NUCLEAR PROCESSES IN DEUTERIUM/NATURAL HYDROGEN - METAL SYSTEMS

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The survey presents the analysis of the phenomena taking place in deuterium - metal and natural hydrogen - metal systems under cold fusion experimental conditions. The cold fusion experiments have shown that the generation of heat and helium in the deuterium-metal system without emission of energetic gamma-quanta is the result of occurrence of a chain of chemical, physical and nuclear processes observed in the system, culminating in both the fusion of deuterium nuclei and the formation of a virtual, electron-modified excited 4He nucleus. The excitation energy of the helium nucleus is transferred to the matrix through emission of conversion electrons, and that, under appropriate conditions, provides a persistent synthesis of deuterium. The processes occurring in the deuterium/natural hydrogen - metal systems have come to be known as *chemo*nuclear *DD*- and *HD*-fusion. The mechanism of stimulation of weak interaction reactions under *chemo*nuclear deuterium fusion conditions by means of strong interaction reactions has been proposed. The results of numerous experiments discussed in the survey bear witness to the validity of *chemo*nuclear fusion. From the facts discussed it is concluded that the *chemo*nuclear deuterium fusion scenario as presented in this paper may serve as a basis for expansion of deeper research and development of this ecologically clean energy source. It is shown that the natural hydrogen-based system, containing 0.015% of deuterium, also has good prospects as an energy source. The *chemo*nuclear fusion processes do not require going beyond the scope of traditional physics for their explanation.

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1. INTRODUCTION

In the last few decades, along with realization of large-scale thermonuclear fusion development programs in the context of international cooperation, a new line of fusion research has begun to develop, though still remaining unrecognized by official science and nearly unfunded by the state. This line of investigation is now often called as the condensed matter nuclear science (CMNS). However, so far this term is not the only one and generally accepted, there exist some other names such as cold fusion [1, 2], LENR [3], LNF [4].

The investigations in this field have originated from the pioneer works by Fleishman and Pons [1], who reported in March, 1989, their observation of the $2D$-fusion reaction in palladium during electrolysis in electrolytes comprising heavy water D_2O. Almost simultaneously with this, the observation of nuclear reactions in the experiments similar to those of Fleishman and Pons was reported by Jones [2]. A great many works dealing with the problem have been performed since then. In the studies of the reactions in condensed matter, the scientists have started to use not only electrolysis, but also gas discharge in deuterium, gas loading, ion implantation and other methods. The results of investigations in the field under discussion were reported at 17 international conferences and at a great number of regional meetings. Thousands of scientific articles and a variety of surveys have been published. Among them, we mention an extensive survey published in 2007 by Storms [3], one of the pioneers in the field of cold fusion research, who generalized the research results throughout the lifetime of this line of research. Many of works cited in that survey were performed at a high experimental level; they are well reproduced in the experiments of investigators from different countries and, therefore, are entirely trustworthy. As of now, more than 100 investigators have argued that they observed excessive heat release during electrolysis in heavy-water electrolytes [5]. The intensity of nuclear reactions registered by different authors ranges from $\lambda \sim 10^{-24}...10^{-23}\, s^{-1}\,(DD)^{-1}$ ("Jones level") to $\lambda \sim 10^{-19}...10^{-14}\, s^{-1}\,(DD)^{-1}$ ("Fleishman and Pons level") [3]. The heat release level observed in some experiments attained $0.8\, kW$ and more per cm3 of palladium (cf., power density in the water-moderated water-cooled reactor is $80\, W/cm^3$ [7]). There is some evidence for local cathode surface melting [3] and even for electrolysis unit blowup [8, 9, 189, 195]. Many investigators have obtained indications of the nuclear nature of the phenomenon, viz., production of "nuclear ash" - helium, transmutation of heavy nuclei, tritium generation, etc.

At present, many people believe that in all cases where appropriate measures are taken in the measurements, "the nuclear reactions in substances" are accompanied by emission of high-energy nuclear radiation of one kind or another (charged particles, γ-, X-rays, etc.). Until recently, it has been commonly believed that in all cases the level of the mentioned radiation is many orders of magnitude lower than the one that might be expected if it is assumed that the reactions of traditional thermonuclear fusion are responsible for the process. However, in their recent works, Storms and Scanlan [10, 11] have indicated that the corpuscular/ electromagnetic radiation level in cold fusion experiments may reach the values comparable to the yields of heat and helium. The level of neutron-emitting reactions is very low. A large number of theoretical investigations in the CMNS area have been carried out. However, at present there is no universally accepted theory as yet. Up till now there are no keys to three main "riddles" of cold fusion [3]:

1. What mechanism removes the Coulomb barrier-stipulated inhibition of the occurrence of D-fusion reactions?

2. How to explain in this case a striking difference between the probabilities for the neutron-emitting reaction and traditional hot fusion reaction to occur in the channels?

3. What is the mechanism of nuclear excitation energy transfer to the crystal lattice of the matrix if no radiation of gamma-quanta or charged particles at the appropriate level is detected?

Equally enigmatic is an extremely-high-at-these-conditions level of heat/helium emission reactions ("Fleischman-Pons level").

The studies on light water (H_2O) and hydrogen hold a special place in the research of nuclear reactions in a condensed matter. The statements made by Mills and Kneizys in 1991 [12] about excess heat production in their electrolysis experiments using nickel as a cathode material and the K_2CO_3 solution in light water as an electrolyte, were unexpected for many investigators. Since that time their experimental results have been reproduced at many laboratories. The methods of heat production with the use of hydrogen have been patented (Patterson I.A. [13], Piantelli [188]). However, at the present time the protium nuclear processes in a condensed matter remain on the whole substantially less well understood as compared to similar processes with deuterium.

Over many years the author of the present paper takes direct part in the set-up and execution of the investigations on the subject at the NSC KIPT (Kharkov, Ukraine). For example, in April, 1989, soon after sensational statements of Fleishman and Pons, a wide experience gained by KIPT workers in the field of radiation-matter interaction physics and nuclear physics encouraged us to discover a number of "anomalous effects" in the experiments on low-temperature implantation of deuterium into palladium. Among them, there were: the charged particle emission after termination of implantation, which pointed to the occurrence of binary (and more complicated) deuterium fusion reactions; the generation of excess heat and tritium, etc. A decisive role of thermoswings in the initiation of anomalous phenomena was disclosed (Sec.3, Ch.1). For the most part, the findings of those experiments were confirmed in our subsequent studies and the experiments of other authors (Sec.16, Ch.1).

Unfortunately, that work in its original version was not published. In the middle of April, 1989, after heated discussion at the NSC KIPT Research Council1[1] the work was sent for publication to the editorial office of the Soviet Physics-JETP (Journal of Experimental and Theoretical Physics). However, the attempt to publish the work in the official journal did not meet with success (as is now often the case with the works in this research field). The article was not accepted for publication for the reason of "a disputable character of the problem". And only after an essential revision (with exclusion of most "disputable issues" such as the excess heat emission, the role of correlated atom collisions in the realization of fusion reactions, etc.), the article was published [16, 17].

Great obstacles were up against publishing another our work (1991) "About the nature of the phenomena that initiate deuterium nuclear fusion reactions in substances" [18]. There, we have put in doubt the very idea of cold fusion "a possibility of existence of the crystal lattice conditions that are favorable for spontaneous fusion of deuterium nuclei at room temperature", and put forward the acceleration mechanism for initiation of these reactions (Sec.3, Ch.1); the effect itself was proposed to be called as "nuclear fusion in substances (NFS)".

Because of the mentioned publishing difficulties, in all our subsequent articles up to the present survey, we limited ourselves to presenting our experimental results without an extended discussion of the causes that gave rise to those results. The present work is the first (after 1991) sufficiently full presentation of our perceptions about the nature of the phenomena responsible for the occurrence of nuclear reactions in the matter.

As known, the negation of findings of any cold fusion investigation by the scientific community is based on an unconditional acceptance of the validity of three theoretical bans on the occurrence of low-temperature transmutation of chemical elements [162], namely:

1. Impossibility of Coulomb barrier penetration;

2. Extremely low cross-sections for weak processes;

3. Low probabilities for many-body collisions.

The analysis of the conditions, at which the nuclear cold fusion processes take place, has persuaded us that under real conditions these inhibitions can be cardinally overcome, and that accounts for a high level of nuclear heat/helium-emitting reactions observed in the experiments. The chain of interrelated particular chemical, physical and nuclear processes, which determine the process, has been given the conventional name the *chemo*nuclear scenario of hydrogen isotope fusion or the chemofusion[2]. Here, for brevity sake, depending on the participating ion, we shall call the processes of *chemo*nuclear fusion as $2D$-, $3D$-, ..., $ND-chemofusion$; HD-, $H2D$-, $HND-chemofusion$ and $2HD$-, ..., $NHD-chemofusion$.

Chapter 1 of the present paper is devoted to a detailed analysis of the processes composing the $ND-chemofusion$, and to the analysis of their compliance with the experiment. A similar analysis relative to the natural hydrogen-metal system is presented in Chapter 2 of the paper. Even a cursory examination of the processes composing the scenario gives grounds to believe that the reactions by the $chemofusion$ scenario will be intense in character. For example, only an increase in the deuteron energy from $E = 0.025...0.1\,eV$ (this energy is generally taken in the consideration of cold fusion processes) up to the energy values $E = 0.2...2\,keV$ expected from the $chemofusion$ scenario increases the $2D$-fusion reaction rate by hundreds of order of magnitude and makes unjustifiable the application of the LENR term to this effect. On the other hand, the cluster nature of

[1]The information about the Council was published in the press by the "Pravda" correspondent [19].

[2]The "chemosynthesis" term has been used in ref. [161] to define the effect of neutron emission in the course of chemical reactions involving deuterons. As it follows from the present paper, the "chemofusion" term refers to a substantially wider range of cold fusion effects.

fusion in the *chemo*nuclear scenario owes its existence to radiation-stimulated chemical gas-phase reactions and cannot be described in CMNS terms. This accounts for the use here of the "$chemofusion$" term and the pioneer term "cold fusion".

It is of importance to note here that, as it will follow below, the *chemo*nuclear processes do not require going beyond the scope of traditional physics for their explanation.

Chapter 1. *CHEMO*NUCLEAR FUSION IN THE DEUTERIUM-METAL SYSTEM

1.1. Three channels of the 2D-fusion reaction in vacuum

As known, the vacuum $2D$-fusion reactions can be realized with different probabilities in three channels (Table 1):

Table 1. *$2D$-fusion reaction channels*

Channel No.	Reaction (particle energy in MeV is given)	Penetrable barrier, MeV [20]		Energy release, MeV	Number of reactions per 1W of energy released $10^{12}s^{-1}$	Reaction cross section at $E = 1\,keV$, cm^2	Reaction yield in channels, %
		Coulimb	Nuclear				
1	$d+d \rightarrow {}^3He(0.82)+n(2.45)$	0	2.2	3.27	1.9	$\sim 6\cdot 10^{-33}$ [4]	~ 50
2	$d+d \rightarrow T(1.01)^+ + p(3.02)$	0.4	2.2	4.03	1.6	$\sim 6\cdot 10^{-33}$ [4]	~ 50
3	$d+d \rightarrow {}^4He+\gamma(23.8)$	0.4	0	23.8	0.26	$\sim 6\cdot 10^{-40}$ [4]	$\sim 10^{-5}$

As it follows from Table 1, in view of the given cross section values, of practical interest today may be only reactions (1) and (2), because the probability for the reaction to occur in channel (3) is six orders of magnitude lower.

This is precisely why the thermonuclear physicists all over the world are presently working to carry out in practice reactions (1) and (2), and primarily, still easier realizable processes, i.e., $d+T$ reactions.

It is known [4] that the nuclear fusion reaction cross section σ

$$\sigma = \frac{S(E)}{E}P(E) \qquad (1)$$

is defined by the product of the "intrinsic nuclear cross section"

$$\sigma_0 = \frac{S(E)}{E} \qquad (2)$$

by the quasi-classical probability $P(E)$ of charged particle penetration through the Coulomb barrier $V(r)$

$$\begin{aligned} P(E) &= \exp[-2W(E)]\,, \\ W(E) &= \int_{r_1}^{r_2}\sqrt{2\mu[V(r)-E]}dr/\hbar = \\ &= \sqrt{2\mu\langle V(E)\rangle|r_2-r_1|}/\hbar\,, \end{aligned} \qquad (3)$$

where $S(E)$ is the "astrophysical factor", i.e., the slowly varying particle energy function, which is constant $S(E) = S_0$ at a low relative energy of interacting particles in the case of nonresonant nuclear reactions (for nonresonant $2D$-fusion reactions $S_0 \approx 0.11\,MeV\cdot bn$); $r_2 - r_1$ are the classical "turning points" in the motion of one of the particles to the field of the other; μ is the reduced mass of interacting particles; $\langle V(E)\rangle$ is the mean height of the potential barrier lying above the E level.

From (1.3) it follows that the barrier width $(r_2 - r_1)$, which is a linear coordinate function, affects the barrier penetration more substantially than its mean height $\langle V(E)\rangle$ entering into eq. (1.3) as a square root.

From (1.2) and (1.3) it follows that the particle energy, the Coulomb barrier width and the astrophysical factor value may be the factors that govern the rate of deuterium fusion reaction in vacuum. However, for binary reactions of traditional hot fusion of deuterium, only the first of the mentioned factors is of practical importance.

At the present time, the most popular method of suppressing the nuclear Coulomb repulsion forces in thermonuclear investigations consists in heating the matter that comprises deuterium (or deuterium+tritium) atoms up to a temperature, at which the kinetic energy of the atoms would provide during their collisions the approach of nuclei sufficient for the realization of fusion reactions. The temperature of the deuterium-tritium mixture, required for the practical use of the method, makes $\sim 2\cdot 10^8\,K(10\,keV)$, this temperature for deuterium being still higher. The problem of maintaining this temperature for the time sufficient for positive energy release presents enormous technical difficulties, to overcome which, many investigators in different countries of the world are working for many decades.

At the same time, as first indicated in ref. [20], the fusion reaction (3) (see Tab. 1) may be expected at certain conditions to hold more promise as an energy source. Collins et al. [20] have paid attention to the fact that the realization of reaction (3) calls for the penetration of a relatively low Coulomb barrier ($\sim 0.4\,MeV$), whereas the initiation of reaction (1) involves the deuteron breakage ($\sim 2.2\,MeV$), and the realization of reaction (2) calls for the both ($\sim 0.4\,MeV$ and $2.2\,MeV$). Considering that the

tunneling reactions are very much dependent on the height and width of the barrier, there are grounds to expect that at appropriate conditions reaction (3) may become a promising source of ecologically clean nuclear energy. However, on this way enormous difficulties arise.

The point is that a low cross-section for the reaction in channel (3) is due to the fact that in the output part of the reaction only one particle is involved. As is known, the laws of conservation of energy-momentum for these reactions can be fulfilled simultaneously only under the condition that the lifetime of the excited nucleus exceeds the time required for the nucleus to release its excitation energy. In the $2D$-fusion case, the excited virtual compound nucleus 4He* exists for $\sim 10^{-22}\,s$ [21]. Up to the present time, there has been no process proposed that might remove the excitation energy of the nucleus within such a short time, and therefore it is customary to assume that there exists the forbiddenness of fundamental nature for the occurrence of reaction (3) (see Tab. 1).

However, this conclusion is in contradiction with the well-established results of numerous experimental works, where at studying the processes in deuterium-loaded solid-state matrices those authors observed both the release of substantial amounts of heat and the generation of helium in the amounts corresponding to reaction (3) (see Tab. 1) [3, 4, 5]. In the presence of the mentioned forbidding, it is also difficult to explain a well-established neutron-free character of heat-generating processes. The contradiction is removed in the chemonuclear fusion scenario considered below. Besides, in the chemonuclear fusion scenario, apart from binary reactions, consideration is given to triple deuterium fusion reactions, for which this problem no longer exists.

1.2. ND-*chemo*nuclear reaction scenario

The model of the ND-chemonuclear fusion scenario describes the ND-fusion reaction in the electron core of the $< {D_n}^+ - heavyatom >$ quasi-molecule resulting from the collision of the deuterium cluster, i.e., ${D_n}^+$ ion ($n = 2, 3...n$), which is accelerated and lined up along the motion direction, with a heavy surface atom of the conducting condensed matter.

The key tenets of the model are as follows.

1. The deuterium cluster, i.e., deuterium ion ${D_n}^+$ loaded in the electron core of the quasi-molecule (Sec.5, Ch.1), serves as an elementary cell, where deuterium nuclear fusion takes place. The fusion occurs as a result of collisions between cluster-composing deuterons as the cluster collides with a heavy atom that forms the quasi-molecule. The collision conditions are considered below.

2. In the process of *chemo*nuclear fusion, the ${D_n}^+$ ion is spontaneously produced in ionized deuterium that fills in cracks, pores and other imperfections of the matrix (Sec.4, Ch.1). At that, the deuterons of the clusters, which comprise an odd number of atoms, exhibit mutually opposite directivity of their spins, this being favorable for the occurrence of the fusion reaction (Table 2). In many cases, the ${D_n}^+$ clusters will also show a "residual" antiparallel orientation of deuteron spins, which is favorable for the fusion (Sec.4, Ch.1). Taking this into account, as well as a relative ion abundance (Sec.4, Ch.1), the *chemo*nuclear fusion scenarios are considered here with respect to the ${D_2}^+$ and ${D_3}^+$ clusters, only.

3. With application of the electric field the clusters get accelerated and lined up along the direction of the accelerating field (Sec.4, Ch.1) (further on called "aligned cluster"). The degree of cluster alignment is determined by the accelerating field potential gradient and by the factors responsible for the violation of the alignment, viz., collisions with initial gas atoms, thermal oscillation of atoms, etc.

4. Depending on the experimental conditions, the electric field responsible for the cluster acceleration can be either the field applied externally, or the field spontaneously formed in the matrix by the internal electric field under *chemo*nuclear fusion conditions (Sec.3, Ch.1). The mechanism of deuteron acceleration is determined by the experimental conditions, i.e., the matrix character, deuterium pressure, etc.

5. The aligned clusters at "head-on" collisions with a heavy target surface atom penetrate into the electron core of the atom, form a quasi-molecule with the atom (Sec.5, Ch.1), slow down in the core until their full stopping to form concentrations, i.e., collisions of atoms forming a part of the cluster, after which they get accelerated in the inverse direction. In this case, the collisional "geometry" often provides sequential atom collisions of the pattern seen in "colliding head-on collisions", thereby attaining the closest possible approach of deuterons. On account of the concepts about the wave nature of the interacting particles in the zone of deuteron merging (Sec.11, Ch.1) and a general qualitative character of process consideration in this work, we assume the head-on collision cross-section in our scenario to be $\sigma \sim \lambda^2$, where λ is the wavelength of colliding deuterons.

6. The deuteron fusion process by the *chemo*nuclear scenario proceeds actively only if the energy obtained by the cluster appears sufficient to load the cluster into the electron core of the quasi-molecule at a depth, where the electron superscreening of the reaction zone and the nuclear excitation energy carry-over by internal γ-conversion electrons cardinally intensify the process of deuterium fusion and other nuclear processes, too. A nonuniform slowing-down of cluster-constituting deuterons in the high-gradient electric field of the quasi-molecule, electron superscreening of the nuclear collision zone (Sec.6, Ch.1), removal of the excitation energy of the compound nucleus by conversion electrons, a favorable directivity of deuteron spins, a relatively long (in nuclear measures) collision time, all these factors provide the deuteron approach and a sharp increase in both the Coulomb barrier transparency and the probability of nuclear fusion (Sec.9-13, Ch.1).

7. If in the process of cluster loading into the

electron core of the quasi-molecule the capture of the electron by the cluster and the $d^+ + e^- + d^+$ quasi-molecule formation take place, the cluster deuteron merging is cardinally facilitated and, as a result, a short-lived entity, namely, an electron-modified virtual nucleus $({}^4He^* + e^-)$, is formed (Sec.10, Ch.1). In synchrony with the process of deuteron merging, the $({}^4He^* + e^-)$ compound nucleus transfers through virtual γ-quantum emission the nuclear excitation energy to the "captured" electron and the electrons of the electron core of the quasi-molecule $\langle {D^+}_n - heavy\,atom \rangle$ (Sec.7, Ch.1). The lifetime of the electron-modified virtual nucleus $({}^4He^* + e^-)$ obeys the laws of electromagnetic interaction, and makes it possible to timely entrain a part of excitation energy ΔE through emission of the "captured" electron, and that prevents the nucleus from the decay into neutrons and charged particles (Sec.9, Ch.1). The resonance synchronization gives an additional impetus to the process (Sec.10, Ch.1). In this case, the occurrence of reaction (3) (see Tab. 1) with release of heat and helium but without emission of $23.8\,MeV$ γ-quanta becomes possible:

$$\left(d^+ + e^- + d^+\right) \rightarrow \left({}^4He^* + e^-\right) \rightarrow$$
$$\rightarrow {}^4\,He_g + Q_{2\,conversion\,el.\,(23.8MeV)}\,. \qquad (4)$$

8. The emission of energetic internal conversion electrons involves the participation of acceleration mechanisms (Sec.3, Subsections 3.2, 3.3, 3.4), and thereby provides a continuous character of the *chemo*nuclear fusion process. On the other hand, the emission of internal conversion electrons increases both the degree of deuterium ionization and the rise in the process power. In this way a positive feedback between the efficiency of the process and its power is attained.

9. It may be the case that one of the deuterons, caught for whatever reason in the zone of D+n cluster collisions ($n \geq 3$), takes no part in the process of deuteron merging. But on finding itself under extreme conditions of the zone of merging of other cluster deuterons (e.g., high density of energy release with participation of conversion electrons, high density of interacting particles, etc.) (Sec.15, Ch.1), this deuteron may be involved in the reaction (1.16) responsible for bineutron production: $d + \check{e}^- \rightarrow^2 n + \nu$ (see eq. (1.16) in Sec.15).

The bineutron generation may proceed by the mechanism proposed in ref. [94], viz., inelastic resonance scattering of conversion electrons by the deuteron (Sec.14, Ch.1).

It can be expected that under these conditions the endothermal character of the reaction as well as an extremely low intensity of reactions of weak interaction forces will be overcome for the most part due to strong interaction reactions and to participation of energetic $\check{e}^-$- ("heavy") electrons in reaction (1.16) [22, 23]. Nevertheless, under *chemo*nuclear fusion conditions, the nuclear fission and transmutation reactions (Sec.16, Ch.1), specified by reaction (1.16), will proceed with an intensity many orders of magnitude lower than that of the reactions responsible for heat/ helium generation. This has qualitatively been confirmed by the experiments, where this ratio was obtained to be 10^{-10} [5]. The participation of "penetration" electrons (Sec.9, Ch.1) in this process permits also the occurrence of a rarer process of proton-to-neutron transformation (required energy of $\sim 0.786\,MeV$) [22]. The neutron generation reaction will take place in the case if in the zone of two-deuteron reaction the proton happens to be instead of the deuteron.

