al. *Phys. Rev. Lett.* 117, 132501 (2016) (arXiv: 1602. 04539 [nucl-th]). DOI: 10.1103/PhysRevLett.117.132501
8. V.I. Dubinko, D.V. Laptev. *Letters on Materials.* 6(1), 16–21 (2016). DOI: 10.22226/2410-3535-2016-1-16-21
9. D.D. Afonichev, T.I. Nazarova. *Letters on Materials.* 7(1), 17–20 (2017) (in Russian) [Д.Д. Афоничев, Т.И. Назарова. *Письма о материалах.* 7(1), 17–20 (2017)]. DOI: 10.22226/2410-3535-2017-1-17-20