10. The zone of deuterium cluster stopping in the electron cloud of the quasi-molecule is the region, where the *chemo*nuclear fusion-contributing factors reach their maximum level, and therefore, the probability of deuteron fusion gets greatly increased. On the other hand, this zone is at the same time the region, where the wave properties of interacting nuclei begin to play the decisive role, and where, as a result, the interaction between the microscopic physical systems obeys the characteristic resonance laws, in particular, the principle of universal resonance synchronization (Sec.11, Ch.1). On this basis, it can be assumed that the anomalously high rate of deuterium fusion with heat/helium release, but without emission of energetic γ-quanta, as observed by many investigators in cold fusion experiments, is the result of overlapping of these two factors, and also, that the resonance synchronization additionally increases the processes responsible for nuclear fusion by the model (Sec.9-11, Ch.1), and thus increases the intensity of the deuterium fusion process up to the level found experimentally [3]. In this case, the reactions will go in a simplified channel (3) (see Tab. 1), without breaking of nuclear couplings, by way of deuteron merging and formation of the electron-modified excited virtual compound nucleus $({}^4He^* + e^-)$. The excitation energy of the compound nucleus is transferred by conversion electrons to the matrix without $23.8\,MeV$ γ-quantum emission. At that, conditions are automatically provided for reproduction of the fusion process (Sec.3, Ch.1). This fusion scenario is in qualitative agreement with experimental results, and staying in the framework of traditional physics, it explains all three "riddles" of cold fusion. The problems outlined in this paragraph are discussed in greater detail in the subsequent subsections of Chapter 1 of the work. Some peculiar properties of processes occurrence in the natural hydrogen-metal systems will be considered in Chapter 2 of this work.

1.3. Spontaneous generation of accelerated particles in hydrogen isotope-loaded solid-state matrices

The question about impossibility of spontaneous deuterium nuclear fusion in the solid crystal lattice under equilibrium conditions at room temperature was first raised in 1991 (see ref. [18]). At the same time, as early as in our first cold fusion studies (1989 [16, 17]

it was revealed that in the palladium target loaded with deuterium by the cryogenic implantation technique with subsequent holding at room temperature, binary and more complicated reactions of deuterium fusion took place. The level of the revealed reactions exceeded the Jones level by factors of 10^5 to 10^6 [2]. This conclusion was drawn by the author from the studies of spectra emitted by the neutron/charged particle-producing target, and also from the level found in the excessive heat generation experiments (Sec.16, Ch. 1). The particles were registered by the well-developed methods of nuclear physics. In accordance with the concepts of traditional nuclear physics, the deuterium fusion at this temperature might be realized with an intensity many (hundreds of) orders of magnitude lower than it was observed in our experiments.

On the other hand, the existence of any, a little bit efficient mechanism of deuteron acceleration in our palladium target experiments has seemed incredible, because in the solid target the incident deuteron energy mainly goes into electromagnetic interactions, viz., atomic excitation and ionization, the cross-sections of which, $\sigma_{el.}$, are substantially higher than the nuclear cross section $\sigma_{nucl.}$ ($\sigma_{nucl.}/\sigma_{el.} \sim 10^{-8}$ [4]). This has made us look for such conditions and processes in hydrogen-loaded solid targets, at which the deuterons participating in the reaction could be accelerated beyond the crystal lattice, e.g., in cracks or some other voids. The first model of the process was suggested in our paper [18] in 1991. The characteristic feature of our model (as well as of its subsequent modifications) lies in the consideration of radiation-stimulated chemical and nuclear processes that take place on the surface and in the volume of matrix voids. This has allowed us to establish the cluster nature of nuclear processes occurring under these conditions, that being, in our opinion, one of the most important factors governing the intensity of cold fusion processes[3]. However, this model could explain only those experiments, where the reactions of traditional hot fusion of deuterium took place in the matrix, but it failed to explain neutron-free reactions of cold fusion.

It should be noted that our work [18] was not the first attempt to propose the mechanism of accelerated charged particle generation in hydrogen isotope-loaded solid matrices. The observation of the deuterium fusion reaction at failure of the LiD crystal was first claimed in 1986 in the paper by V.A. Klyuev, A.G. Lipson et al. [24]. In their interpretation of the phenomenon those authors have put forward the idea of the initiation of electrostatic field-generating charges on the crack periphery. It was assumed that the field could accelerate the electrons and ions arriving at the crack up to an energy of ~ 1 to $10^2\,keV$, and that led, in the authors' opinion, to the occurrence of deuteron fusion reaction in the crack volume.

Later, the mechanism was also used to explain anomalous nuclear phenomena observed in deuterium-loaded transition metals Pd, Ti, etc. The issue has been considered at length by P.I. Golubnichiy and V.A. Tsaryov [25]. They understood that the extension of the fusion scenario from ionic crystals, as was the case in ref. [24], to the materials showing metallic conduction, which are the transition metal hydrides, calls for additional clarification of some issues. In particular, there is no clarity about the mechanism of appearance of the electric potential difference on the crack periphery. It is also unclear why in this case the electric field of the crack persists for $10^{-12}...10^{-13}\,s$ (the time necessary for deuteron acceleration in the crack [4]), while in the matrix having metallic conduction this time must be many orders of magnitude shorter ($\sim 10^{-15}\,s$). In our model, this contradiction is removed due to taking into account the hydrogen plasma reaction with the metal surface.

Our impact fracture experiments on deuterium-loaded palladium and titanium have not corroborated the version about possible occurrence of hot fusion by the acceleration mechanism [26] under these conditions. At the same time, the results of the experiments were not contradictory to our model of 1991 [18]. The acceleration mechanism in the form presented in ref. [25] (just as our mechanism of 1991 [18]) does not explain the neutron-free character of deuterium fusion reactions in the substance, which was revealed in cold fusion studies.

For the period of time since our publication in 1991 [18], we have developed and investigated four modifications of the 1991 model. In accordance with each of them, or their combination, at appropriate conditions in condensed substances, there may occur the processes of both traditional hot fusion and neutron-free fusion of deuterium nuclei [18, 26, 28, 139]. We shall dwell on the models as applied to the deuterium-metal system.

1.3.1. *The fractoplasma mechanism of charged particle acceleration in the condensed matter*

In the process of metal loading with hydrogen, and also, in the redistribution of hydrogen under conditions of local variations in temperature, pressure, etc., internal stresses and strains build up in the metal. The main source of stresses stems from variation in the metal volume as it gets loaded with hydrogen. For example, the alpha-beta phase change of the $Pd-H$ alloy at palladium loading to the concentration $Pd-H_{0.7}$ is accompanied by a 10 % increase in the volume. A subsequent saturation of the alloy up to $Pd-H_{0.8}$ leads to an additional 6 % increase in the volume [3]. In view of a substantial hydrogen embrittlement of the metal, this change in the volume causes the formation of numerous cracks and fractures. Since hydride phases have crystal lattices

[3] In the overview of 1994 [92], our model got in this connection the name as "fractoplasma" model.

of different sizes, the stress arises not only within the phases, but also at their interfaces.

In this case, the cracks often go along the phase interfaces, and the crack faces represent the outcrops of various crystallographic planes of the crystal. At the same time it is known that at hydrogen adsorption on transition metals such as palladium, titanium, nickel, et al., significant changes take place in the structure of $d-f$-orbitals of surface atoms and in the electronic structure of the molecules formed (s- and p-electrons), with the result that surface complexes are formed [27]. Of great importance for our consideration is the fact that in this case a part of surface complexes appears polarized and acquires a charge. Equally important is also the fact that the formation of complexes is a thermodynamically specified process, and therefore, this surface structure will be reproduced each time after its damage or at new surface formation.

To the best of adsorption reversibility, the mechanism of nuclear reaction initiation under discussion can be activated to a greater or lesser degree through variations of gas pressure over the target, the target temperature, etc. For example, the deuterium desorption at a short-time local overheating of the matrix (e.g., in the thermal peak), followed by cooling, will aid in activating the fractoplasma mechanism of nuclear fusion initiation.

Depending on the symmetry of the crystalline field, which includes the metal atom, its interaction with the molecule or hydrogen atom will vary in the character of the resulting coupling and energy. As a consequence of this, the charging rate and even the charge type (positive or negative) of different single crystal faces may be different, and that gives rise to a strong electric field inside the crack.

So, if the data of [4] on the crack sizes and the electron density on the crack face are taken as representative for our case:

crack thickness - $d = 1\mu = 1 \cdot 10^{-6}\, m$,

crack length - $l = 10\mu = 1 \cdot 10^{-5}\, m$,

ionic density on the crack face:

$\sigma = 1 \cdot 10^{13}\, ion/cm^2 = 1.6 \cdot 10^{-2}\, C/m^2$,

then the potential difference on the crack faces will be

$$V_1 - V_2 = \frac{\sigma \cdot d}{\varepsilon_0 \cdot \varepsilon} = \frac{1.6 \cdot 10^{-2} \cdot 1 \cdot 10^{-6}}{8.8 \cdot 10^{-12} \cdot l} = 2 \cdot 10^3\, V\,,$$

where ε_0 is the electrical constant, ε is the permittivity of the medium.

It can be believed that at specific experimental conditions the potential difference may reach still higher values, when it is considered that the surface ion number density may take on the values an order of magnitude higher than the density value used in our calculation.

At the same time, it has been demonstrated in ref. [18] that on emission from metal hydrogen (deuterium) often comprises an appreciable ionic component (molecular ions, protons, deuterons). The component may be of natural origin, e.g., the effect of cosmic rays, the product of decay of radioactive impurities in the matrix material, etc. The penetration of this gas in the electric field of the crack will be accompanied by production and multiplication of both energetic deuterons and their clusters (Sec. 4, Ch. 1), and also, by deuterium fusion in different channels:

- traditional hot fusion reactions in the deuterium volume that fills in the crack;

- fusion reactions at random collisions of two deuterons inside the condensed matter;

- fusion of deuterium as a part of the D_n^+ cluster in the electron cloud of quasi-molecule on the surface of the crack, pore, etc., of the condensed matter (Sec.9, Ch.1).

The probability of fusion process occurrence, in particular, reaction occurrence in channel 3 (see Table 1), increases substantially as the factors, considered here as favorable for the fusion, come into play. In the process, the character of the fractoplasma mechanism, i.e., fusion initiation due to electric potential generation on the opposite crack faces, initially remains prevailing. The fusion process at this stage will be enhanced, first of all, due to increased number of cracks and their increased total area. However, as the matrix gets cracked, the processes determined by generation of conversion electrons in the matrix (Sec.7, Ch.1) become to play a greater role.

1.3.2. *Nanostructure mechanism of deuteron acceleration*

As the matrix becomes cracked and nanoparticles accumulate in it, the fusion process will be contributed more and more by the microfields (which arise around the nanoparticles due to electric charge carry-over by conversion electrons from the particles), and also, by conversion electron-specified increase in the deuterium cluster density in the pore volume. We now estimate the parameters of the first of the mentioned processes. As shown in Sec. 7, Ch. 1, the majority of conversion electrons that participate in the $2D$- and $3D$-fusion process in the solid matrix have an energy up to $9\, keV$. For crude estimation we assume that half of the total nuclear excitation energy is carried over by $\sim 3\, keV$ electrons. Then at each event of $2D$- and $3D$-fusion, the nanoparticle, within which it took place, emits $(23.8 \cdot 10^6/3 \cdot 10^3) \cdot 2 \approx 4 \cdot 10^3$ conversion electrons.

As it follows from refs. [29-34], the fusion reactions in deuterium-loaded nanostructure matrices grow stronger as the particles are reduced in size, intensively proceeding at particle sizes of $\sim 2\, nm$ (Fig. 1). Then, for the particles, which are sufficiently isolated from the matrix (the time of charge elimination considerably exceeds the time of deuteron cluster acceleration $\tau \sim 10^{-12}\, s$ [4]) and which have the mentioned size, each event of $2D$-fusion will be accompanied by the appearance of the potential, being positive with respect to the matrix $U \sim 3 \cdot 10^3\, V$ on the particle, and

as a consequence, to the continuous deuterium fusion process, which needs no external energy input.

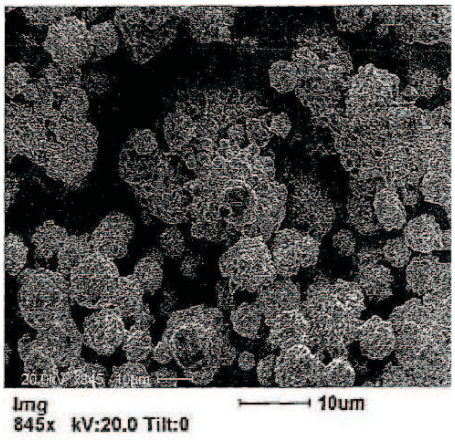

Fig.1. *[185]. Micrograph of nickel nanopowder*

The above-considered mechanisms of acceleration are efficiently realized at reduced deuterium pressure values, when the process of deuteron/deuteron cluster acceleration, and also, the process of cluster alignment are not violated by collisions of accelerated particles with residual gas atoms. These conditions are fulfilled, for example, in gas discharge experiments, during β-, α-transitions in deuterium-loaded palladium, etc. At the same time, the occurrence of anomalous nuclear reactions at gas pressure of $1\,atm$ and higher is a well-established experimental fact. The acceleration of ions at these conditions up to high energies calls for essentially higher electrical potential gradients. That can be attained at corona discharge conditions typical of electrodes that have the minimum bend radius [35]. However, steady potential gradients of $\sim 1 \cdot 10^8\,V/cm$ can be attained only in solid dielectric matrices.

1.3.3. *Microacceleration mechanism of fusion initiation in deuterium-loaded metal-insulator composite matrices*

As indicated above, the initiation of fusion reactions at high gas pressures calls for high potential gradients attainable in solid dielectric matrices. However, the charged particle acceleration at these conditions, as already stated, is impossible. As it is obvious from Fig. 2, the conditions for deuteron acceleration at a high acceleration rate can be realized in cracks (pores, fractures, etc.) of the insulator adjacent to the metal surface.

The conversion electrons, emitted in the ND-fusion event, give rise to high potential gradients in the metal-bordering insulator and, as a consequence, to a kind of charged particle microaccelerators in the cracks piercing the insulator. It is of vital importance that the potential difference results here from charge accumulation in the insulator volume surrounding the pore, and will be determined by the integral effect of deceleration of matrix-emitted conversion electrons. It can be believed that at these conditions the accelerated cluster energy will reach by this time a few kiloelectronvolts.

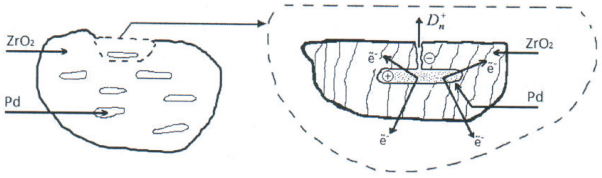

Fig.2. *Microacceleration mechanism of deuterium fusion initiation in the "metal-insulator" matrix: $D+n$ - accelerated deuterium cluster, D_n^+ - energetic conversion electrons*

It has been shown recently [183] that the excessive heat release in palladium electrolysis experiments increases as the Al_2O_3 film builds up on the cathode surface. A more detailed consideration of the phenomenon can be found in ref. [84]. The results obtained in the experiments can be treated as an evidence for functioning of the microacceleration mechanism.

1.3.4. *Quasimolecular mechanism of fusion initiation in deuterium/natural hydrogen-metal systems*

Sections 9 to 11 in Chapter 1 of this work are concerned with the model of *chemo*nuclear deuterium fusion. It is demonstrated there that in the processes constituting the *chemo*nuclear deuterium fusion scenario, the intermediate links such as the quasi-molecule $(d^+ + e^- + d^+)$ formation, the deuteron acceleration inside the quasi-molecule, and the deuteron merging into a virtual electron-modified nucleus $({}^4He^* + e^-)$, are the most important scenario links responsible for the Coulomb barrier overcoming. The mechanisms discussed in 3.2 and 3.3 replicate the process due to the conversion nature of fusion. At a high process power, the failure of the structures enabling the replication precludes the uncontrolled power growth of the fusion process.

1.3.5. *Proton (deuteron) acceleration due to collective electron beam-plasma ion interactions*

As indicated in our work of 1991 [18], experiments, where reactions simultaneously take place on both the cathode and the anode, represent a special case. This case may be observed in the experiments with a high-current plasma discharge, when at spark breakdowns, because of a strong collective interaction between the electron beam and plasma ions, the ions may acquire a very high energy $E_i \sim (mi/me)^* E_e \gg E_{e-}$. For example, as early as in the first experiments of this kind by Plyutto [159], protons of energy between 4 and 5 MeV at an applied potential of 200 to 300 keV were obtained. It

may be assumed that under certain conditions this mechanism of deuteron acceleration may take place in cold fusion experiments. In conclusion, we note that the mechanisms discussed in this section can generate particles in a wide energy range. At specific experimental conditions, a low interacting particle energy can be compensated by an increasing number of potential reaction sources, as is the case in deuterium-nanopalladium and hydrogen-nanonickel systems (Ch. 2).

1.3.6. *Experimental confirmation of the mechanisms of deuterium fusion initiation by the chemonuclear 2D-scenario*

The above-considered scenarios of deuterium fusion initiation are in satisfactory agreement with many well-established results of cold fusion experiments. By way of example, we discuss the two best known experimental results.

1. The generation of excess heat, helium and the origination of a great number of various discontinuities such as cracks, fractures, pores, etc., in cold fusion experiments - these are the three most often observed concurrent phenomena of cold fusion. This statement is well illustrated by the curves of heat release (Fig. 3) and heat-producing material density (Fig. 4) as functions of deuterium content in the materials (taken from the papers of well-known cold fusion researchers McKubre [193] and Storms [3]).

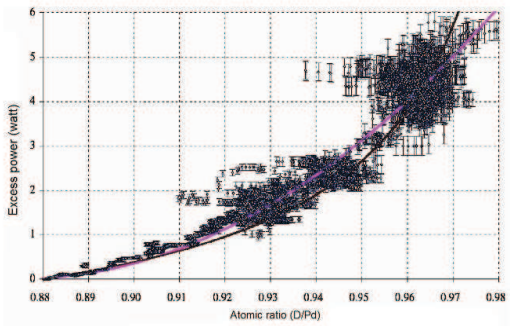

Fig.3. *Excess heat release curve as a function of the mean D:Pd ratio in the palladium cathode [193]*

The behavior of the curves in Figs. 3 and 4 appears naturally explicable by the *chemo*nuclear fusion scenario. The appearance of cracks and other fractures in the matrix (irreversible change in volume on the curve of Fig. 4) gives rise to nuclear fusion reactions by mechanism of Sec. 3, Ch. 1, this being illustrated by the heat release curve in Fig. 3. An intensive heat release increase with a further saturation of the matrix with deuterium (Fig. 3) can be due to matrix cracking and an increased contribution to the process of conversion electron fusion by the models of 3.2, 3.3 and acceleration mechanism of 3.4 (see Sec. 3, Ch. 1). The heat release increase may be also contributed by the buildup of oxide films on the cathode surface [183, 184].

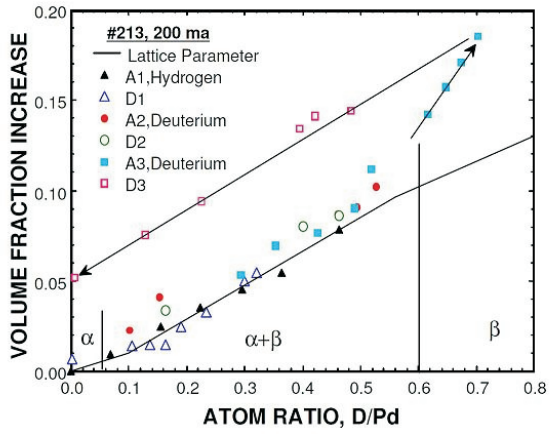

Fig.4. *Relationship between deuterium concentrations in palladium and specific volume, obtained by physical measurements and calculated from lattice parameters [3]*

2. The data in favor of the acceleration mechanism by the models described in 3.2, 3.3 and 3.4 were obtained in the works by Arata and Zhang [194]. Those authors have shown that the fine palladium powder ("palladium black"), on being loaded to gaseous deuterium, often generates excess heat, helium and tritium [31, 34, 73, 134, 135]. Those results were reproduced in a variety of works by other authors, in particular, in detailed studies of McKubre et al. [72, 76, 193]. In ref.[194] Arata and Zhang have demonstrated a positive effect of nanoparticle loading into ZrO_2 matrix on the phenomena under discussion. In that work, the palladium powder, milled down to 50$\mathring{A}$ and dispersed in the ZrO_2 matrix, on being held in the deuterium atmosphere for 50 hours without any heat supply from the outside, maintained the autoclave temperature at above room temperature. At first, the autoclave temperature rose from 20°C up to 70°C. The experiment was demonstrated by Arata in spring of 2008 in the presence of numerous world community representatives. Subsequent studies have shown the appearance of an excessive amount of helium in the autoclave during the experiment, which gave evidence for occurrence of nuclear reactions in the cell [176]. It is believed that under those experimental conditions the fusion process by the *chemo*nuclear scenario is enhanced by specific character of the properties of palladium nanoparticles saturated with deuterium up to excessively high concentrations, as indicated by Arata in his works.

1.4. $H_n^+ - (D_n^+ -)$ cluster generation during hydrogen (deuterium) gas discharge

The studies on the properties of hydrogen discharge plasma have shown that the concentration of molecular ions $H_2{}^+$ in the discharge column essentially prevails over the concentration of hydrogen atomic ions [36].

The situation is more complicated with the generation of polyatomic ions of hydrogen. The thing is that the neutral molecule H3 is unstable, and therefore, the usual ionization of the initial neutral molecule is inapplicable for production of a triatomic hydrogen ion.

Langevin [37] was the first to discover in 1905 the process of triatomic hydrogen ion production in ionized hydrogen. By the present time this process has been well understood [38, 39]. It has been shown that the $H_2{}^+$ ion, produced in the gas discharge, can polarize the H_2 molecule at collisions, and this is frequently accompanied by molecule dissociation. As a result, the process of $H_3{}^+$ ion generation goes by the reaction

$$H_2{}^+ + H_2 \rightarrow H_3{}^+ + H + 1.7\,eV. \qquad (1.5)$$

Since reaction (1.5) is the exothermal process, its cross-section may be many times (10 to 100) higher than the cross-section for neutral molecule collisions [39] and, as a consequence, the $H_3{}^+$ concentration may reach high values. The binding energy of the H_3^+ cluster, $4.18\,eV$, is close to the binding energy of the H_2 molecule, $4.48\,eV$. The $H_3{}^+$ cluster has a linear structure $(H + H + H)^+$ [40]. With application of an external electrical field the cluster lines up with the field. Under conditions of mobility measurement experiments, the H_3^+ cluster has an enormous charge-exchange cross-section ($\sim 1 \cdot 10^{-14}\,cm^2$), that hampers the generation of energetic clusters. As the cluster energy increases, the charge-exchange cross-section decreases, and the process of energetic cluster generation gets intensified.

With some correctives, the above-said may be also referred to both deuterium atom and deuterium clusters. Isotopic effects at cluster formation in protium-deuterium mixtures have not been found.

$D_3{}^+$ generation conditions are well fulfilled at hollow-cathode discharge, where the yield of triatomic deuterium atoms can attain 50% and more [41, 42, 43]. Favorable conditions for the process may also arise in the case of pulsed discharge. In ref. [44], a sharp increase in the D3+ yield (up to 70%) was observed as the magnetic field $H = 700...1500\,Oe$ was imposed on the zone of deuterium ionization by an electron beam at low pressures. In ref. [39] attention was directed to the favorable effect of the processes taking place in the target body on the $D_3{}^+$ yield.

The critical characteristics of the nucleus that determine its behavior in the interaction with other nuclei are the spin value and directivity. For deuterons (deuteron-boson) being within the distance of nuclear force action, the $2D$-reaction goes intensively only if their spins have antiparallel orientations, because only in this case, the merging of spin-one deuterons and the production of spin-zero helium nucleus will need no additional spin rotation and overcoming of centrifugal barrier. Tab. 2 gives some properties of deuterium ions.

Table 2. *Physical properties of deuterium ions*

Ion	D^+	$D_2{}^+$	$D_3{}^+$	$D_4{}^+$	$D_5{}^+$
Number of electrons in the shell	0	1	2	3	4
Nuclear spin orientation	$\uparrow$	$\uparrow\uparrow$	$\uparrow\downarrow\uparrow$	$\uparrow\uparrow\uparrow\uparrow$	$\uparrow\downarrow\uparrow\uparrow\downarrow$
Astrophysical factor		Sdd $1 \cdot 10^2$ $keV \cdot V$ [45]	$Sddd$ $1 \cdot 10^8$ $keV \cdot V$ [45]	$Sdddd$ $1 \cdot 10^{11}$ $keV \cdot V$ [45]	–

As it is obvious from Tab. 2, this condition is fulfilled for the $D_3{}^+$ and $D_5{}^+$ ions, for which mutual magnetic-moment compensation of ionic electron shells takes place and the nuclei are oriented as a result of interaction of their spins. In view of this, the nuclear reactions with participation of ions having an even number of atoms, $D_2{}^+$ and $D_4{}^+$, may be expected to be impeded. However, it should be kept in mind that the data of Tab. 2 refer to the steady-state processes. At transient conditions typical of cold fusion, the nuclei will not always have time for spin orientation rearrangement, and therefore, the spins of nuclei participating in the reaction may substantially differ from those given in Tab. 2. It can be expected that, for example, the $D_2{}^+$ ions in the reactions will often have the "residual" deuteron spin directivity peculiar to the initial molecule D_2, because the ion acceleration time at the experimental conditions may appear substantially shorter than the time required for spin reorientation. For example, for the crack 1 to $10\,\mu m$ wide, the time of deuteron acceleration to energy of up to $1000\,eV$ makes $\sim 10^{-13}...10^{-12}\,s$ [4], while the time it takes for spin reorientation in the deuterium molecule is $\sim 5 \cdot 10^{-8}\,s$ [46]. The spin

directivity in the initial D_2 molecule can be inferred from Tab. 3, which gives the temperature dependence of orthodeuterium-paradeuterium concentration ratio.

Table 3. *[47]. Temperature dependence of the ortho-para-deuterium ratio*

T, K	Orthodeuterium content $(\uparrow\uparrow)$, %	Paradeuterium content $(\downarrow\uparrow)$, %
0	100.0	0.0
70	71.78	28.82
140	66.81	33.19
300	66.65	33.35

Under normal conditions the ortho-para transition in deuterium is a very slow process. The transition is speeded up in the presence of catalytic agents (O_2, carbon, etc.), and also, by action of ionizing radiations [47]. Thus, the spin orientation of molecular deuterium ions may strongly depend on the experimental conditions. That up to now this circumstance has not been taken into account in cold fusion studies, may account for poor reproducibility of the results of investigations in this area.

The foregoing shows that the thermodynamic conditioning of deuterium cluster formation with reaction-favorable spin orientation of constituting deuterons is, in our opinion, one of the strong features of our present cluster model of fusion. In this case, as indicated above, the main contribution to the fusion reaction comes from the ${D_2}^+$ and ${D_3}^+$ ions because of their essentially higher concentration as compared to the ${D_5}^+$ cluster (the rate constant k of ${D_3}^+$ and ${D_5}^+$ ion production in molecular gases at room temperature is equal to $30 \cdot 10^{-30}$ and $45 \cdot 10^{-32}\, cm^6/s$, respectively [48]). However, it is not improbable that there may be the conditions when the D5+ clusters will play a decisive role by reason of extremely high values of astrophysical factor in this case.

The cluster nature of deuterium fusion in condensed substances is in satisfactory agreement with the experiment.

1.5. The role of quasi-molecular states in chemonuclear reaction scenarios

It is convenient to consider the processes taking place during deuterium cluster collision with a surface heavy atom of the target in the quasi-molecule representation. The quasi-molecule model is applicable when the so-called adiabatic conditions are fulfilled (as in our case) for the velocities

$$\left(\frac{V_l}{U}\right)^2 \ll 1\,, \qquad (1.6)$$

where V_1 is the relative velocity of colliding atoms, U is the orbital velocity of the electron. The model assumes that during collisions the electrons may adiabatically (without heat exchange with the environment) change their states and form (at each sufficiently close distance $R(t)$ between scattering Z1 and Z2 nuclei) quasi-molecular orbits in the two-center Coulomb field of two nuclei Z_1 and Z_2. In the limiting case $R \to 0$, the quasi-molecular states go over into the states of quasiatom with the effective atomic number $Z = Z_1 + Z_2$ [49]. In our case, the situation is much more complicated by virtue of the fact that at the first stage of the process, a complex formation, i.e., the deuterium cluster lined up along the direction of motion, which continuously changes its dimensions as it penetrates the electron cloud of the quasi-molecule, serves as one of the quasi-molecule centers. At the second stage, still more complicated and less understood processes take place. These are the deuteron merging, the discharge of energy of the excited compound nucleus by internal conversion electrons and, as a consequence, the X-ray emission, etc. (Sec. 7-11, Ch. 1). The question of the role of quasi-molecular states in the chemonuclear fusion scenario is also discussed in Sec. 9, 10, Ch.1 and Sec. 2, Ch. 2, where it is demonstrated that the quasi-molecules $(d^+ + e^- + d^+)$ and $(p^+ + e^- + d^+)$ are most important participants of the fusion process by DD^- and HD^- cold fusion scenarios, respectively.

1.6. Electronic screening of reacting deuterium nuclei in condensed media

If the $2D$-fusion reaction takes place in a conducting condensed medium, then deuterons get enveloped in conduction electrons of the medium, screened from each other by negative charge of the electrons with the result that the penetrability of the nuclear Coulomb barrier increases and the fusion reaction cross section increases, too [50].

The point of intrigue here is that the increase in the fusion reaction, attained experimentally, is many orders of magnitude greater than its theoretical value. The screening potential value, established in the experiment $(600...800\,V)$, is higher by a factor of 2 or more than the maximum potential value $(150...200\,V)$ found by theory. The mechanism of formation of such a high screening potential is yet to be explained. As indicated by Kasagi [56], the mechanism cannot be explained by a high electron density only, "because in this case a similar effect would be also observed at deuteron collisions with the host metal nuclei, so far unobserved by anybody"[4]. Today, the very existence of such a great screening effect at deuteron energy close to zero cannot be evidently considered as sufficiently confirmed, because up to now the lowest experimentally testable energy of deuterons makes about $200\,eV$. The extrapolation of obtained results to the region of interacting particle energy, which is four orders of magnitude lower, calls for a strong substantiation. This has been indicated, in particular, in ref.[58].

[4]This statement is not indisputable, as in 1938 Strain [59] detected the $p - N$ reaction threshold to be $\sim 3\,MeV$, i.e., essentially lower as compared with the common literature value $\sim 4.6\,MeV$.

The electron screening effect in the fusion reaction in palladium at deuteron energy of about $1\,keV$ has been considered by Luo et al. [60]. Those authors assume that the difference between experimental and calculated electron screening potential values is due to a generally neglected contribution to screening from the electrons of atomic inner electron shells, whereas at deuteron energy of $\sim 1\,keV$ this contribution can make up a high percentage of the total screening effect. In that work, it has been shown that at gas discharge conditions the $\sim 1\,keV$ deuteron can approach to the palladium nucleus at a distance of 0.1?. By calculations of the authors [60], the $2D$-fusion reaction cross-section at their conditions increases by 5 orders of magnitude (from $6\cdot 10^{-33}\,cm^{-2}$ to $6\cdot 10^{-28}\,cm^{-2}$) as compared with its value found at traditional thermonuclear fusion conditions. This cross-section value is evidently most probable for binary ("random") deuteron fusion reactions at cold fusion conditions. The reactions of this intensity can account for the results of Jones's experiments [2]. However, since the electron screening does not change the probability of deuteron fusion to occur in different channels (see Table 1), then even "superscreening" by electrons of reacting nuclei can't explain the neutron-free character and other peculiarities of the cold fusion reaction.

The electron screening of reacting nuclei occupies a prominent place in the *chemo*nuclear fusion scenario, too. However, in our scenario the above-considered results may have another treatment. For example, the 2- or 3-fold excess of experimental screening potential values over the ones found by theory may be considered as an evidence for functioning of acceleration mechanisms (Sec. 3, Ch. 1) at experimental conditions of refs. [51-57]). The difference between the experimental and theoretical potential values is in good agreement with this supposition. The results can be considered as experimental validation of our model.

1.7. Conversion electron emission in *chemo*nuclear fusion scenarios

Conversion electron emission and X-ray flashing during deuterium fusion in a condensed matter are the links of one and the same phenomenon and must proceed in synchronism with equal intensities (in the number of events). However, while X-ray radiation is the phenomenon, which is well-established in cold fusion experiments (Sec.8, Ch.1) and is being investigated over many years, few reliable data can be found in the literature on the emission at these conditions of fast electrons, which might be considered as conversion electrons accompanying the X-ray radiation. We shall discuss this issue in greater detail.

As it follows from the works cited here, the deuterium fusion in a condensed substance is realized with participation of conversion electrons, widely ranging in energy. However, most of the conversion electrons belong to one of the two groups: the first group includes the electrons, which are ejected from the quasi-molecule electron core orbital nearest to the reaction zone, and have an energy up to $9\,keV$ ("standard" γ-conversion); and the second, relatively small, group that includes the electrons resulting from the "penetration" effect and having an energy up to a few megaelectronvolts ("anomalous" γ-conversion) (Sec. 9, Ch. 1).

Let us analyze for what reasons the conversion electrons of the mentioned parameters could remain unnoticed in cold fusion experiments.

To answer the question, it is necessary, first of all, to note that the assumption of the decisive role of internal γ-conversion electrons in the process of deuterium fusion in a condensed substance, as made in our scenario, is introduced here for the first time. Generally, the assumption of the existence of fast electrons under these conditions is considered as unjustified and, hence, is neglected. This refers primarily to high energy electrons, which belong by our classification to the second group. As an example, when the authors precluded a possible participation of fast conversion electrons in the fusion process, let us consider a well-conducted and tool-equipped work carried out by a group of well-known authors: Lipson, Roussetski, Karabut, Miley [54]. In their experiments with high-current pulsed discharge in the $Ti-D_2$ system they have revealed the occurrence of high-intensity $2D$- and $3D$-fusion reactions accompanied by emission of anomalously strong ionizing radiation. As the authors note, the radiation might be due to both a flux of soft X-rays ($E = 1.2...1.5\,keV$), and equally, to the electron flux of energy ranging from a few tens to a few hundreds of kiloelectronvolts. Taking into account a high experimental level of the work [54], those results can be treated as a direct evidence for deuterium fusion realization by our scenario involving the participation of conversion electrons. However, the authors of ref. [54] draw another conclusion. Their line of reasoning is that "... since it is difficult to assume the existence of electrons of these energies under gas discharge conditions at acceleration voltage of 1.5 to $2.5\,keV$, it remains to recognize soft X-rays responsible for the observed effects". A similar approach to the treatment of the experimental results can be seen in a number of other papers [106, 123, 158].

As a second example of that approach, we consider the work [106], which reports the results of long-term investigations by Karabut's group. Their experiments with a high-current gas discharge in deuterium have shown the emission of fast electrons. The electron flux power attained 10 to $12\,W$. The phenomenon was reliably reproduced in many experiments. In Karabut'c opinion, the emission of fast electrons in the experiments was a secondary process specified by the interaction of X-ray radiation with a solid. Without casting any doubt on the possibility of fast electron generation in this way, we note that under close examination of the data presented in ref. [106] one may come to another conclusion. The results can

be treated as an evidence that the observed ionizing radiation presents a flux of energetic (a few hundreds of keV and higher) conversion electrons, and also, of X-ray radiation, bremsstrahlung and beta-decay radiation. In this case, it appears possible to explain a high electron current power, observed in [106], which otherwise is difficult to explain by the occurrence of weak secondary processes in the matrix. As a secondary process of the same nature as that described in ref. [106], the author explains also the results of his earlier work, where at glow discharge in deuterium a flux of fast electrons was reliably registered beyond the experimental chamber [158]. Fig. 5,a, taken from ref. [158], shows the schematic of the experiment.

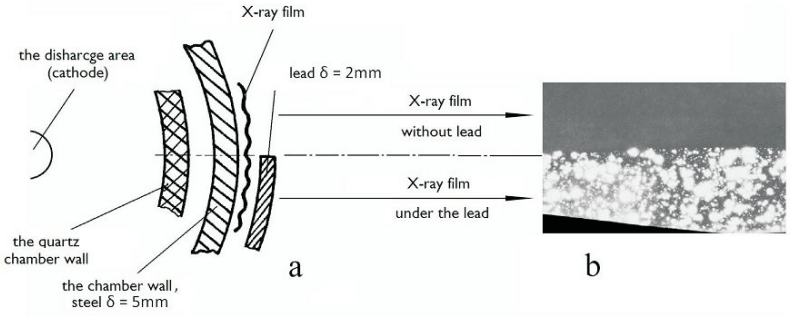

Fig.5. *[158]. (a) Experimental layout; b) X-ray film exposed in the experiment of ref. [158]*

The right-hand side of Fig. 5 shows the picture illustrating the radiative effect on the X-ray film exposed at different experimental conditions. It is easily seen that the X-ray film could be lit up in this way on condition that during the discharge the conversion electrons of energies between 6.5 and $7\,MeV$ were generated. Having passed through a steel chamber wall, these electrons remain yet sufficiently energetic ($\sim 0.5...1\,MeV$), and therefore relatively weakly interact with both the chamber wall and the emulsion layer of the X-ray film. This is demonstrated by the upper half of the picture in Fig. 5,b [158]. However, on coming to lead, the electrons lose their energy as early as at a depth of about $0.5\,mm$. This is accompanied by intense secondary-electron and X-ray radiations, just as demonstrated by the light mark in the bottom part of the film shown in Fig. 5,b [158].

To some extent, the process can also be contributed by γ-quanta that leave the excited helium nucleus after its predischarging by the "captured" electron (Sec. 9, Ch. 1). This conclusion is confirmed by the results of the recently published article by Storms and Scanlan [187] "Nature of energetic radiation emitted from a metal exposed to H_2". The residual gamma-activity found in the experiment was attributed by the authors to potassium activation under the action of the initial energetic photon radiation. The latter can take place only in the case if γ-quanta of energy $E \geq 10.1\,MeV$ ($^{41}K\ \gamma - n$-reaction threshold) are present as part of the primary radiation [187]. On the whole, the results of ref. [187], just as the results of the above-discussed work [158], testify in favor of the version about the decisive role of γ-conversion in the *chemo*nuclear scenario.

As regards the reasons, for which the 1st-group electrons ($E < 10\,keV$) are not detected in cold fusion experiments, here we note that on getting acquainted with the literature on the issue we found that in none of the experiments performed by the present time the electrons of energy below $10\,keV$ could be registered, because in all the experiments the registering instruments were coated with protective films that absorbed electrons of the mentioned energies.

And this is the answer to the third cold fusion "riddle", viz., in all the cold fusion studies done by now the overwhelming majority of the conversion electrons responsible for fusion energy removal could not be registered, while the thermal effect of the fusion reaction was registered with reasonable reliability.

Among the experimental studies, in which the observation of fast electron emission was claimed, we mention the following. The emission of $0.8 \pm 0.1\,MeV$ electrons during gas discharge in deuterium was registered in work [10]. However, in the subsequent study by the same authors, where a magnet was applied for electron identification, the electron emission was not detected [11]. In view of the aforesaid, this is quite an expected result, because in [11] the electrons of energy $E < 9\,keV$ were absorbed by the beryllium film. So, it may be thought that the experiments of refs. [10, 11] confirm the validity of our fusion scenario.

The authors of ref.[63] investigated the electron emission from a palladium target exposed to gas discharge in deuterium. A flux of energetic electrons of intensity between 10^{-6} and $10^{-8}\,A$ was observed for a few minutes after the discharge was switched off. The electron energy was not measured in this case. In the author's opinion, it is the beta-decay of excited nuclei that serves as an electron source. It may be thought that in this case, too, the registered electron flux is much contributed by conversion electrons.

Fig. 6 shows our experimental data from the study on the emission of negatively charged particles from the palladium cathode subjected to ir-

radiation in the pulsed gas discharge in deuterium [174]. The irradiation parameters were as follows: $I_{max} \sim 300\,mA$, $U_{max} \sim 1100\,V$, filling factor - 40%, deuterium pressure - 10 to $12\,mm\,Hg$, cathode thickness - $0.2\,mm$, irradiation area $\sim 0.7\,cm^2$.

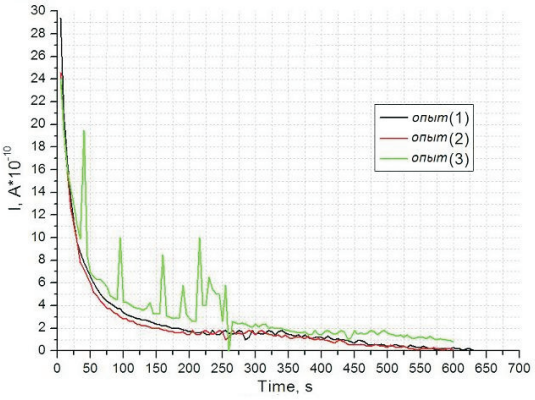

Fig.6. *Negative particle emission from the palladium cathode surface after irradiation in the deuterium discharge*

The first irradiation of the cathode lasted for about 3 hours (curve 1, Fig.6) with flashing for $10\,min$. After that, the cathode irradiation was repeated several times for $t \sim 3\,min$, then de-excitation for $\sim 10\,min$ followed in each case.

The highest recorded current value was observed after the first exposure. It was measured to be $3 \cdot 10^{-9}\,A$, whereas after the 2nd and 3rd exposures the current value dropped down to $2.4 \cdot 10^{-9}\,A$. Within 10 to 15 minutes, the current for all three exposures dropped down to $2 \cdot 10^{-10}\,A$. As it can be seen from Fig.6, the first exposure is characterized by considerable current spikes.

It can be believed that in this experiment, just as in experiment [53], along with the beta-decay, a substantial contribution to the registered flux of negative particles comes from conversion electrons. This is indicated, in particular, by the fact that the negative particle emission sharply increases with deuterium pumping.

So, the currently available experimental data on the conversion electron emission in cold fusion experiments are in qualitative agreement with our scenario concepts about the decisive role of γ-conversion electrons in the realization of deuterium fusion in the deuterium-metal system. However, this conclusion calls for further investigations.

1.8. X-ray emission in *chemo*nuclear fusion scenarios

In accordance with the *chemo*nuclear deuterium fusion scenario, along with energetic electron emission discussed in the preceding section, the X-ray emission is another basic mechanism of nuclear de-energization in cold fusion experiments. We list here the requirements to be met, in our opinion, for the process of X-ray emission in cold fusion experiments.

1. Deuterium reactions are the primary cause of nuclear process initiation in a condensed substance. Therefore, the X-ray emission of this type may take place only in the case when the reaction gas comprises deuterium, and when the process of deuterium fusion proceeds by our scenario.

2. The de-excitation of the $^4He^*$ compound nucleus is realized mainly by transfer of the excitation energy to the nearest electron from the electron core of the quasi-molecule. The occupation of the vacancy arising in this case by the electron is accompanied by X-ray radiation, which is just observed in cold fusion experiments. It suggests that the radiation energy should be, first of all, determined by the depth of cluster penetration to the electron core of the quasi-molecule, i.e., eventually, by the initial cluster energy, and should not depend strongly on the type of the heavy atom incorporated into the quasi-molecule.

3. Depending on the experimental conditions, the cluster energy may be specified by various factors (Sec.3, Ch.1). In case of Fleischman-Pons-type experiments [1], the cluster energy is assigned by intrinsic acceleration factors of the medium. In gas discharge experiments the energy is determined by simultaneous action of intrinsic acceleration factors of the medium and the factors specified by the cathode surface processes. The contribution of each factor is determined by the experimental conditions.

4. Under the conditions of our scenario, apart from the above-mentioned processes, the X-ray radiation can be caused by other, weaker processes. For example, when passing through the matrix, the fast conversion electrons participating in the above-considered processes, can initiate characteristic radiation and bremsstrahlung. In the case, when the *chemo*nuclear scenario is accompanied by nuclear reactions, the picture is supplemented with the radiation stemming from these reactions, etc.

5. The process of nuclear reaction initiation in a condensed matter by our scenario is the process connected with the occurrence of the state in the crystal lattice of the matter, far from being equilibrium, e.g., high concentration and nonuniform distribution of deuterium, production of macro- and microdefects, internal stress generation, etc. Termination of external action in this case cannot stop at once the processes of deuterium fusion and X-ray generation. The nonequilibrium state relaxation will continue for some time to create the conditions for functioning of particle acceleration and deuterium fusion initiation mechanisms, and thereby, will provide the aftereffect.

It can be demonstrated that the above-given requirements are in satisfactory agreement with the experimental cold-fusion data. For example, the statement that an intense X-ray emission of the type under consideration should take place only in the experiments involving deuterium, has been confirmed by numerous studies, and nowadays, seems to be supported by the majority of the cold fusion investigators [3].

Table 4. *[106]. Characterization of X-ray radiation in experiments with high-current gas discharge in deuterium*

Cathode material	Al	Sc	Ti	Ni	Mo	Pd	Ta	Re	Pt	Pb
Discharge voltage, V	1650	1540	1730	1650	1420	1650	1600	1520	1650	1610
Discharge current, mA	130	130	170	150	210	138	138	125	138	138
X-ray energy during discharge, keV	1.54	1.26	1.45	1.91	1.48	1.98	1.62	1.36	1.47	1.36
X-ray energy after discharge termination, keV	1.68	1.5	1.46	1.96	1.33	1.71	1.62	1.38	1.75	1.45

There are numerous evidences, which confirm that the X-ray energy is mainly determined by the energy of the cluster lined up along the direction of motion, and is little dependent on the type of the heavy atom being part of the quasimolecule. A convincing evidence for the fact is presented in Table 4 taken from Karabut's team work [106].

As it follows from Table 4, the X-ray energy is close to the potential difference across the discharge, and is little dependent on the cathode material. The fact of functioning of the above-mentioned two factors, responsible for particle acceleration, in the cathode material at cold fusion conditions can be believed as a well-established fact, too. For example, in a well-conducted experiment by Miley et al. [123], the X-ray radiation of energy $600\,eV$ and higher (internal factor) was reliably registered in deuterium discharge at an accelerating voltage of $300\,V$ (external acceleration factor). In some cases (Pd, Ni, etc.), the X-ray energy also exceeds the discharge voltage (see Table 4 [106]).

In many experiments, the X-ray energy attained a few tens/hundreds of kiloelectronvolts [3]. As indicated in item 4, this radiation may be due to secondary processes such as nuclear reaction occurrence in the matrix and interaction of energetic conversion electrons with the matrix.

Lastly, the aftereffect mentioned in item 5, was observed by many investigators on different "anomalous" cold fusion phenomena (excess heat; generation of charged particles, gamma-quanta and X-rays [3]) and was even eloquently called "Life after death" [122]).

Among the first studies testifying to the existence of the aftereffect we mention our experiments of 1989 [16, 17], where the fusion reactions were demonstrated to take place after discharge termination in palladium and titanium targets, loaded with deuterium at cryogenic implantation. The aftereffect at registration of X-rays and gamma-radiation was observed in works [61, 123]. It has been shown in ref. [123] that spontaneous deuterium release at room temperature from the deuterium-loaded palladium cathode under electrolysis is accompanied by X-ray emission of the same energy as that in the gas discharge but with intensity 10 to 11 orders of magnitude lower than in the gas-discharge experiment.

The examples considered here provide, in our opinion, a reliable testimony that an intense X-ray emission in the cold fusion experiments is caused, before all, by the occurrence of nuclear reactions by the *chemo*nuclear fusion scenario.

1.9. Deuterium fusion in the D_2^+-cluster in the quasi-molecule electron core ($2D$-*chemo*nuclear fusion)

Today, the production of "nuclear ash", i.e., helium, and the accompanying heat release without gamma-ray radiation of energies typical of thermonuclear fusion ($23.8\,MeV$), or any other radiation, which could provide the transfer of $^4He^*$ nuclear excitation energy to the matrix, is considered as one of the most well-established and "enigmatic" phenomena of cold fusion. At an early stage of the studies aimed to solve this "enigma", Schwinger [64] and Preparata [65] have proposed the mechanism of photon-phonon energy transfer from the excited nucleus to the crystal lattice of the matrix. However, in a later-dated paper [21] it was shown that the time it takes for de-energization of the $^4He^*$ nucleus by the photon-phonon mechanism without catastrophic destruction of the matrix makes about $10^{-13}\,s$, this being 9 orders of magnitude longer than the lifetime of the compound nucleus ($\sim 10^{-22}\,s$). By the present-day concepts, the deuterium fusion in the deuterium-loaded conducting matrix takes place under the conditions when the virtual compound nucleus $^4He^*$ is away from the nuclei, atoms and the matrix lattice at a distance greater than $10^{-8}\,cm$. In this case, the

nuclear excitation energy transfer (as well as of any other signal transfer) cannot occur within the time less than $\Delta t = 1 \cdot 10^{-8}/3 \cdot 10^{10} = 3 \cdot 10^{-19}\, s$. And this interval is much longer than the lifetime of the excited $^4He^*$ nucleus ($\sim 10^{-22}\, s$). As a result, the probability of $^4He^*$ decay with emission of $[n]/[T]/[\gamma]$ remains practically constant as $0.5/0.5/10^{-7}$ for E_k ranging from 0 to $100\, keV$ (E_k is the relative kinetic energy of deuterons) [21]. The probability of the reaction yield in the channels might be changed, should it appear possible during the lifetime of the excited state of the helium nucleus to reduce its energy to the level when the nuclear decay with emission of charged particles becomes impossible [21]. For example, in accord with the decay scheme, Fig. 7 [121], the decrease in the excitation energy of helium down to $E < 20.5\, MeV$ forbids the nuclear decay with neutron emission, and a further decrease in the excitation energy down to $E < 19.8\, MeV$ results in that the helium nucleus in its ground state becomes the final product of nuclear decay (after full de-energization).

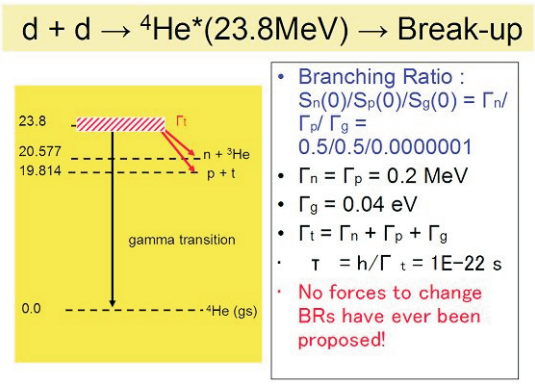

Fig. 7. *[121]. Decay channels of the 2D-fusion reaction*

However, as it can be seen from the above estimates, the photon-phonon mechanism cannot provide the necessary discharge rate of the excited helium nucleus. In our fusion scenario, the nuclear energy is carried away by conversion electrons. An essentially higher penetrating power of electrons, as compared with the photon penetrability, enables the electrons to de-excite the nucleus without any catastrophic failure of the matrix within a substantially shorter time. The idea of internal γ-conversion electron participation in the $2D$-fusion reactions in condensed materials was first put forward by the authors of ref. [20] in 1990. In their opinion, anomalies in the behavior of fusion reactions in condensed materials are determined by specific properties of deuteron environment, and, in the first place, by anomalously high density of atomic electrons and conduction electrons at the deuteron location site. By contrast, in the acceleration experiments, all electrons nearest to the reacting deuterons will be ionized or excited to high atomic or molecular levels, so that the electron density in the nuclear region will be very low in comparison with the $1s$-electron density. On this basis, the authors have assumed the occurrence of the following electron-conversion reactions in condensed materials:

$$d + d + e^- \rightarrow^4 He\,(ground\,state) + e^-\,(E = 23.84\, MeV)\,, \qquad (1.7)$$

$$d + d + e^- \rightarrow^4 He^*\,(20.1\, MeV\, level) + e^-\,(E = 3.7\, MeV)\,. \qquad (1.8)$$

Due to the fact that the nuclear excitation level of He (20.1 MeV) is below the neutron-producing reaction threshold (Fig. 7), the authors of [20] considered the reaction

$$^4He^*\,(20.1\, MeV\, level) \rightarrow t(E = 0.08\, MeV) + p\,(E = 0.23\, MeV) \qquad (1.9)$$

as a secondary reaction.

At that, it was assumed that the processes of tunneling and electron conversion ran concurrently. On the assumption that the electron conversion probability depends on the imparted energy as $\Delta E^{-5/2}$, the probabilities of reactions (1.7) and (1.8) were calculated to be 0.97 % and 99.03 %, respectively. This version of fusion mechanism was not corroborated by subsequent experiments, as they revealed no emission of conversion electrons expected in reactions (1.7) and (1.8).

However, as it will be shown below, it does not mean that the idea of occurrence of electron-conversion reactions in a condensed material is erroneous as a whole. In ref. [129], consideration has been given to the mechanism of solid-state internal conversion as applied to the *pd*-fusion reaction. The participation of electron conversion was shown to exceed the reaction rate by more than 3 orders of magnitude. The conversion efficiency with participation of heavy particles was significantly lower.

The solid body was considered in [129] only as a high-density substance, and its crystalline structure was not taken into account. In paper [130] by the same authors, the effect of the matrix lattice on the process was given consideration. It was shown that in this case the reaction intensity could increase to a still greater degree.

For example, for the reaction $p + d \rightarrow^3 He\,(5\, keV) + \gamma(5.4\, MeV)$ in the palladium lattice the estimated coefficient of internal γ-conversion with electron participation increases by a factor of $\sim 3 \cdot 10^{10}$ as compared with the coefficient estimated for the isolated deuterium atom. The authors of the cited two works note that "whenever fusion reactions take place in the solid-state environment, they are for sure accompanied by the process of solid-state internal conversion".

However, turning to the $2D$ fusion reaction, it should be recalled that by now there is no way found to change the probability of decay of the excited $^4He^*$ nucleus in different channels if the lifetime of the excited nucleus is equal to $10^{-22}\, s$ [21]. This is the main

reason why none of the proposed up to now processes is capable of solving the secret of cold fusion. Let us see how the probability of helium nuclear decay in the channels (see Table 1) will change in the case when deuterium fusion is realized by our scenario with participation of internal γ-conversion electrons. First we consider the conditions of conversion electron generation in cold fusion experiments.

As is known, the level density of the atomic nucleus grows with an increase in the excitation energy [7]. Concurrently, the level width also sharply increases. This is due to the fact that the main role in the nucleon separation from the nucleus belongs to nuclear forces, i.e., strong interactions. The strong-interaction decay widths are great, and the nuclear spectrum levels in the excitation energy region

$$E_{exc.} > E_{nucl.\,separation}\,, \qquad (1.10)$$

as is the case with the $^4He^*$ nucleus, overlap. The nuclear spectra become continuous. The energy spectrum continuity of the excited nucleus, and hence, the energy spectrum continuity of conversion electrons, strongly hampers the detection and investigation of conversion electrons. In our opinion, this is one of the main reasons why the electron conversion under cold fusion conditions still remains unexplored up to now.

Based on general considerations, we estimate the energy that can be acquired by the conversion electron under typical experimental conditions of gas discharge in deuterium [60]. As is customary to consider, in the process of internal γ-conversion the nucleus emits a virtual γ-quantum, which is immediately absorbed by the atomic shell electron. This property allows us, using the uncertainty relation [66]

$$\Delta E \cdot \Delta t \approx \hbar\,, \qquad (1.11)$$

to estimate the maximum energy that may be acquired by the conversion electron under gas discharge conditions. For estimation we shall use the data of Luo et al. [60]. Based on those data it can be expected that the "aligned" D_2^+ - cluster of initial energy $1\,keV$, penetrates the electron core of palladium to a depth, where the electron density makes 60 to 90 electrons per $\mathring{A}^3$. In this case, the distance between the cluster, where a virtual $^4He^*$ nucleus arises, and the nearest shell electrons of the quasimolecule electron core will make $\sim 2.4\cdot 10^{-9}\,cm$. Then the lifetime of the virtual γ-quantum will be

$$\Delta t \approx 2.4 \cdot 10^{-9}/3 \cdot 10^{10} \approx 8 \cdot 10^{-20}\,s \qquad (1.12)$$

and the maximum energy transferred to the electron ("standard" γ-conversion) will come to

$$\begin{aligned}\Delta E \;&\approx\; \hbar/\Delta t \approx 1.05\Delta 10^{-27}/8\Delta 10^{-20} \approx \\ &\quad 1.3 \cdot 10^{-8}\,erg \approx 9\,keV\,. \end{aligned} \qquad (1.13)$$

It is evident that the conversion process having these parameters cannot provide a timely energy *de*-excitation of the $^4He^*$ nucleus, and therefore, influence the probability of excited nucleus decay in different channels if the nuclear lifetime is $\sim 1\cdot 10^{-22}\,s$ [21]. However, the situation may radically change if the energy discharge of the helium nucleus proceeds by the mechanism of anomalous conversion with "penetration" electron participation, because the lifetime of the excited nucleus is here determined by the time of penetration electron emission by the nucleus, i.e., by electromagnetic interaction forces, and will substantially exceed the lifetime of the excited nucleus in vacuum. Let us consider this issue in more detail.

The anomalous conversion process realized by the "penetration" electrons is the process when the electron penetrates the nucleus more deeply than the nucleon, with which the electron interacts during conversion at the moment of nuclear transition ("the penetration effect"). The essential role of the effect in the case of strongly hindered γ-transitions was first indicated in 1956 by Church and Wenser [67]. They also analyzed the experimental results relating to the effect. Later on, a similar analysis of experiments was carried out by many authors; the phenomenon gained wide recognition; tables listing the known cases of anomalies in the electron γ-conversion coefficient were compiled [68].

Let us see how the ideas of the dynamics of anomalous conversion process of penetration in a condensed matter match the concepts of the *chemo*nuclear fusion scenario. It is clear that any consideration of this sort without thorough investigation into the mechanism of anomalous γ-conversion as applied to such an "exotic" object as the quasimolecule is (recall that the latter results from the collision of the deuterium cluster lined up along the direction of motion with a heavy surface atom of the matrix) may have only a known hypothetical character. However, the correspondence of the findings of this consideration to well-established experimental data will provide, in our opinion, serious grounds for intensive study of the phenomenon.

As experimental results we take the data presented in Sec. 7, Ch. 1, of the present paper. It has been shown there that the process of deuterium fusion in a condensed matter in a pulsed gas discharge [158] is accompanied by emission of conversion electrons of energies ranging between 6.5 and $7\,MeV$ ("anomalous γ-conversion"). It was shown above that in a typical gas-discharge experiment the standard γ-conversion electrons have the energy up to $9\,keV$. Our estimated parameters of conversion processes that accompany the electron emission of the mentioned energies are presented in Tab. 5.

Table 5. *Parameters of conversion processes at de-energization of the excited helium nucleus in the Pd matrix*

Conversion electron energy (maximum), MeV	Estimated time of the process, s	Excited nucleus-electron spacing, cm
6.5...7 0.09	$\leq 1.05 \cdot 10^{-22}$ $\leq 8 \cdot 10^{-20}$	$\leq 3.23 \cdot 10^{-12}$ $\leq 2.4 \cdot 10^{-9}$

The data of Table 5 encourage us to draw the following conclusions important for understanding the *chemo*nuclear fusion process:

1. In the course of deuterium *chemo*nuclear fusion, along with a standard conversion process, when the nuclear excitation energy is transferred to the electron of the nearest-to-the-reaction-zone electron core orbital of the quasi-molecule, there also occur anomalous processes of nuclear energy conversion by the "penetration" electrons. In this case, the *de*-energization of the nucleus is the responsibility of the electron "captured" in the virtual compound nucleus during deuteron approach as the cluster stops at its collision with a heavy atom.

We denote this electron-modified virtual compound nucleus by $(^4He^* + e^-)$.

2. At gas-discharge experimental conditions, the compound nucleus $(^4He^* + e^-)$ measures $R \leq 3.23 \cdot 10^{-12}\, cm.$ [5]

3. The compound nucleus $(^4He^* + e^-)$ obeys the laws of electromagnetic interactions, and therefore, its lifetime cannot be less than $\sim 10^{-20}\, s$.

Taking into consideration the "penetration effect", we offer a hypothetical picture of the processes that may take place at collision of the aligned deuterium cluster D_2^+ with a heavy surface atom of the target. Above all we note that along with a heavy atom that forms a part of the quasi-molecule, its second component, i.e., the D_2^+-cluster compressed in the quasi-molecule electron cloud, presents the formation, which is radically different from both the D_2 molecule and the helium atom. In the deuterium cluster region, the electron density of the electron cloud, which forms during drawing together of "atomic" centers of the quasi-molecule, is significantly higher than that observed in the electron core of the deuterium molecule or the helium atom. The specific character of deuteron motion in the "aligned cluster" in the cluster-heavy atom collision zone, the anomalously high density of electrons in this zone, and also, the antiparallel directivity of deuteron spins, all these factors contribute to the realization of the electron capture by the cluster and the formation of the electron-modified deuterium quasi-molecule, i.e., short-lived linear entity $(d^+ + e^- + d^+)$ [128, 178] (Sec. 10, Ch. 1). The characteristic property of the entity consists in binding of positively charged deuterons by the captured electron and, concurrently, in suppression of mutual Coulomb repulsion of deuterons by the same electron. This drastically increases the probability of deuteron drawing together in the cluster, and, as a result, initiates deuteron fusion and formation of the transient state, viz., a short-lived electron-modified virtual compound nucleus $(^4He^* + e^-)$. In synchrony with the process of deuteron merging, the compound nucleus $(^4He^* + e^-)$ transfers through virtual gamma-quantum emission the nuclear excitation energy to the "captured" electron and to the electrons of quasi-molecule electron core, and goes to its ground state.

In such a manner, the "captured" electron plays here the role of the "penetration" electron.

The lifetime of the virtual nucleus $(^4He^* + e^-)$, modified by the "captured" electron, is determined by the time of "captured" electron emission (electromagnetic interaction forces) $\geq 10^{-18}...10^{-20}\, s.$, and its *de*-energization is realized due to the conversion processes considered in Tab. 5. A substantial portion of the helium excitation energy ($\sim$ 6.5...7 MeV) is carried over by the "captured" electron. In this case, the excited nucleus loses its ability to decay with emission of charged particles and neutrons (Fig. 5), and the excitation energy can now be relieved with participation of energetic γ-quanta. However, the major portion of nuclear excitation energy in the processes will be taken away by electrons of the quasi-molecule electron core by energy portions of up to $9\, keV$. In this case, the fusion reaction is realized in the relieved channel (3), without nuclear bond breaking (Tab. 1, Ch. 1). According to ref. [20], the reactions in channels (1) and (2) proceed at these conditions with very low intensity, this being in agreement with an experimentally established neutron-free character of cold fusion reactions.

So, the fusion reactions in the $2D$ chemonuclear scenario take on the form

$$(d^+ + e^- + d^+) \rightarrow (^4He^* + e^-) \rightarrow {}^4He_{g.s.} + Q_{conv.el.}\,(23.8\, MeV)\,. \qquad (1.14)$$

This result is in good agreement with the main finding of cold fusion experiments, viz., release of heat

[5] This conclusion is in qualitative agreement with theoretical calculation of A.S. Davydov for the maximum permissible deuteron radius $4 \cdot 10^{-12}\, cm$ [167].

and helium without emission of high-energy gamma-quanta, and provides evidence for the validity of the *chemo*nuclear scenario of deuterium fusion.

1.10. On the mechanism of Coulomb barrier suppression under chemonuclear fusion conditions

An idea that electrons are responsible for the proton (deuteron) tunneling over the Coulomb barrier was first advanced and developed by Gryzinski in his investigations on chemical bonds in 1967-1987 [160, 178]. Within the framework of classical physics Gryzinski has studied bound states of the system consisting of two protons and one electron and discovered that there is a whole class of solutions when the attraction between protons and negatively charged electrons predominates over the repulsion of protons, and two initially free nuclei can approach to each other at very short distances. Gryzinski has come to a conclusion that upon atomic collisions the Coulomb barrier overcoming by particle tunneling is a process of three bodies of which one is an electron. Such a view on the tunneling process was fruitful while using it in many fields of physics: in physics of atomic collisions [179], in atomic spectroscopy [180], in investigations into atomic and molecular diamagnetism [181]. In 1989 Gryzinski, regarding the cold fusion phenomenon, has drawn far-reaching conclusions "... in principle, two deuterons in the presence of an electron can emerge at any temperature" [166]. In [128] Gryzinski presented a model developed within the framework of classical physics which describes the protium (deuterium) behavior in the palladium crystal lattice. According to this model, protium (deuterium) in the palladium crystal lattice exists in the form of a superbound state - linear quasi-molecule - "needle" in which the electron takes place strictly in the center of mass of two protons (deuterons). The electron position, such as this, provides the binding of positively charged protons (neutrons) and simultaneously suppresses the Coulomb repulsion of these particles. During the palladium phase α-β-transition the quasi-molecule losses its stability and "collapses". In the case of a D_2^+ quasi-molecule this leads to the formation of a tightly bound system - $^4He^*$. According to this model, the ^4He nucleus excitation energy is relieved by the soft X-ray radiation.

In 1990 Barut [131], while using the apparatus of the Bohr-Sommerfeld quantum theory of metals, has made up an analogous conclusion that there are three bodies in the system: two deuterons and one electron of the superbound metastable quasi-molecule - D_2^+ and obtained for the quasi-molecule binding energy the value of $50\,keV$. In 1992 Vigier [140] presented the analysis similar to the analysis by Barut.

The above-mentioned models have not obtained the recognition for some reasons. First, as was noted in the review [92], under real conditions of deuterium fusion in the condensed matter, the existence in the models of an assumed quasi-molecule strict symmetry, and, consequently, a long-living quasi-molecule, are highly improbable extraordinary events. Second, these models do not explain a neutronless character of the cold fusion process. And, at last, the process of 4He nucleus excitation energy relieving by the soft X-ray radiation, accepted in the models, can't provide the timely $^4He^*$ nucleus de-excitation, and, therefore, can't explain the fusion reaction running by the third channel of Tab. 1 (see Sec. 9, Ch. 1) with heat and helium generation, but without emission of high-energy γ-quanta. However, under conditions of fusion chemonuclear scenario development, the Gryzinski conception on the role of electrons in the Coulomb barrier overcoming takes on determining significance. In the fusion chemonuclear scenario the conception provides not only a theoretical basis for explaining of the most important part of the fusion process - a nuclear fusion under conditions of the Coulomb nuclear repulsion suppression by an electron, but, also, extends the region, where fusion reactions can occur, onto any section of the matrix lattice where in the course of experiment created are the conditions favorable for the tunneling realization by the Gryzinski mechanism. Thereby, the above-mentioned factors, forbidding the Gryzinski model existence in its original form, automatically fall away. Indeed, as it follows from the preceding paragraph, the $(d^+ + e^- + d^+)$ quasi-molecule and the electron-modified virtual $(^4He^* + e^-)$ nucleus exist, under conditions of cold fusion experiments, only as short-living transition states of the system of interacting particles, and, in this connection, are no longer rare events.

The second and the third prohibitions are no longer acting too. So, under *chemo*nuclear scenario conditions the nuclear excitation energy is relieved by the conversion electrons, while the electron, participating in the tunneling process, is simultaneously both an electron modifying a virtual helium nucleus and a "penetration" electron providing the energy relieving of the nucleus. Thus the "timely" *de*-energization of the nucleus and the reaction running by the third neutronless channel of Table 1 is provided.

The question remains as to whether the tunneling processes by the Gryzinski mechanism outside the quasi-molecule electron core can be sufficiently intensive for the intensive behavior of the first-group cold fusion phenomena (Sec. 1.6 Ch. 1) to explain with taking into account that the electron density in this case decreases by 1.5...2 orders of magnitude in comparison with the electron density in the heavy quasi-molecule core. What can we say apropos of this? First of all, note that according to [129, 130] (see Sec. 9, Ch. 1) the electron participation in the process of conversion in the conducting matrix crystal lattice ("solid state conversion") enhances the internal conversion coefficient during the $p + d \rightarrow^3 He$ reaction more than by 10 orders of magnitude in comparison with the free deuterium atom conversion coefficient. It should be expected that a like effect will take place in the case of the $d + d \rightarrow^4 He$ too.

Taking into account the above, the factors such as a high deuterium concentration, being characteristic for cold fusion experiments, exceptionally high "imperfection" of the deuterium-containing matrix ("defects" from the Frenkel pairs up to microcracks and fractures shown in Fig. 4, Fig. 11), high deuterium fluxes through the matrix etc. give grounds to expect that the tunneling process by Gryzinski can run with an appreciable intensity in the matrix and outside the quasi-molecule electron core.

So, the tunneling process by Gryzinski can occur as a final stage of the fusion process initiated by other mechanisms, as well as, an independent process of the deuteron chemonuclear fusion scenario. In any case the fusion process sustaining and development is provided by the conversion electron participation in the fusion process by our model.

1.11. Wave properties of interacting particles in the chemonuclear fusion scenario

From general statements of physics it follows that the zone of deuteron approach before the fusion, is also the site where, in the course of processes providing the deuteron fusion, the wave properties of interacting particles begin to play a decisive role. To understand how this factor can change the process picture at this stage, let us quote a relevant statement by E.Schroedinger, one of quantum mechanics' authors: "The one thing which one has to accept and which is the inalienable consequence of the wave-equation as it is used in every problem, under the most various forms, is this: that the interaction between two microscopic physical systems is controlled by a peculiar law of resonance."

Let us take into account this statement and see how the above-mentioned fusion process picture will change at this stage, having in mind that the processes in our microsystem are controlled by the resonance laws.

The question about the resonance phenomenon participation in the processes of wave system interaction was discussed in the review by F.A. Gareev, I.E. Zhidkov, Yu.A.Ratis (preprint of the Joint Institute of Nuclear Research R-4-2004-68, Dubna, [89]. The authors have examined the state of the problem under consideration for the long period beginning from the articles by H.Huygens and ending by E. Schroedinger and noted: "If in the hierarchical system the subsystem motions have almost comparable frequencies, then, as a result of interaction, the motions in the system will be synchronized, and the subsystem will move with almost comparable frequencies independently on the level of organization of the matter and micro- and macrosystem fields, as well as, interactions realized in them. And there is no interaction intensity threshold here. Basing upon the vast factual material on atomic and nuclear physics, solid state physics, molecular physics of living and inert systems, a hypothesis on the universality of a resonance synchronization principle was suggested and verified ... The resonance synchronization principle is a consequence of the fundamental law of conservation of energy ... The universal principle acts as a universal coordinating "conductor" of hierarchical systems in the micro-, macro- and megaworld ...". Then the authors of [89] note that the absence of synchronization threshold is a very important factor. "The self-synchronization necessarily will take place, provided that the difference between the partial frequencies of objects is sufficiently little. The locking in synchronism is accompanied by the established well-defined phase relations between oscillations, while in the case of self-synchronization phase absence the phases are random. The question about the time necessary for the motion synchronism be established is of importance".

The topic about the role of universal resonance synchronization processes as a universal coordinating factor of hierarchical systems was further developed in the recent paper by the authors of [125]: "Universal cooperative resonance principle of synchronization and breakthrough technologies".

Preprint [89] and paper [125] contains a conclusion which is very important for our case, namely: "It may be supposed that the resonance synchronization so much enhances weak and electromagnetic processes that the cold nuclear transmutation can be possible in principle".

Taking into account the foregoing it might be expected that the resonance synchronization contribution into the *chemo*nuclear fusion process will be especially significant since in this case many factors promoting the nuclear fusion in the *chemo*nuclear scenario will be also sufficiently effective in the formation of conditions for the resonance synchronization of motions in the interacting objects (nuclear approach, increasing the time of object interaction etc.) Now we may suggest the following: an anomalous high rate of deuterium fusion reaction with the heat and helium generation without high-energy γ-quanta, observed in the cold fusion experiments, is due to the coincidence of the above-mentioned factors. Besides, the resonance synchronization in this case additionally enhances, by optimal way, the processes responsible for the nuclear fusion by our model (Sec. 9, 10 Ch. 1). As a result, the deuterium fusion process intensity increases up to the level, observed in the cold fusion experiments. In this case the reaction goes by the facilitated way (reaction 3, Table 1) without bond breakage, nuclear fusion and formation of transition states - of an excited virtual compound-nucleus $(^4He^* + e^-)$. Synchronously with this process the conversion electrons relieve the excitation energy of the compound-nucleus without radiation of γ-quanta with the energy $E = 23.8\,MeV$.

The proposed fusion model is in good agreement with experiment and clears up all 3 mysteries of the cold fusion [3]:

- offers the mechanism permitting to reject the Coulomb barrier-caused forbidding for the fusion reaction occurrence in the condensed matter;

- explains the neutronless character of the cold fusion reaction;

- introduces into the fusion scenario a conversion mechanism of energy transfer to the matrix from nuclei subjected to the nuclear reaction that explains the third mystery of the cold fusion.

It is shown below that this model in the general case is valid also for the D_3^+ cluster (Sec. 12 and Sec. 13, Ch. 1).

The offered deuterium fusion scenario, not exceeding the scope of solid state physics and traditional nuclear physics, at a qualitative level, all the findings of cold fusion experiments.

1.12. Deuterium fusion in the cluster in the quasi-molecule electron core ($3D$ *chemo*nuclear fusion)

The scenario of deuterium fusion in the condensed matter will cardinally change if the third deuterium nucleus participates in the fusion reaction, as it is supposed in our model. The most important characteristics of $^6Li^*$, formed by fusion of three deuterons, is its lifetime in the excited state. A very long lifetime of $^6Li^*$, in comparison with the characteristic time of electromagnetic interaction processes ($10^{-18}...10^{-20}\,s$ and $10^{-15}\,s$, respectively [21]), allows one to consider the electron conversion contribution into the process of lithium nucleus de-excitation as a determining component in the fusion process of three deuterium nuclei.

On the other hand, the participation of the third heavy particle in the fusion reaction increases the intranuclear cross-section σ_0. The transition from binary collisions to the collision of three deuterium nuclei increases the astrophysical factor S and, consequently, the reaction rate too, in 10^6 times [45]. However, under conditions of the conventional hot fusion the probability of ternary reactions of deuterium nuclei is negligible low. By the estimation given in [85] the probability of such reactions in the target of inertial laser fusion, having the deuteron density higher by a factor of 100 than that of metal deuterides, will be lower in 10^{10} times than the probability of binary fusion reactions. It is due to a little lifetime of the $^4He^*$ excited state ($10^{-22}\,s$) and a comparable short reaction time for $10\,keV$ deuterium nuclei.

According to our cluster model the deuterium fusion in the deuterium-metal system is realized, in general, via the reaction of three nuclei. The resulting increase of the astrophysical factor can be one of the main causes for the high intensity of nuclear reactions under these conditions [84, 85].

As is shown in Table 2, the D_3^+ cluster, being under conditions of our scenario, has an antiparallel deuteron spin direction that promotes nuclear fusion and provides high efficiency of $3D$-fusion in the deuterium-metal system.

In Sec.9-11, Ch.1 the hypothetic model of the nuclear approach and fusion in the D_2^+ cluster, modified by the electron "captured" in the cluster, is under consideration. Conditions for such processes can occur in the case of the $3D$-fusion are close to these which exist in the $2D$-fusion. Therefore, we have every reason to assume the fusion model (Sec.9-11, Ch.1) as a process responsible for the Coulomb barrier overcoming and nuclear fusion in the case of the $3D$- fusion too. Here, similarly to the $2D$-fusion case, the high-intensity reactions would be expected to occur without need for the nuclear bond breakage.

The performed qualitative analysis of factors favorable for $3D$-fusion running by the *chemo*nuclear scenario permits to suggest that in the experiment the $3D$-fusion process might be drastically enhanced in comparison with the calculation made by the conventional methods of nuclear physics. Let us see whether this conclusion is in accord with the experiment.

1.13. $3D$-fusion reactions in the deuterium - $TiD_{1,4}$ system

For the first time a proposition to use the $3D$-fusion reaction for explaining nuclear processes in a condensed matter was made by Bekker A. [77] and Takahashi A. [78] in 1989. During next years this problem was investigated by Rabinowitz M. [79], Kim Y.E. [80] Takahashi A. [81], Kasagi J. [82], Engvild K.C. [83]. One of the first works, where this problem has been studied experimentally, was that made by Kasagi in 1995 [163]. By bombarding a deuterium-loaded titanium target with $150\,keV$ deuterons Kasagi detected protons and α-particles of energies which can't take place in the binary DD-reactions.

The complex particle spectra observed in the experiment of [163] were explained on the supposition that in the target the three-particle reactions take place, namely:

$D + D + D \rightarrow p + n + d\,.$

Unexpected was the fact that the values obtained for the reaction rate ratio $3D : 2D$ were by twelve orders of magnitude higher than the calculated values. This peculiarity was not explained in [163]. The most sequential study of a role of the $3D$-fusion reaction in the cold fusion experiments was done by the Takahashi group. Table 6 presents the decay schemes of compound nuclei $^5Li^*$ and $^6Li^*$ formed in the condensed matter. The table is made with taking into account the data obtained by Takahashi in 1995 [85]. According to the statements of the *chemo*nuclear scenario of fusion in channels (4) and (5) given in the Takahashi table [85], we have changed in Table 6 the photon-phonon mechanism of nuclear excitation energy relieving by the electron conversion mechanism. Let us see how the data given in Table 6 agree with the experiment. For this the experimental data are taken from the reports done by the Takahashi group in 2003 [84]. The authors have summarized in this report their investigations for 12 years and convincingly demonstrated that in the $TiD_{1,4}$ target, being implanted with ions of deuterium, hydrogen or silicon,

the $3D$-fusion processes were observed. In the spectra of emitted particles they have detected such ones the presence of which unambiguously evidences that in the target the decay of excited $^6Li^*$ and $^5Li^*$ takes place (Table 6, channel 1, 2, 3 and 6, 7 respectively).

Table 6. *Scheme of $^5Li^*$ and $^6Li^*$ decay channels*

$D + D + D \rightarrow^6 Li^* (25.32\,MeV) \rightarrow$

- $d(15.9\,MeV) +^4 He\,(7.90\,MeV)$ - (1) [85];
- $t(4.75\,MeV) +^3 He\,(4.75\,MeV)$ - (2) [85];
- $n + p +^4 He + 20.1\,MeV$ - (3) [85];
- $^6Li^*\,(5.7\,MeV) + Q_{conv.el.}\,(19.62\,MeV)$.
- $d\,(2.81\,MeV) +^4 He\,(1.41\,MeV)$ - (4) [*this paper*];
- $^6Li_{(g^*s)} + Q_{conv.el.}\,(23.9\,MeV)$ - (5) [*this paper*].

$H + D + D \rightarrow^5 Li^* (21.88\,MeV) \rightarrow$

- $p(19.1\,MeV) +^4 He\,(4.77\,MeV)$ - (6) [85]
- $d(3.3\,MeV) +^3 He\,(2.20\,MeV)$ - (7) [85]

Also, it has been reliably established that the $3D$-fusion under similar conditions is a result of secondary processes due to the implanted particle-target atom interaction which slightly depends on the particle nature, as it must follow from the fusion *chemo*nuclear scenario. However, under conditions of experiments done by particular authors, two results, obtained in [84], at first sight do not consist with notions on the 3D-fusion conception by our scenario. Consider the first of these results. It follows from Table 6 that the decay by channel (4) is accompanied by the emission of high-energy particles, $d\,(2.81\,MeV)$ and $^4He\,(1.41\,MeV)$, while in the emitted particle spectrum [84] these particles are not detected. At the same time in other experiments, done under similar experimental conditions, the emission of these particles was reliably evidenced, for example, emission of $2.81\,MeV$ deuterons [54], and $1.41\,MeV$ α-particles [86].

The supposed contradiction can be explained by the following. The question on the contribution of the reactions by channels (4) and (5) to the total yield of reactions in Table 6 is not studied. However, the fact, that in the cold fusion experiments the reactions, producing a larger thermal yield, are not accompanied by the appreciable γ-activity generation, means that the reaction contribution by channel (5) significantly exceeds the reaction contribution by channel (4) and the charged-particle emission by channel (4) goes with a low intensity. A particle flux of such intensity could not be detected at the high background level in this part of the spectrum obtained in (84) and this is the case of this work.

Now let us consider the second, of the abovementioned experimental results of [84]. Here, similarly to Kasagi paper [163], a very high value of the $3D/2D$ fusion reaction ratio was obtained. So, the value of the $3D/2D$ fusion reaction ratio calculated by nuclear physics method is $\sim 1 \cdot 10^{-30}$, and the value of this ratio obtained experimentally in [84] is $1 \cdot 10^{-3}...1 \cdot 10^{-4}$, i.e. higher by a factor of $10^{25}...10^{26}$. Taking into account the peculiarities of $3D$-fusion reaction running in the deuterium-$TiD_{1,4}$ system (see Sec.12, Ch.1), this mystery can be explained satisfactorily at a qualitative level. First, as is indicated in this paragraph, under influence of chemofactors inherent to the medium, the intensity of the $3D$-reaction in the deuterium-$TiD_{1,4}$ system can be drastically enhanced in comparison with its values obtained under conditions of the hot fusion. Second, as follows from the Table 4 and discussion in Sec.4, Ch.1, the thermodynamically-conditioned parallel direction of deuterons, forming the $2D$-cluster, can, under proper conditions, cardinally suppress the intensity of nuclear reactions in the $2D$-cluster. In that case the ratio of $3D/2D$ reaction rates can get an extremely high value (see [84, 163]). So, the results of [84] and [163] are satisfactory explained from the position of chemonuclear fusion and, therefore, they can be considered as experimental substantiation of our nuclear fusion scenario.

1.14. Bineutron hypothesis in the current studies

The law of charge independence of nuclear forces, that is the object of wide speculation since 40th years of the past century, is directly concerned with a hypothesis on the existence of a bineutron ^2n [90, 91]. According to the Pauli principle the bineutron can't exist in the ternary state (neutron-fermion), and exists only in the singlet state (antiparallel spin direction). At the same time, it is well-known that the singlet $(p-n)$ has no bound states. Therefore, the fact of the bineutron existence, provided that it is reliably established, might evidence that the law of charge invariance of nuclear forces does not exist [66]. To present day, despite repeated attempts, the bineutron existence was not confirmed by the nuclear physics methods.

At the same time, as is noted in [90], the peak observed in the continuous spectrum of C particles, when studying the C particle energy spectrum in the $A+B \rightarrow C +^2 n$ reactions, evidences on the existence of the neutron-neutron attraction that is somewhat insufficient for the bound state formation.

In the latter article (1985) Bochkarev et al. [144] have shown that $45 \pm 10\%$ of the yield of ^6He excited state decay is made by bineutrons. Seth and Parker [145] found confirmations of bineutron participation in the decay of ^5H, ^6H, ^8He. In [168] the report on the tetraneutron emission as a result of ^{14}Be decay is given. Today the fact that bineutron is a short-living metastable particle composed of two neutrons can be considered as recognized [146-149]. The energy of this system in the singlet state exceeds by about of $70\,keV$ a zero-point energy [90]. Near the surface of neutron-excess nuclei the bineutron can exist as a bound system [150].

Since 1989 the hypothesis on the bineutron existence is attracted for explaining anomalous nuclear

phenomena found in the experiments done by Fleischman and Pons. Critical analysis of their experimental results was performed by the known specialists in the field of CMNS: Chechin, Tsarev, Rabinowitz, Kim in 1994, review [92]. Let us cite the corresponding part of this review: "This model of the formation of two coupled n's, a bineutron ($2n$) under e-capture is similar to that of Section 4.1.5:

$$e + d \rightarrow^2 n + \nu_e. \qquad (1.15)$$

It was proposed independently by Andermann (1990), Pokropivny et al (1990), and Russell (1990,1991a, 1991b), and later by Yang (1991). The 2n energy levels were estimated from pn scattering data. The energy of the singlet 2n state was calculated to be $\sim 125..143\,keV$ by Pokropivny et al. This is close to that for $d \sim 67\,keV$. The ^2n lifetime was estimated by different approaches as $\sim 10^{-15}\,s$. They claim this is enough for CF. They assume, that the lifetime may be increased up to between 10^{-9} and $10^{-7}\,s.$, if the electron momentum can be transferred to a group of atoms or the entire crystal as in the Mossbauer effect.

The authors think that this model can explain, n, t, and He production and their absence in some experiments, as well as the sporadic nature of CF. They think that an electron with the needed energy $\sim 60\,keV$ may be produced in the electrolytic double layer, during fracture, etc."

Below the extracts from the article by Pokropivny, 1990 [94] dedicated to this model are quoted: " ... a rigorous substantiation ... is reduced to the consideration of a quantum-mechanical problem of the inelastic resonance scattering on the deuteron with the energy of $\sim 70\,keV$ close to the energy of the virtual quasi-discrete level of a two-nucleon system in the singlet or triplet state with taking into account the crystal field. A quasi-stable state of the electron with a deuteron, being arising, bound by the low centrifugal potential ($\sim 1\,MeV$) can be considered as a quasi-neutron, the lifetime of which is the higher, the closer is its energy to the virtual state of the two-nucleon system ... So, a necessary condition for obtaining a quasi-stable bineutron by the endothermal e-capture reaction is the high energy and the high electron density, as well as, observation of the indicated resonance condition ... Difference in experimental results is explained, very likely, by the difference between the electron energy and resonance values.

To verify the proposed mechanism, the parameters of experiments on the *chemo*nuclear fusion observation should be changed so that the accelerated electron energy can be changed in the range from 1 to $\sim 100\,keV$. Then, at certain values, corresponding to the energy of bineutron virtual levels, the fusion reaction rate will be significantly increased. In conclusion note: if the existence of quasi-stable bineutrons in the metal lattice will be reliably proven, than a new type of nuclear reactions with bineutron participation will be discovered - of both the fusion and the fission of lattice atoms or impurity atoms".

The author of review [92], estimating the experiments of [93-98], note the following: "There are two main objections against the bineutron model. First, the experimental data from nuclear physics testifies against the existence of $2n$. Second, the probability for the weak interaction electron capture reaction is extremely small. Even if one overlooks the necessity of having electrons with very high energy to initiate such a reaction, the small probability makes this mechanism incapable of explaining CF".

Apparently, the authors of [92] have no doubt that the bineutron generation process supposed in [93-98] exists but show up two weak points in the model which, in their opinion, make the model unsuitable for explaining the cold fusion.

What one might say about such an estimation of the results from [93-98].

First of all note, that the conclusion of the authors of [92], that the model proposed in [93-98] is incapable of explaining the cold fusion, completely coincides with the estimation of this model in the *chemo*nuclar fusion scenario (Sec. 15, Ch. 1). According to this scenario, the weak-interaction reactions in the cold fusion are secondary ones, relatively to the reactions conditioned by strong interactions which are responsible for the heat and helium generation. Therefore, these reactions can possess only a much weaker intensity as compared to the intensive primary reactions. As is noted in Sec. 15, Ch. 1, this conclusion is in good agreement with the experiment of [3-5].

However, it is necessary to consider once again the conclusion made by authors of [92] that the existence of bineutrons is not confirmed by nuclear physics. In this connection let us demand as far as possible in principle to reproduce chemonuclear fusion conditions in the nuclear physics experiments? There are four peculiarities in our scenario, being the most important for this case, which must strongly promote the production and short living of a bineutron that is impossible under conditions of the traditional nuclear physics:

1. According to the fusion chemonuclear scenario a bineutron is produced inside the $3D$-cluster at the instant when two cluster deuterons are merging due to the capture of deuterons of energetic conversion electrons, arising in the fusion process, by the third cluster deuteron (Sec. 15 Ch. 1).

2. The density of the quasi-molecule electron core in the region, where the deuterium fusion process and bineutron production occur, is higher by several orders of magnitude than the electron density that might be observed in the reaction zone under conditions of nuclear experiment (Sec. 9, Ch. 1).

3. Under conditions of our scenario the bineutron, since the production to the instant when it is absorbed by the nucleus forming the heavy atom quasi-molecule, may do not leave the quasi-molecule electron core. A very high electron core density promotes the bineutron life time.

4. One may expect that under conditions of high densities in the fusion reaction, a considerable contri-

bution to the bineutron generation would be obtained from the generation process by the Pokropivny mechanism [87, 94] on the matrix deuterons outside the nuclear fusion zone (Sec. 15, Ch. 1).

It follows from the foregoing that the situation in the electron environment of the zone, where reaction (1.15) proceeds, radically differs from that one in the *chemo*nuclear scenario where this process can occur in the experiments of nuclear physics. Therefore, the data obtained in the nuclear physics can not be sufficient to answer the question about the bineutron existence under conditions of cold fusion experiments.

At the same time, as early as in 1947 in the articles by E.Serge [99] and R.Dandel [100] it has been shown that the radioactive decay constant, for nuclei decaying with orbital electron absorption, can be changed by introducing these nuclei into different chemical compounds.

Later, Ya.B. Zeldovich and I.D. Novikov in their book [101] (1967) emphasized that "... nuclei with the neutron excess are stabilized by the electron presence". As noted above, according to [150] near the surface of neutron-excess nuclei the bineutron can exist as a bound system. Apropos of this S.V. Starodubtsev in his monograph (1969) has written: "For the last 10 years researchers obtained strong evidences of the fact that the probability of the processes, such as an electron capture or internal conversion of γ-rays, depends on the state of electron shells of decaying atoms" [102, p. 218]. To date there are many known research works in which these phenomena are reliably established and studied. These problems are thoroughly considered in the review [89], 2005. The authors of the review make a conclusion: "Energy-weak external effects can serve as a "trigger" for the forbidden processes to open or for unforbidden ones to enhance, for example, under the laser action on the photofission, the fission probability can be increased by 3-4 orders of magnitude. The nuclear β-decay into the atomic bound states can be enhanced due to the ionization by 9 orders of magnitude, and the enhancement of the spontaneous fission from the nuclear isomeric state, as compared to the ground state, can reach 20-29 orders".

And, at last, in Sec. 15-16, Ch. 1 it is shown that admission of the fact of bineutron existence permits to clarify some phenomena, reliably established in the cold fusion experiments, but not yet explained: nuclear fission and nuclear transmutation, generation of high-energy neutrons, protons and α-particles, tritium production etc.

Thus, there are reasons to admit the hypothesis, as a working one, on the metastable bineutron existence under cold fusion conditions and to see how this hypothesis agrees with the notions of the deuterium fusion running by the *chemo*nuclear scenario.

1.15. Weak-interaction reaction and the bineutron in the deuterium *chemo*nuclear fusion scenario

As it follows from the above-mentioned discussion (Sec. 9-13, Ch. 1) the deuterium fusion *chemo*nuclear scenario satisfactorily explains the nature of phenomena responsible for the heat and helium generation in the cold fusion experiments. However, at the early stage of this direction developing in the experiments other phenomena were also discovered, but much weaker as compared to the before-named, e.g. production of chemical element impurities having an isotope composition distinct from the natural one, generation of high-energy neutrons, protons, ?-particles etc. The intensity of the processes of this group is lower by ten and more orders than the intensity of processes responsible for the heat and helium generation [3, 5,156]. Existence of these processes can be considered as an evidence of weak-interaction reactions, taking place under cold-fusion conditions, which are highly improbable under vacuum conditions.

Let us consider this problem in more details. To initiate the reaction with weak-interaction of two protons in vacuum, accepted today in astrophysics,

$$p+p \rightarrow d+e^{+}+\nu_e\,, \qquad (1.16)$$

it is necessary for one of protons in the left side of reaction (1.16) to transform into neutron

$$p \rightarrow n + e^{+} + \nu_e\,(-1.8\,MeV). \qquad (1.17)$$

This, as follows from (1.17), is a deep endothermal process which can be realized in the case of fluctuation weak proton decay into neutron, positron and neutrino. That is why reactions (1.16) and (1.17), having a very low intensity, were not observed in the laboratory conditions.

The astrophysical factor S for reaction (1.16), characterizing the intensity of intranuclear processes, is in 10^{24} times less than the values of this factor for $d-d$-reactions [121].

If the deuteron generation process takes place in the conducting matrix, similarly to the case of cold fusion experiments, then the matrix electron participates in the reaction and the reaction takes the following form

$$p + p + e^{-} \rightarrow d + \nu_e\,, \qquad (1.18)$$

Under these conditions the transformation of one of protons in reaction (1.18) into neutron goes via the weak-interaction reaction - by the k-capture of the electron

$$p+e^{-} \rightarrow n+\nu_e\,(-0.786\,MeV). \qquad (1.19)$$

Reaction (1.19) is appreciably more intensive as compared to reaction (1.17): first, in reaction (1.19) a very slow stage of reaction (1.17) is excluded - a weak fluctuation process of proton decay into neutron, positron and neutrino, and, second, in this case the reaction threshold was decreased from 1.8 to $0.786\,MeV$. However, because of the endothermal character of reaction (1.19) and the slow process of electron transformation into neutrino, reaction (1.19) is still an improbable event: the calculated value of the reaction cross-section in this case is $\leq 10^{-20}\,barn$ [169, 170]. When reaction (1.19) takes place on the proton, being in the nuclear composition, the energy necessary for the reaction is provided due to the nuclear rearrangement in the course of k-capture. It is

natural that this event happens only on the nuclei predisposed to this process: upon observation of selection rules and conservation laws existing in nuclear physics and, first of all, if it is an energy- favorable process [171, 192]. Then the reaction duration is determined, above all, by the time necessary for the nuclear structure transformation and often comes to the well-observed values.

Under *chemo*nuclear fusion conditions the character of this process can be cardinally changed. The cluster nature of the fusion process in this scenario creates real preconditions for overcoming the energy barrier of the neutron production reaction (1.19) and the bineutron production reaction (1.20), now due to the strong-interaction reactions, namely, the reactions generating ^3He and ^4He by our model (Sec.9-11, Ch.1). Let us consider this process by the example of the $3D$-fusion reaction in the conducting condensed matter. In the course of *chemo*nuclear fusion one of three deuterons, getting into the zone of D_3^+-cluster collision with a heavy surface atom, may not participate, for some reason, in the deuteron fusion process. Then such deuteron, being under extreme conditions of the zone where two other deuterons are merging (local release of energy in large quantities, high intensity of gamma-conversion processes, high density of interacting particles etc.), can be involved into the reaction responsible for the bineutron production by the Pokropivny mechanism [94]:

$$D + \tilde{e}^- \rightarrow^2 n + \nu_e\,, \qquad (1.20)$$

where, $\tilde{e}^-$ - is a high-energy electron, ^2n is a bineutron.

Participation of quasi-molecule electron-core electrons in the excitation energy relieving not only excludes a slow stage of reaction (1.16) - a weak fluctuation process of proton decay into neutron, positron and neutrino, but also provides conditions under which the energy, transferred to the proton being in the deuteron composition, is sufficient to compensate the endothermal character of reaction (1.20) ($E \sim 60\,keV$) [94].

Due to the participation of "penetration" electrons in this process (Sec. 9, Ch. 1) there a more rare (requiring the energy of $\sim 0.786\,MeV$) process of proton conversion into neutron takes place [22]. The neutron generation reaction can occur in the case when in the zone of two-deuteron reaction a proton instead of a deuteron will takes place. The particles -neutron and bineutron, produced in these reactions will possess ultra-low energies. Neutrons of such energy, having a very large cross-section of interaction with nuclei of elements, will be absorbed by nuclei within the range of several angstrom units [22]. A bineutron, most probably, will interact with the nuclei of a heavy atom forming a quasi-molecule.

Tab. 7 presents the most possible nuclear reactions which can take place in the deuterton-palladium system, if quasi-stable bineutrons are participating in the reaction [142]. To simplify the examination and to improve the evidence in the table a particular case is under consideration: the deuterium fusion reaction in the $D3$ - cluster at the cluster collision with a nuclide $_{46}Pd^{104}$ of the palladium-target.

Table 7. *Nuclear reaction with bineutron participation in the chemonuclear $3-D$ fusion*

$(d^+ + e^- + d^+ + e^- + d^+) \rightarrow (d^+ + e^- + d^+) + d^+ \rightarrow (^4He^* + e^-) + d^+ \rightarrow^4 He_{g.s.} + Q_1(\tilde{e}^-_{conv.}) + d^+ \rightarrow$ $\rightarrow^4 He_{g.s.} +^2 n + \nu_e\,;$	(1)
$(d^+ + e^- + d^+ + e^- + p^+) \rightarrow (d^+ + e^- + d^+) + p^+ \rightarrow (^4He^* + e^-) + p^+ \rightarrow^4 He_{g.s.} + Q_2(\tilde{e}^-_{conv.}) + p \rightarrow$ $\rightarrow^4 He_{g.s.} + n + \nu_e\,;$	(2)
$\mid \rightarrow\ f \rightarrow Nu_1(_{26}Fe^{58});$	
$\mid \rightarrow\ f \rightarrow Nu_2(_{20}Ca^{48});$	(3.1)
$_{46}Pd^{104} +^2 n \rightarrow_{46} Pd^{106*} \rightarrow \langle \mid \rightarrow\ _{46}Pd^{105} + n\,(8.48\,MeV);$	(3.2)
$\mid \rightarrow\ _{45}Rh^{105} \quad \beta;\ 35.4\,hr + p\,(7.2\,MeV);$	(3.3)
$\mid \rightarrow\ _{44}Ru^{102} + \alpha\,(11.6\,MeV);$	(3.4)
$\mid \rightarrow\ _{46}Pd^{106} + Q_3\,(\tilde{e}^-_{conv.});$	(3.5)
$d +^2 n \rightarrow T\,(1.56\,MeV) + n\,(4.64\,MeV) - d + T\,(1.56\,MeV) \rightarrow \alpha\,(6.9 - 1.44\,MeV) + n\,(12.5 - 17.7\,MeV)$	(4)
$_{46}Pd^{104} + n \rightarrow_{46} Pd^{105*} \rightarrow_{46} Pd^{105}_{g.s.} + Q_4(\tilde{e}^-_{conv.})$	(5)

In Tab. 7 the symbol Q_n ($\tilde{e}^-_{conv}$) designates the excitation energy of the nucleus Q_n taken away by fast conversion electrons ($\tilde{e}^-_{conv}$).

1.16. Cold fusion - deuterium *chemo*nuclear fusion in the deuterium-metal system

From the above consideration it follows that the numerous anomalous phenomena observed in the cold fusion experiments can be divided into two large groups. The first group includes phenomena leading to the heat and helium production. To date these phenomena are reliable evidences observed in the studies of more than hundred researchers [5]. An anomalous high intensity of the first-group phenomena indicates to their nuclear nature. In the *chemo*nuclear scenario the existence of these

processes is related with the fusion reaction running through the relieved third channel of Tab. 1. These processes occur with participation of Dn-clusters where $n \geq 2$. The model of deuterium *chemo*nuclear fusion explains all the observed phenomena from this group (including three cold fusion "mysteries") and therefore in the part of a strong-interaction reaction the model can be considered as reliably confirmed by the cold fusion experiments ((Sec. 9-13 Ch. 1).

The second-group phenomena are: production, in the cold fusion experiments, of elemental impurities having an anomalous isotope composition, generation of energetic neutrons, protons and α-particles, tritium recovery etc. The intensity of phenomena of this group is lower by 6 - 10 orders of magnitude than that of the first-group phenomena. In the *chemo*nuclear fusion scenario the existence of the second-group phenomena is related with the occurence of weak-interaction reactions under cold fusion conditions (Sec. 14-15 Ch. 1). As is noted in Sec. 15 Ch. 1, in accordance with the statements of nuclear physics the endothermic character of the reaction with proton transformation into neutron (1.19), when neutron enters into the nuclear composition, is overcome due to the strong interactions, i.e. nuclear rearrangement [7, 171, 192]. A cluster nature of the *chemo*nuclear fusion process has permitted us to apply a similar approach to the virtual compound nucleus (which is an electron-modified nucleus $({}^4He^* + e^-)$ (Sec. 15 Ch. 1) formed at the collision between the "aligned" $3D$ cluster and the heavy atom), and to consider the second-group phenomena as a result of weak-interaction reactions radically enhanced in the zone of deuterium nuclear fusion.

In this connection it is obvious that the second-group phenomena require more than two deuterons to be realized. As a result of the $D + D + D$ cluster inclusion bineutrons are generated, and when the $D + D + H$ cluster is joined, then neutrons are generated (Tab. 7, Sec. 15 Ch. 1). The neutron emission detection in the cold fusion experiments indicates the participation in the fusion process of the clusters composed of 3 or more atoms. The purpose of this paragraph is to show that the second-group phenomena also can be satisfactorily described at a qualitative level by the deuterium *chemo*nuclear fusion scenario.

1.16.1. *Production of impurities having an anomalous isotope composition*

From Table 7, reaction (3.1) it follows that the impurity production in the process of *chemo*nuclear $3D$-fusion is related, first of all, with fission of target nuclei excited as a result of bineutron absorption. So, in the case when a nuclide ${}_{46}Pd^{104}$ serves as a quasi-molecule heavy atom, according to Table 7, the bineutron absorption by the nucleus ${}_{46}Pd^{104}$ leads to the formation of a nucleus ${}_{46}Pd^{106*}$ excited to $E_{excit} \approx 16\,MeV$. At the same time, as is shown in [142], the level of fission of this nucleus by the channel with production of stable nuclei is $E_{fiss} \approx 13.2\,MeV$. Thus, as a result of bineutron absorption the palladium nucleus may break apart in two stable fragments ${}_{26}Fe^{58}$ and ${}_{20}Ca^{48}$ [142]. The fragments produced by reaction (3.1) in other cases will be of a stable character too. It is determined by two factors. A main factor is a "slow" nature of fission process under these conditions. The fission reaction rate in the *chemo*nuclear fusion reaction is determined by the "alternating" absorption of neutrons within the bineutron, by the heavy nucleus constituting the quasi-molecule, and, thereby, has a relatively slow character. At the same time, as is shown in [151] the fission reactions, being of a slow character in comparison with uranium-235 fission reactions, do not produce neutrons, α-particles and gamma-rays and do not form radioactive fragments. This is because in the case of "slow" fission the excited nucleus has the time for the choice of the most thermodynamically suitable fission channel - in order to break apart into stable nuclei.

On the other hand, the residual radioactivity of palladium fission fragments will be low as these fragments have a much higher surface tension, as compared with heavy uranium fission fragments, and, consequently, have a stable spherical form [142]. Nuclei of this type can't possess a residual radioactivity, inherent to heavy deformed nuclei of uranium fission fragments, conditioned by the nuclear shape relaxation. Let us give an example which evidences on the nuclear fission reaction contribution to the impurity element production in the cold fusion experiments and on the bineutron fission initiation.

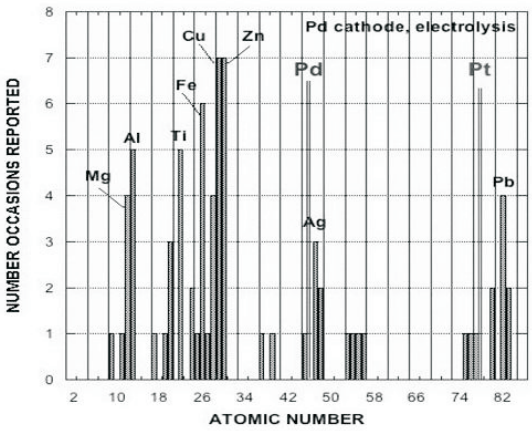

Fig.8. *Histogram showing a number of occasions reported when on the cathode surface observed were anomalous chemical elements against the atomic number of these elements*

Fig. 8 presents the histogram taken of Preprint [172], showing a number of occasions, when authors observed impurity elements on the cathode surface after electrolysis and gas-discharge experiments, as a function of the atomic number of these elements. In experiments a cathode material was palladium and in electrolysis experiments platinum was used as an anode material. It is seen from the histogram that the impurity is composed, for the most part, of elements

with the atomic weight almost equal to the half of the palladium atomic weight. This corresponds to the supposition that these products are produced as a result of palladium nuclear fission (and, in some cases, of platinum which is transported to the cathode by the electrolysis). Radioactive products, among these presented in the histogram, are observed rarely and, as a rule, they refer to the heavy nuclides taking place in the region of palladium and platinum. The appearance of radioactive products indicates on the running of reactions (2), (3.2), (3.3), (3.4) and (3.5), Table 7.

An argument for the bineutron mechanism of nuclear fission is also the correlation between the excess heat release and impurity production observed in a series of experiments (see [177]). According to the *chemo*nuclear fusion scenario the bineutron generation is in direct relationship with the fusion process intensity by this scenario.

"Heavy" tracks detected in [153, 154] using a CR-39 detector are, as is noted in [151], a direct evidence for the nuclear fission reaction occurrence under cold fusion conditions. So, the version, accepted in this paper, about participation of weak-interaction reactions and bineutron in the deuterium *chemo*nuclear fusion is in good accordance with the experiment.

1.16.2. *Bineutron mechanism of generation of energetic α-particles, protons and neutrons*

Emission of energetic (10...14 MeV) α-particles is one of the cold fusion phenomena which still await clarification [3, 136]. Up to now there is no explanation for experimental results obtained by A. Roussetski in [136], where the generation of protons with the energy from 5.8 to 7.8 MeV has been reliably established, and by J. Kasagi in [163], where the generation of neutrons with the energy from 3 to 10 MeV was observed. Let us show that the emission of such particles in their experiments might be a consequence of the reaction occurrence with bineutron participation.

The bineutron absorption leads to excitation of a heavy atom nucleus up to the level when the nuclear excitation energy E_{excit} significantly exceeds the energy of nucleon separation from the nucleus - $E_{nucl.separ}$. In this case, the energy de-excitation of the nucleus, if it has not had yet split, before nuclear fission (see p. 1 Sec. 16 Ch. 1) will happen due to the emission of n, p nucleons or their clusters d, T, ^3He, ^4He.

The probability of nuclear γ-quantum radiation in the region of high excitation energies $E_{excit} > E_{nucl.separ}$ is substantially lower than the probability of nucleon emission as the electromagnetic interaction constant is lower by two orders than the strong interaction constant. In Tab. 7 the process of nuclear relieving due to the fast particle emission is demonstrated by reactions (3.2)-(3.4). In Table 8 the calculated values of the fast particle energy, we have obtained in reactions (3.2)-(3.4), Tab. 7, are compared with experimental ones. It follows from Tab. 8 that all the calculated energy values are in good accord with the experiment.

So, the experimental results given in this paragraph convincingly confirm the bineutron mechanism of origin of energetic α-particles, protons and neutrons in the cold fusion experiments.

Table 8. *High-energy α-particles, protons and neutrons in the deuterium chemonuclear fusion scenario*

Palladium isotopes	102	104	105	106	107	108	110
E_ω, calculated, MeV	14,436	11,627	12,054	11,464	2,05	10,139	8,756
E_ω,, experimental, MeV [136, 156]	14,0 ... 9,2	14,0 ... 9,2	14,0 ... 9,2	14,0 ... 9,2	14,0 ... 9,2	14,0 ... 9,2	
E_p calculated, MeV	8,86	7,2	6,74	5,26	5,45	-	-
E_p, experimental, MeV [136, 156]	7,8	-	-	5,6	-	-	-
E_n, calculated, MeV [156, 163]	7,54	8,84	9,48,	6,47	9,47	6,09	5,7
E_n, experimental, MeV [156, 163]	10...3	10...3	10...3	10...3	10...3	10...3	10...3

However, the neutron generation in the cold fusion experiments is a phenomenon for which contradictory, in many respects, results were obtained. In this connection this problem will be considered in more details. As stated above, to date most of the cold-fusion experimental results show that the intensity of this phenomenon is lower by ten of orders as compared with phenomena responsible for the heat and helium generation [5]. Nevertheless, some cases are known when in the properly done experiments the neutron emission was recorded with a high reliability at a much higher intensity level [3]. As an example let us consider the results of our above-mentioned experiment done in 1989 [16]. The main results on neutron emission were obtained in experiments with palladium and titanium samples. First the samples were subjected to cryogenic saturation with deuterium and then to heating in vacuum at a temperature from 78 K to 1300 K and a rate from 1.5 to 3 Ks^{-1}. Experiments were carried out with simultaneous recording of the neutron yield, mass-spectroscopic monitoring of the partial D_2 pressure ($m = 4\,amu$) and flows of desorbed gases with masses from 1 to 6 amu.

Experimental results obtained have shown that the neutron detector counting rate depends on the

sample temperature. For both metals two temperature regions with exceeding the neutron detector counting rate above the background response were observed. For Pd they are the temperature regions of 100...400 K and 900..1300 K, and for Ti of 100...300 K and 600..1200 K.

For titanium the curves of temperature dependence of the neutron detector signal normalized to the average background value n/n_ϕ in this experiment are shown in Fig.9. The values of n/n_ϕ, given in the plot, are the averages taken over the data of 15 experiments. The vertical "whiskers" indicate the values of root-mean-square errors of n/n_ϕ, and horizontal ones - the errors in the temperature evaluation.

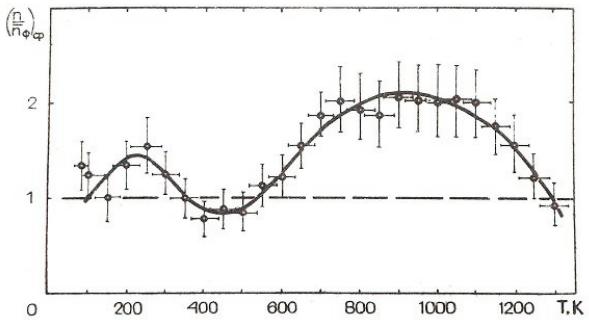

Fig.9. *Temperature dependence of (n/n_ϕ) for Ti irradiated with ions ($E = 25\,KeV$) to doze of $1 \cdot 10^{19}\,cm^{-2}$*

As is seen from Fig.9 the maximum average values of the detector counting rate exceeding above the background response are 2...3.3 that, in the case of an average background response of $\sim 2 \cdot 10^{-2}\,pulses \cdot s^{-1}$ and detector counting efficiency of $2 \cdot 10^{-4}\,pulse/neutron$, corresponds to the hypothetic neutron source intensity of $\sim 10^2\,neutron/s$. The heat generation level in this study we have evaluated by the target heating in the cryogenic experience and obtained $0.075\,W$. If assume that the excess heat generation is produced by the reaction (3) Table 1, the ratio of the number of neutron production reactions to the number of heat generation reactions in our experiments in 1989 is $\sim 5 \cdot 10^{-9}$ that significantly exceeds the value of $\sim 10^{-10}$ accepted for this ratio in reviews [3, 5].

The same high values of the reaction levels in this study were also obtained in records of the charged particle yield [16, 17].

It should be noted, that in the case of preliminary evacuated samples, as well as, evacuated and H^+ implanted samples, the neutron counting rate was not exceeded and the charged particle emission during the target heating was not observed.

Comparison between the temperature dependences of $n/n\phi$ and the curves of thermal desorption from the deuterium-implanted titanium (Fig.10) shows that there is a correlation between the neutron detector counting rate increase and the desorption of deuterium from titanium.

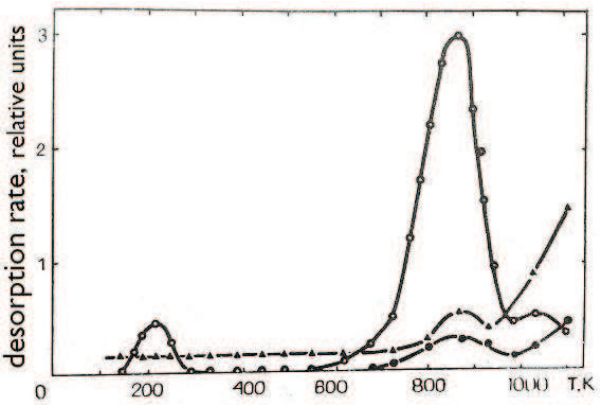

Fig.10. *Thermal desorption spectrum of the Ti sample irradiated with D_2^+ ions ($E = 25\,keV$) to doze of $1 \cdot 10^{19}\,cm^{-2}$. Heating rate is $1...3\,K \cdot s^{-1}$; $\circ - D_2$; $\bullet - m = 3\,amu$; $\triangle - m = 2\,amu$*

Qualitatively a similar picture takes place for the palladium target too.

In the thermal desorption spectra obtained in our experiments the particles with masses (in amu) $1(H)$, $2(D,\ H_2)$, $3(HD,\ ^3He,\ T)$ and $4(D_2,\ ^4He,\ HT)$ were observed. The particles with masses 5 and 6, corresponding to DT and T_2 were not found, though the presence of tritium produced in the process of target irradiation with the ion beam was detected in the thermal desorption products using the radiographic method.

The presence of hydrogen in the thermodesorbed gas, probably, is related with the hydrogen impurity presence in deuterium used in these experiments, and the separation method, applied for the ion beam formation, did not permit to separate ions D_2 and DH_2.

As regards the problem on the neutron generation mechanism in [16] it should be noted that the double-humped shape of the temperature dependence curves for neutron emission and deuterium desorption is in good correlation with the results of the detailed investigation on the deuterium-titanium system fulfilled by the Kharkov researchers using the cryogenic implantation method [182]. According to these investigations, the peak in the thermal desorption curve at $T_{max} \sim 200\,K$ corresponds to the superstechiometric deuterium release from the solid solution in TiD_2, and the peak in the region of 1000K is explained by the thermal decomposition of this compound.

The neutron emission under these conditions, probably, could be provided by the running of reaction (1) - (3.2) and reaction (2), Tab. 7.

A high concentration and large deuterium flows in the matrix, high levels of internal stresses and matrix "imperfection" up to the matrix fracture and cracking (Fig. 11), caused by the nucleation and decay of phases, as well as, other phenomena accompanying the experience with rapid evacuation of titanium implanted with deuterium by cryogenic method - all these factors promote the effective involvement of mechanisms (Sec. 3, Ch. 1) initiating

the chemonuclear fusion and occurrence of nuclear reactions from Tab. 7 at an abnormally high level.

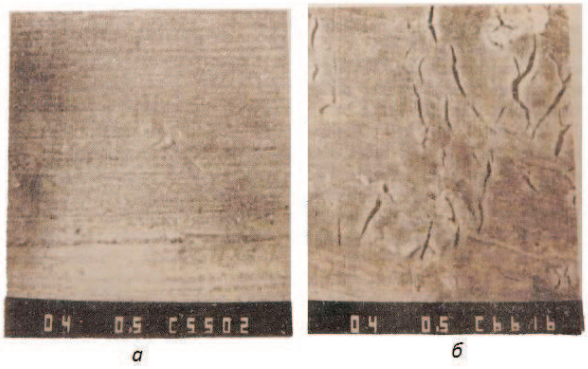

Fig.11. *Photomicrograph of the surface of Ti implanted with deuterium to dose of* $1 \cdot 10^{19}\, cm^{-2}$ *after heating to 300K (a),* $850\, K$, $\times 1000$

The foregoing explains the high levels of heat generation, neutron- and charged particle yield observed in [16, 17]. In specific experimental conditions the different level of neutron yields observed in the cold fusion experiments is determined by the degree of participation of different reactions from Tab. 7 in the fusion process. It follows from Tab. 7 that the neutron generation in experiments of [16, 17] is provided by the running of reactions (1)-(3, 2) and reaction (2) from this table. However, only reactions (1)-(3.2) are responsible for the neutron yield recorded in [16, 17] (Fig. 9), because the neutrons emitted by reaction (2) have an ultralow energy and, as is noted above, will be absorbed by the matrix not reaching the neutron detector (Sec. 15, Ch. 1).A minimum level of neutron yield takes place in the reactions with $2D$ cluster participation ("neutronless" reactions). A neutronless character of many cold fusion experiments proves that reactions in these experiments go by the chemonuclear $2D$-fusion scenario ((Sec. 9-11, Ch. 1). Such a picture qualitatively explains all the peculiarities of neutron generation observed in the cold fusion experiments.

1.16.3. *Tritium generation*

Tritium generation is one of the first cold fusion phenomena which has been reliably established but not explained for the time being [3, 133, 138]. The intensity of this process is by 5-9 orders of magnitude higher than the neutron emission intensity. This proves that the neutron emission in these experiments is not related directly with the conventional hot fusion process.

Table 9. *Tritium production in the process of pulsed electric discharge in electrolytes based on heavy-water and natural-water [186]*

Experience ence	Electrolyte composition	Cathode-anode material	Tritium content Bq/kg^*	Background exceeding
1 [185]	$1\, M Li + D_2O$	$Nb - Ni$	1340	$450\, times$
2 [186]	$0.2\, M$ $K_2CO_3 + H_2O$	$Ta - W$	160	$53\, times$

**Analysis was performed by the specialized laboratory of the Institute of Environmental Geophysics, NAS of Ukraine*

Tab. 9 presents our results obtained in the experiments on the tritium production in the process of pulsed electric discharge in the heavy-water based electrolyte and in the electrolyte which is $0.2\, M\, K_2CO_3$ solution in the natural water. The results under consideration have two evident peculiarities - a very high level of tritium accumulation in the heavy water-based electrolyte and tritium accumulation, though with much lower rates, in the natural water-based electrolyte. In both cases the tritium accumulation level significantly exceeds a possible measurement error that removes all doubts in the reality of the tritium generation process in these experiments.

As it follows from Tab. 7 in the deuterium fusion chemonuclear scenario the tritium generation is the result of the deuteron-bineutron reaction by the channel 4 of this table.

Fig. 12 presents the energy spectrum of particles emitted by the titanium target in the process of cryogenic implantation of $12.5\, keV$ deuterons into this target. This spectrum was obtained in our experiments in 1989 [16] and in 1998 [126].

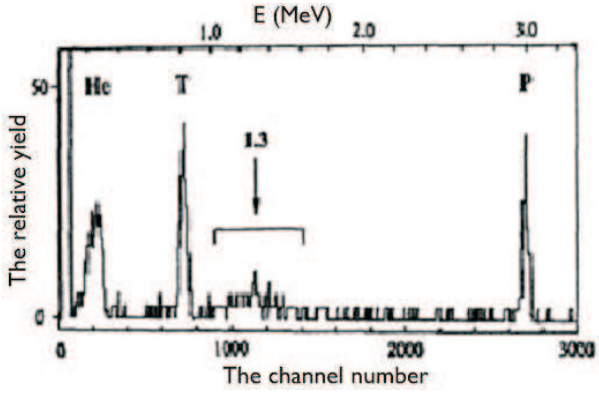

Fig.12. *[126]. Energy spectrum of charged particles from the Ti sample irradiated with ions* $(E = 25\, keV)$ *to dose of* $1 \cdot 10^{19}\, cm^{-2}$. *The peak in the centre of the spectrum corresponds to tritons having the energy of* $\sim 1.5...1.6\, MeV$

The detector in this experiment was closed with a nickel film of a $0.57\,\mu m$ thick. The spectrum under consideration was analyzed with taking into account the energy losses and corresponding shifts of spectral peaks due to the generation of energetic α-particles, tritons and protons which are inherent in the conventional DD-fusion. It has been established that in the formation of the spectrum, besides the processes of conentional hot fusion of deuterium, participating are the processes responsible for generation of $1.5...1.6\,MeV$ tritons (peak of $\sim 1.3\,Mev$ in the spectrum of Fig. 12).

As it follows from Tab. 7 the source of these particles is a chain of reactions (4) initiated by a bineutron. This is an additional reliable evidence for the deuterium fusion chemonuclear scenario being considered in the present paper.

1.16.4. *Emission of three α-particles*

Let us consider once more a phenomenon recognized in the cold fusion phenomenon - emission of three α-particles from the very small detector volume [3]. In [86, 164, 165] this phenomenon is explained as an evidence for the carbon nuclear splitting reaction subjected to the fast neutron action

$$C + n \rightarrow 3\alpha + n + Q\,. \qquad (1.21)$$

According to estimations done in the investigation of α-particles [165], the energy of a neutron initiating reaction (1.21) is $E_n \approx 13.25...13.47\,MeV$. At present, there is no conventional mechanism of such-type neutron generation. The secondary hot fusion $d-T$ reaction, accepted in [165] as a neutron source, might proceed with participation of primary $d+d$ reactions at a level never observed in the cold fusion experiments. This condition was noticed in our paper [126], 1998 and [136], 2000. It follows from Table7 that under *chemo*nuclear fusion conditions the chain of bineutron initiated reactions (4) is responsible for the splitting of carbon nuclei. Tritons of $1.5...1.6\,MeV$ energy, generated in this reaction chain, are clearly observed in the spectrum (Fig. 12) that additionally testifies to this claim.

1.16.5. *Low radioactivity of cold fusion processes*

A low radioactivity of cold fusion processes is one of the most known and attractive features of this phenomenon. In the *chemo*nuclear fusion scenario this is explained by a number of causes. The main of them are:

1. Nuclear energy generated in the process of fusion is taken by conversion electrons. Thereby a main potential gamma-radiation source in the cold fusion experiments is eliminated.

2. Nuclear fission process, the second potential radioactivity source under cold fusion conditions, goes with the intensity lower by 10 orders, as compared to the first-group phenomena and, as was noted above, is not accompanied by formation of radioactive fragments and emission of gamma-quanta, electrons and energetic heavy particles (see p. 1, Sec. 16).

3. Under conditions of an anomalous high local density of the fusion reaction, as it often takes place in the cold fusion processes, the radioactivity caused by the nuclear rearrangement, has a tendency to decrease due to the lifetime reducing and to the nuclide "burning", as their nuclei are enriched with neutrons.

So, the *chemo*nuclear fusion scenario adequately explains the causes of a low radioactivity in the cold fusion experiments, therefore, the assertion, made in some articles, that the residual radioactivity in these experiments is absent in all the cases is not valid. This is confirmed by the reactions from Tab. 7 and by many experimental data [3].

For example, in the well-prepared experiments by Savvatimova [173], during the gas discharge in deuterium, the γ-activity of tungsten and tantalum cathodes was observed at a high reliability level. The experiments show that the gamma-radiation does not cease even after discharge stopping. And the radiation has the same spectral distribution of lines (with significantly less line intensity) as in the gas discharge process.

Generation of lighter nuclides than the ones cathode material consists, discovered in the gas-discharge experiments, is in good conformity with an idea of bineutron reaction with output of nuclides and nuclide clusters. In our electrolysis and gas-discharge experiments with deuterium we have also observed more than once the residual radioactivity of discharge zone elements at a level of $5\,sigma$ and above[120].

Our investigation of the residual radioactivity in the gas-discharge cell (palladium cathode and anode), done after the experiment with gas discharge in deuterium [174], permitted to reveal in the γ-spectrum a series of induced activity lines. The most intense lines belong to the decay products of radon-222 and radon-220 - Pb-214, Bi-214 and Pb-212. Activity of the brightest lines, in comparison with the background, was increased in the experiment by a factor of 2.5...3.

Earlier we have shown [175] that under gas discharge conditions the processes of radon-222 decay product concentration on the charged surfaces might took place that causes spurious effects of the nuclear processes occurrence in these experiments. In [174, 186] it is shown that besides the processes considered in [175] in the formation of an increased activity of radon decay products also participate the nuclear processes.

The presence of nuclear reactions (see Tab. 7) under conditions of deuterium *chemo*nuclear fusion is confirmed by the change of the palladium isotope composition discovered in our experiment [174]. Fig. 13 and Tab. 10 present the data on the change of the isotope composition in the palladium cathode surface layer [174]. As would be expected, in the course of gas discharge the palladium isotope composition is appreciably changing (see Tab. 10).

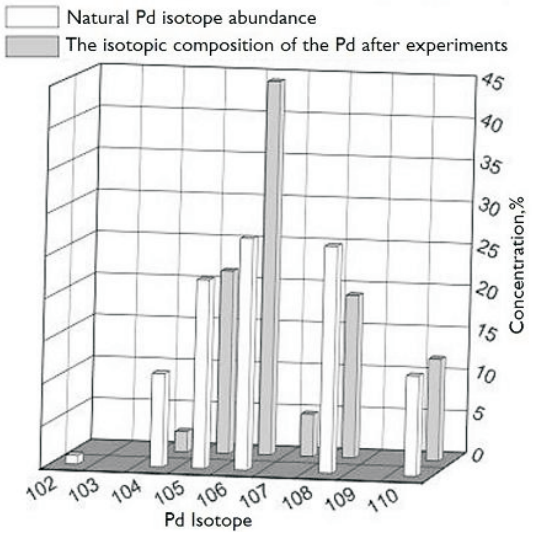

Fig.13. *[174]. Change of the isotope composition of the palladium cathode surface in the experiment on the gas discharge in deuterium*

In the spectrum of the experiment [174] also the line of ${}_{46}Pd^{109m}$, $E = 0,189\,MeV$ is reliably observed. This nuclide was formed as a result of neutron capture by the nuclide ${}_{46}Pd^{108}$.

The histogram in Fig. 13 and Tab. 10 confirm the presence of this process and show that under conditions of the gas discharge experiment in deuterium the ${}_{46}Pd^{106}$ concentration increases from 27.3% to 42.3%, and the ${}_{46}Pd^{108}$ isotope concentration decreases from 26.7% to 18.4%. The change of the isotope composition of palladium qualitatively correlates with the cross-section value of the neutron capture on deuterium isotopes [48]. The evidence for this process is also the nuclide ${}_{47}Ag^{109}$ production in the deuterium discharge experiment as a result of the nuclide ${}_{46}Pd^{109*}$ β-decay that is noted in several papers [3].

Table 10. *Change of the palladium isotope composition in the course of the gas-discharge experiment in deuterium [174]*

Pd isotope	102	104	105	106	107	108	110
Natural *Pd* isotope abundance, %	1	11	22.2	27.3	-	26.7	11.8
Pd isotope abundance after experiment, %	-	2.3	20.7	42.3	4.7	18.4	11.5

In conclusion note that the satisfactory fit between the results expected from the reactions of Tab. 7 and the results reliably established in the cold fusion experiment, demonstrated in this paragraph, can be considered as an experimental proof of the weak-interaction reaction participation in the cold fusion processes, and the above-mentioned *chemo*nuclear scenario as a model of this process.

Chapter 2. *CHEMO*NUCLEAR FUSION IN THE NATURAL HYDROGEN-NICKEL SYSTEM (*HD-CHEMO*NUCLEAR FUSION REACTION)

2.1. Anomalous effects in the natural hydrogen-metal system

The first claim for an excess heat release in nickel samples exposed to natural hydrogen was from Piantelli [3] in 1990. In 1991 Mills et al. [12] discovered the excess heat effect in electrolysis experiments with the use of a nickel cathode and normal water solution of K_2CO_3 as an electrolyte. In succeeding years the heat excess in electrolysis experiments with natural hydrogen has been observed by many researches [107-110]. A positive influence on the thermal effect of the heavy water addition into the light-water electrolyte was discovered in [109, 112, 113].

A nuclear nature of this phenomenon is favourably evidenced by the occurrence of nuclear transmutation processes in the light-water experiments [108, 109], tritium production [112] and X-ray and gamma emission [110, 111].

Also a series of experiments on the natural hydrogen-nickel system have been carried out. The heat generation in nickel treated by different methods and exposed to hot hydrogen was, more than once, observed in experiments by Focardi et al. [114-116]. In some cases these experiments were accompanied by the gamma emission and nuclear transmutation. Most frequently the anomalous phenomena happened in experiments using the nickel sample with a nanocrystalline surface structure formed as a result of nickel treatment, or when the nickel sample was a fill of nickel nanopowder. Formation of nanocrystalline surface structures on the surface of transition metals in the natural hydrogen-metal systems is a

main subject of Patent by Piantelli: "Method for Producing Energy and Apparatus Therefor" [188].

However, as is mentioned above, the problem on anomalous phenomena in the cold fusion experiments with the use of hydrogen was studied much worse than in the experiments with deuterium. A theory that might pretend to explain the cold fusion phenomenon is not developed. As it has been noted, the problem complexity consists in that the $p-p$ system has no bound states. Nuclear reactions in this system are possible only with participation of weak interactions and have in vacuum an extremely low intensity (Sec. 15, Ch. 1).

On the other hand, the reaction of direct proton-nucleus interaction in nickel suppressed by the high Coulomb barrier also has a maximally low probability to occur under these conditions ($\sim 4.7\cdot 10^{-1059}$ [15]). Moreover, as is noted in [190], the $p-Ni$ reaction, running with intensity necessary to explain a thermal effect in experiments on the hydrogen-nickel system, if it might take place owing to any case, is accompanied by emission of hard gamma-rays, never observed till now, in doses mortal for a living organism.

At the same time, as is shown in Chapter 1, in the deuterium-saturated conducting condensed substance there are existing factors (*chemo*factors) capable, under appropriate conditions, to intensify cardinally nuclear processes in the deuterium-metal system. Protium and deuterium are isotopes of the same chemical element, namely, hydrogen, therefore the protium behavior should be similar, in many respects, to the deuterium behavior under like conditions. Below a hypothetic scenario of nuclear reactions in the natural hydrogen-nickel system, developed proceeding from above statements, is described.

2.2. HD fusion *chemo*nuclear scenario

The DD fusion *chemo*nuclear model presented in Sec. 9-11 Ch. 1 describes well the deuteron-particle (deuteron-boson) interaction and is not applicable to the fermion-formed systems as in the case of the proton-proton system. However, in the natural hydrogen-nickel system, hydrogen always contains a trace of deuterium (0.015%).

Table 11. *Nuclear reactions in the HD fusion scenario*

$(p^+ + e^- + d^+) \rightarrow^3 He_{g.s.} + Q_1(\tilde{e}^-_{conv.})$;	(1)
$(p^+ + e^- + d^+ + e^- + p^+) \rightarrow (^3He^* + e^-) + p \rightarrow (^3He_{g.s.} + Q_1(\tilde{e}^-_{conv.}) + p) \rightarrow$ $\rightarrow^3 He_{g.s.} + n + \nu_e$;	(2)
$(n + p) \rightarrow d + Q_3(\tilde{e}^-_{conv.})$;	(2.1)
$(n +^x_{28} Ni) \rightarrow^x_{28} Ni^* \rightarrow^{x+1}_{28} Ni_{g.s.} + Q_4(\tilde{e}^-_{conv.} + \gamma)$;	(2.2)
$(p^+ + e^- + d^+ + e^- + p^+ + e^- + p^+) \rightarrow (^3He^* + e^-) + (p^+ + e^- + p^+) \rightarrow^3 He_{g.s.} + d + \nu_e$;	(3)
$\mid \; + 2p \rightarrow 2d + Q_3(\tilde{e}^-_{conv.})$;	(3.1)
$\mid \; +^x_{28} Ni \rightarrow^{x+2}_{28} Ni^* \rightarrow^{x+2}_{28} Ni_{g.s.} + Q_6(\tilde{e}^-_{conv.} + \gamma)$;	(3.2)
$\mid \; +^x_{28} Ni \rightarrow^{x+2}_{28} Ni^* \rightarrow^{x-2}_{26} Fe + \alpha(9 - 14\,MeV)$;	(3.3)
$d + \tilde{e}^-_{conv.} \rightarrow^2 n \rightarrow \quad \langle$	
$\mid \; +^x_{28} Ni \rightarrow^{x+2}_{28} Ni^* \rightarrow^{x+1}_{27} Co + p(6.77\,and\,10.24\,MeV)$;	(3.4)
$\mid \; +^x_{28} Ni \rightarrow^{x+2}_{28} Ni^* \rightarrow^{x+1}_{28} Ni + n(6.98\,and\,8.19\,MeV)$;	(3.5)
$\mid \qquad\qquad\qquad\quad Nu_1$;	
$\mid \; +^x_{28} Ni \rightarrow^{x+2}_{28} Ni^* \rightarrow f \; \langle$	(3.6)
$\mid \qquad\qquad\qquad\quad Nu_2$.	
$d +^2 n \rightarrow T\,(1.56\,MeV) + n\,(4.64\,MeV) - d + T\,(1.56\,MeV) \rightarrow \alpha\,(6.9 - 1.44\,MeV) + n\,(12.5 - 17.7\,MeV)$;	(4)
$^3_2He + n \rightarrow^3_1 H(0.191\,MeV) +^1_1 p(0.573\,MeV)$.	(5)

In Tab. 11 the symbol $Q_n(\tilde{e}^-_{konv})$ denotes the excitation energy of nucleus Q_n taken by the conversion electrons $(\tilde{e}^-_{konv})$.

This provides in the ionized hydrogen the formation of natural $(p^+ + e^- + d^+)$- clusters the behavior of which can be described (after adequate correction) by our DD *chemo*nuclear model. In the Gryzinski tunneling mechanism by the HD scenario a system takes part with participation of proton, electron and deuteron, and short-living formations: $(p^+ + e^- + d^+)$ as a quasi-molecule and $(^3He^* + e^-)$ as an electron-modified compound-nucleus.

Tab. 11 presents the nuclear reactions which, in accordance with this $p_n d^+$ cluster property, can occur in the natural hydrogen-loaded condensed substance. In Table 11 only the pd^+-, p_2d^+-, p_3d^+- clusters and alone nickel target, as a target, are entered that permitted to decrease the table size.

Note some features of the HD *chemo*nuclear fusion scenario.

1. An astrophysical factor of the $(p-d)$ reaction is in $1.5\cdot 10^{-5}$ times lower than that of the $(d-d)$ reaction [121]. However, the value of the reduced mass for the $(p-d)$ reaction is significantly less, as compared with the $(d-d)$ reaction (see [119]). Consequently, in the range of low particle energy values, being of interest to us, a probability for the $(p-d)$ reaction to occur in vacuum is two orders of magnitude higher than that for the $(d-d)$ reaction. The low value of the reduced mass would be expected to be

a favourable factor for the HD *chemo*nuclear fusion scenario too, as compared to the DD *chemo*nuclear fusion.

2. In the HD *chemo*nuclear fusion scenario the heat generation is accompanied by the helium-3 production by the reaction (1) Tab. 11. However, according to Tab. 11 in the HD *chemo*nuclear fusion process the reactions accompanied by the neutron and tritium production are participating too. Under these conditions the real helium-3 concentration will be determined by the concurrence of reactions (1.1) and (2.2), Tab. 11, on the one hand, and reaction (4) of this table, on the other hand. In this case the helium-3 production decrease will be compensated by the tritium production increase. A high intensity of this process is promoted by the exceptionally high value of neutron capture on ^3He nucleus (for thermal neutrons $\sigma_{therm.} = 5330\,barns$).

3. Reaction (1), Tab. 11 occurs without nuclear bond breakages and therefore this reaction, similarly to the DD reaction by channel 3, Tab. 1 (Sec. 9-11, Ch. 1), will get an intensive character under favorable conditions. A low value of the reaction cross-section in vacuum is related with the infinitesimal nucl, determined by the γ-quantum radiation [4]. Under conditions of HD *chemo*nuclear scenario, as in the case of DD-scenario, the participation in the nuclear fusion process of a "captured" electron and core electrons cardinally increase the yield of reaction (1), Tab. 11. Reaction (1), Tab. 11 being under strong interactions and extremely enhanced by the medium chemofactors, is a prime cause and a source of nuclear process energy in the pd^+-, p_2d^+- and p_3d^+-clusters in the natural hydrogen-nickel system.

4. The factor restricting the prospects of natural hydrogen use in the high-power *chemo*nuclear energy installations is a low initial deuterium content. There are two ways to get over this complicating factor.

The first way is to develop low-power energy installations using natural hydrogen in which burned deuterium will be compensated by filling in time a fresh fuel - natural hydrogen. A present-day technological knowledge gives every reason to consider the problem of the low-power energy installation developing as a principally feasible idea. The energy reserve in natural hydrogen, resulting from reaction (1), Table 11, equals to $3.6 \cdot 10^{12}\,J/cm^3$ under pressure of 1 at. Note, for comparison, that the energy reserve in methane under the same pressure is lower by a factor of 90.

The second way of problem solving is to create conditions under which in the HD-scenario the reactions responsible for the deuterium recovery will be intensified. To date this approach is not adequately investigated neither theoretically not experimentally. However, the results of the recently published paper by Szpak, Dea [189] (see Sec. 3, Ch. 2) demonstrate that in the cold fusion experiments, with the use of a "codeposition" technology, the conditions of deuterium breeding are spontaneously fulfilled.

Let us appreciate the opportunity of deuterium recovery in the *chemo*nuclear HD-fusion scenario.

In accordance with the HD-scenario the deuterium recovery in the natural hydrogen-nickel system is realized by reactions [(2) - (2.1)], (3) and (3.1), (Table 11). Reactions (2) and (3) occur with participation of weak interactions and, consequently, have a low intensity. The process of deuterium breeding in this case means that there are steady conditions for cardinal intensification of weak-interaction reactions due to strong-interaction reactions by the mechanism described in Sec. 15, Ch. 1. At the initial stage the energy source in this process will be the reaction of interaction between the proton contained in the HD-cluster and deuteron. As the deuterium concentration increases the contribution of higher-energy DD-reactions to this process becomes more and more significant.

It would be expected, also, that in this case in the system maximally realized are all the advantages of the HD *chemo*nuclear fusion scenario: cluster nature of fusion - fusion reaction in the structure of a cluster being accelerated and aligned in the quasi-molecule electron core; effective conversion process of nuclear excitation energy de-excitation; little reduced mass of reacting particles etc.

In addition, of a particular importance might be a factor of the effective use of conversion electrons. Insulating properties of the matrix forming a microaccelerator in mechanism (3.3...3.4) (Sec. 3, Ch. 1), are determined by a number of accelerated clusters per 1 event of nuclear fusion. In the matrix, having high insulating properties, this number will be significant that will have a favorable effect on the deuterium gain factor.

5. According to the fusion *chemo*nuclear scenario the generation of accelerated particles in the hydrogen-nickel system is realized by the nanostructure mechanisms, in particular, microaccelerating mechanism (Sec. 3, Ch. 1). The reaction zone in these cases has a limited volume (for the microaccelerating mechanism it can be $10^{-7}...10^{-10}\,cm^3$) and a relatively high isolation from the main volume. Thus, the deuterium concentration in the reaction volume increases more rapidly and the latent period of the power gaining process reduces in $10^3...10^6$ times. The fact that in many light-water experiments one did not observed anomalous nuclear processes can be explained by the circumstance that the reaction volume in those cases was not isolated from the main volume [3, 120]. Beginning from some deuterium concentration the decisive contribution to the power generation will be given by the DD-fusion reactions with a ^4He generation as a fusion product. A factor conditioning a high power gain rate of in this case will include both the deuterium concentration and the much higher heat of the dd-reaction, as compared to the pd-reaction ($23.8\,MeV$ and $5.5\,MeV$, respectively).

As is noted in Sec. 3, Ch. 1 the participation of conversion electrons in the *chemo*nuclear fusion, as well as, the cluster fusion mechanism itself provide the process efficiency increase with its power increase.

The latter should be taken into account when solving the problem of *chemo*nuclear fusion use in practice.

2.3. *HD chemo*nuclear fusion scenario - cold fusion in the natural hydrogen-metal system

Application of the *HD chemo*nuclear scenario for explanation of cold fusion phenomena in the natural hydrogen-metal system will be demonstrated on the example of a recently published large article by Szpak S. and Dea J. "Evidence for the Induction of Nuclear Activity in Polarized $Pd/H + H_2O$ System" [189]. Below a brief description of the paper is given.

2.3.1. *Experimental technique and equipment*

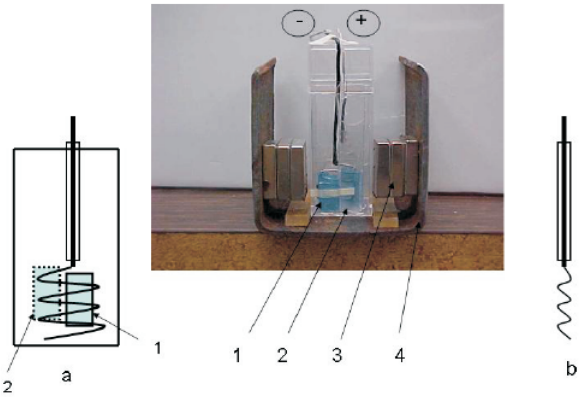

Fig.14. *[189]. Electrochemical cell: 1 - CR-39 detector outside the cell, 2 - CR-39 detector inside the cell, 3 - neodymium magnets, 4 - magnet holder. 14a - Cathode assembly*

In experiments of [189] the device presented in Fig. 14 was used. A rectangular vessel made of clear plastic served as an electrochemical cell. The cathode assembly is shown in Fig. 14,a. A platinum wire in the shape indicated in Fig. 14,a was used as a substrate for the Pd/H film deposition by the codeposition method. The codeposition is a process by which palladium is deposited, with hydrogen presence in the solution, onto the substrate that does not absorb hydrogen (here the platinum wire).

The structure of the electrodeposited palladium is given by the electrolyte composition and the current regime and can have a complicated branched surface pattern (Fig. 15). In experiments the water solutions $0.03\,M\ PdCl$ and $0.3\,M\ LiCl$ were used as an electrolyte. The procedure of film formation was a many-hour electrolysis with a stepwise current intensity increase from $1.0\,mA \cdot cm^{-2}$ at the initial stage to $30\,mA \cdot cm^{-2}$ at the final stage of the process formation. Then the cell was placed into the external magnetic field ($0.2\,T$) (Fig. 14-4) and the cyclic operating mode of the experiment was set: imax=400mA for 90 s and imin=5mA for the following $5\,s$. In the course of experiments the neutron recording was performed by two CR-39 detectors fastened inside the cell (2) and by an external detector (1) (Fig. 14).

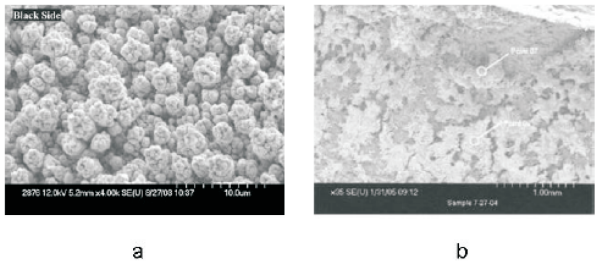

Fig.15. *[189]. Electron-microscope image of the electrode surface: (a) with no magnetic field, (b) with applied magnetic field*

2.3.2. *Experimental results*

The results obtained in [189] clearly show that in the course of the experiment intensive nuclear processes take place. Mass-spectrometric analysis of the gas dissolved in the cathode reliably confirms the fact that in the course of the experiment the isotope gas composition is changing. In all the cases after the experiment in the gas a dominant component was deuterium and the detected amount of tritium was negligible.

As a rule, the D/H atomic ratio was above a unity. In some cases the deuterium amount exceeded the protium amount by a factor of five.

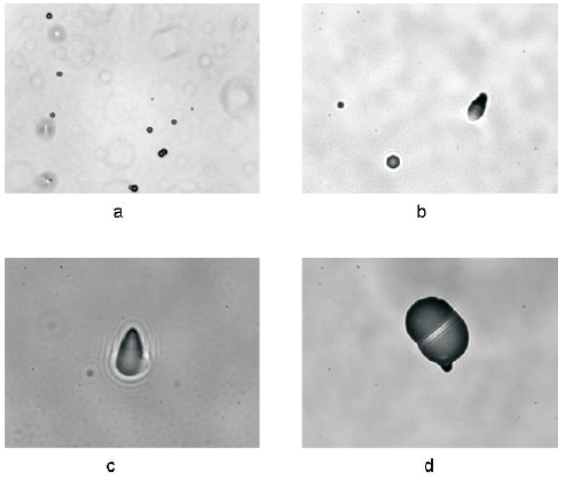

Fig.16. *[189]. Images of tracks, formed in the course of the experiment in $CR-39$ detectors: (a) distribution of tracks, $40\,x$, (b) tracks at different angles of incidence, $500\,x$, (c) single track,$1000\,x$, (d) double track, $500\,x$*

Fig. 16 shows typical images of tracks recorded in these experiments by the CR-39 detectors. The track nature is similar for all the detectors, but the track density is much higher for the detector located forward of the cathode. This confirms the fact that in the course of codeposition the fast neutrons are produced and that the processes responsible for the neutron generation occur in the cathode region. In three cases out of ten ones the experiments were interrupted because of catastrophic thermal effects. In

one case after three days of electrolysis with a current in the cell varying between 300 and $5\,mA \cdot cm^{-2}$, a catastrophic heat release has happened and caused the cell deformation and electrolyte loss as a result of evaporation and leaking through the punctured cell bottom (Fig.17).

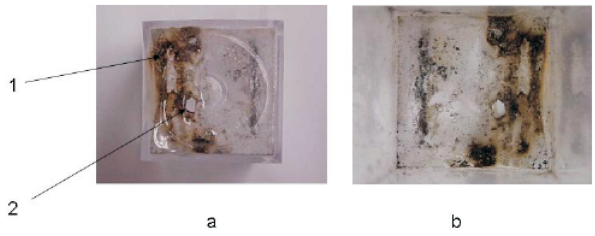

Fig.17. *[189]. Damaged cell bottom: (a) outside view, (b) inside view. Arrows indicate the damage areas*

About 1/3 of the total cell bottom area (Fig. 17) was damaged because a very hot object came in contact with plastic material.

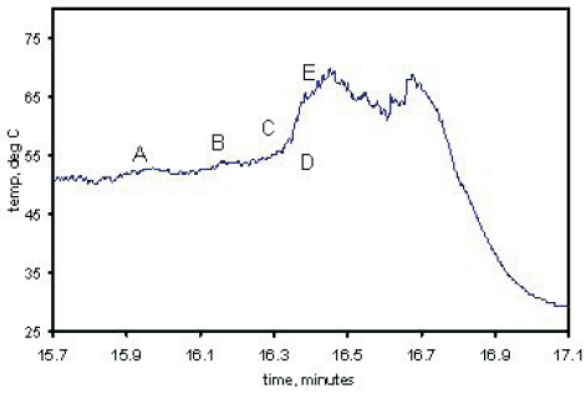

Fig.18. *[189]. Temperature profile during the thermal explosion*

Fig. 18 shows the electrolyte temperature records made for the period of catastrophic thermal explosion. The rapid electrolyte heating ($2.6°C/s$) shown in the curve (DE part) is the evidence of the catastrophic heat release in this period. Basing on the analysis of the electrolyte heating curve the authors of [189] concluded that in the course of the experiment the energy of more than $10\,eV/Pd$ atom was released, that significantly exceeds the heat generation of chemical reactions. In the process of thermal explosion the cathode was damaged. Fig. 19,a presents the SEM photo illustrating the separation of the PdD film from the Pt substrate obtained by the author of [189] in the experiment with deuterium.

Fig. 19,b shows the tracks of transmutation processes taking place at the interface. The authors assert that a similar picture was also observed in the experiment with hydrogen. In conclusion the authors of [189] compare the scale and character of the catastrophic thermal phenomena observed in their light-water experiment with the results of heavy-water experiments carried out earlier by other authors [8, 9, 195].

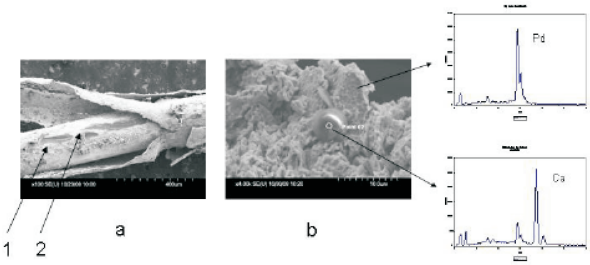

Fig.19. *[189]. SEM photo illustrating the Pd/H film separation from the Pt substrate*

They concluded that for all these experiments the phenomenon has a nuclear nature of the same type and that the effect value is proportional to the palladium amount used in the experiment.

At the same time, one can see that the HD fusion *chemo*nuclear scenario, described in the foregoing paragraph, explains satisfactorily, at a qualitative level, the results of experiment [189]. A high level of nuclear activity observed in the experiment [189] proves that the hypothetic factors (Sec. 2 Ch. 2) of *chemo*nuclear process efficiency increase under experimental conditions of [189] are completely realized. However, in this case a high level of the nuclear activity can be determined, first of all, by the specific character of deposit formation on the cathode. In the process of ionic compound settling-out from the electrolyte and deposit formation a metal-insulator structure will be created being optimum for the deuterium fusion running by microaccelerating mechanisms 3.3 and 3.4 (Sec. 3, Ch. 1). It is necessary to consider more particularly the catastrophic thermal phenomena, which has interrupted three times the experimental procedure in [189]. In Sec. 2, Ch. 2 we have paid attention to the positive process efficiency increase with its power increase that is peculiar to the *chemo*nuclear scenario. This can be one of causes for anomalous thermal phenomena. However, the catastrophic thermal phenomena observed in [189] can be also provoked by causes directly related with the target structure features and the target state under conditions of the experiment. As is mentioned above, the target surface in the experiment with "codeposition" has a complicated branched nature. The internal surface of electrolyte-filled coating voids practically does not participate in the *chemo*nuclear fusion process by our model and is a potential energy source continuously increasing with the deuterium concentration increase. At the same time, during the experiment a continuous deuterium generation occurs that is accompanied by the heat generation density increase and cathode temperature rise. As a result, when the deuterium concentration in the coating amounts to certain level and there are thermal fluctuations in the cathode points with a maximum local temperature, then the electrolyte in the coat-

ing voids reaches the boiling temperature, evaporates and the voids "dry out". On the internal surface of voids an insulating film is growing of the $LiCl$ and $PdCl$ compounds deposited from the electrolyte, and the voids are filled up with gas, desorbed from the coating, containing a high deuterium concentration. Thereby, in the voids created are conditions, being optimum for the fusion initiation by the microaccelerating mechanism (see p.3.3, 3.4 of Sec. 3 Ch. 1), and DD- and HD-fusion processes take part accompanied by the heat release according to our model. The fusion process by this scheme extends onto the neighboring cathode parts, rapidly develops and results in the catastrophic thermal events described in [189].

2.4. *HD chemo*nuclear fusion and abundance of tritium and helium isotopes on the Earth

Let us consider how the *HD chemo*nuclear fusion scenario can explain the anomalies in the abundance of tritium and helium isotopes in the Earth.

Tab. 12, taken from [191], gives the data on the content of tritium and helium isotopes in different volcanic lakes of the world. Analyzing the data of Table 12 the authors of [191] come to a conclusion that: " The excess ^3H correlate fairly well with mantle helium (^3He) in each lake ", and further "...we suppose that the ^3H and ^3He might be produced by

Table 12. *Helium and tritium content in volcanic lakes [191]*

Volcaniclake	$^3He_{ex}/^4He_{ex}$, 10^{-6}	^3He *concentration*, C_{air}	^3He *flow*, $mol/m^2 \cdot c$	*Excessof* ^3H, *TU*
Laacher (Germany)	7.42	50	$1.2 \cdot 10^{-16}$	~ 1.4
Nemrut (Turkey)	10.1	190	$\sim 1 \cdot 10^{-16}$	3.7
Van (Turkey)	12	1.5	$6 \cdot 10^{-18}$	~ 0.9
Panvin (France)	9	500	$9 \cdot 10^{-18}$	~ 4

C_{air} - atmospheric helium-3 content in water; Average (global) value of ^3He flow: $6.6 \cdot 10...20\, mol/m^2 \cdot s$, TU - single tritium atom per 1018 hydrogen atoms.

nuclear fusion ($d-d$ reaction) occurring in an environment of enriched H atoms and $(U + Th)$ deep in the earth, at high temperatures and preesure. The physical mechanism of natural fusion in the deep Earth, however, remains an open question."

In our opinion it will be more reasonable to explain the results of Tab. 12 with attracting the *HD chemo*nuclear fusion by our model. Then it would not need to consider the most difficult-to-explain part in the discussion of results given in Tab. 12 [191], i.e. generation and concentration of deuterium in the Earth interior and creation in it conditions for the hot DD-fusion realization. At the same, the spontaneous formation of conditions for initiation of charged particle acceleration mechanisms by our models (3)-(4) (Sec. 3 Ch. 1), in the small parts of the earth's crust below volcanic lakes, seems to us a much more probable process. A favourable circumstance here is the fact that for generation of very weak helium-3 flows observed in the experiments a very low intensity of reaction (1), Tab. 11 is required.

CONCLUSIONS

Analysis of multiple experimental results obtained to date in the field of research, conventionally named as "deuterium cold fusion", shows that there is no doubt that the cold fusion phenomenon really exists and is very promising for practical applications.

"Damnation", in one's time declared by the traditional science to this direction of research, was a natural reaction since in that period the researchers of the cold fusion frequently explained this phenomenon as a synthesis of deuterium nuclei in the solid lattice under equilibrium conditions at a room temperature. At the same time, in the traditional physics there are generally accepted fundamental prohibitions of such processes occurrence.

Taking into account the foregoing and regarding the results of cold fusion experiments (and results of our own experiments) as trustworthy ones, we have focused efforts onto the study of real conditions under which this phenomenon happens. The present paper contains the results of our investigations.

As it follows from the present paper, we have succeeded in discovering a chain of interrelated particular chemical, physical and nuclear phenomena capable under corresponding conditions to accelerate cardinally the nuclear processes in the deuterium-metal system. A mechanism for stimulation of weak-interaction reactions due to the strong-interaction reactions under chemonuclear fusion conditions is offered.

The above-mentioned fusion scenario can not be completely described within the framework of earlier accepted definitions and has been named a deuterium chemonuclear fusion scenario. The chemonuclear fusion scenario developed in the present paper is of a hypothetic qualitative character and requires an adequate quantitative treatment and thorough experimental and theoretical investigations. Nevertheless, the abundant experimental evidences of the deuterium chemonuclear fusion scenario gives grounds to

start, with a justified risk, the works for the purpose of a thorough investigation and development of this environmentally pure energy source.

It is demonstrated that the system with natural hydrogen participation also holds much promise for use it as an energy source. The processes in this system are initiated by the reaction of hydrogen with deuterium being in natural hydrogen as a deuterium impurity.

We suggest that the industrial use of chemonuclear fusion processes is today a task of primary importance, having in mind the Earth's energy and ecological problems.

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ЯДЕРНЫЕ ПРОЦЕССЫ В СИСТЕМАХ ДЕЙТЕРИЙ/ПРИРОДНЫЙ ВОДОРОД-МЕТАЛЛ

В.Ф.Зеленский

Представлены результаты анализа явлений, имеющих место в условиях опытов холодного синтеза в системах дейтерий-металл и природный водород-металл. Показано, что генерирование в опытах холодного синтеза в системе дейтерий-металл тепла и гелия без эмиссии энергичных гамма-квантов – результат протекания в этой системе цепочки химических, физических и ядерных процессов, завершающихся слиянием ядер дейтерия и образованием модифицированного электроном виртуального, возбужденного ядра гелия-4. Энергия возбуждения ядра гелия передается матрице эмиссией конверсионных электронов, что при соответствующих условиях обеспечивает незатухающий процесс синтеза дейтерия. Процессы в системе дейтерий/природный водород-металл получили название – хемоядерный DD- и HD-синтез. Предложен механизм стимулирования в условиях хемоядерного синтеза дейтерия реакций слабого взаимодействия за счёт реакций сильного взаимодействия. Рассмотренные в работе результаты многочисленных опытов свидетельствуют в пользу достоверности хемоядерного синтеза. Делается вывод о том, что сценарий хемоядерного синтеза дейтерия в том виде, как он представлен в работе, может служить основанием для разворачивания работ по глубокому изучению и освоению этого экологически чистого источника энергии. Показано, что система с участием природного водорода, содержащего 0.015 % дейтерия, также имеет серьезные перспективы для использования в качестве источника энергии. Процессы хемоядерного сценария синтеза не требуют для своего объяснения выхода за рамки традиционной физики.

ЯДЕРНІ ПРОЦЕСИ В СИСТЕМАХ ДЕЙТЕРІЙ/ПРИРОДНИЙ ВОДЕНЬ-МЕТАЛ

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Представлені результати аналізу явищ, що мають місце в умовах дослідів холодного синтезу в системах дейтерій-метал і природний водень-метал. Показано, що генерування в дослідах холодного синтезу в системі дейтерій-метал тепла і гелію без емісії енергійних гамма-квантів – результат протікання в цій системі ланцюжка хімічних, фізичних і ядерних процесів, що завершуються злиттям ядер дейтерію і утворенням модифікованого електроном віртуального, збудженого ядра гелію-4. Енергія збудження ядра гелію передається матриці емісією конверсійних електронів, що при відповідних умовах забезпечує незгасаючий процес синтезу дейтерію. Процеси в системі дейтерій/природний водень-метал отримали назву – хемоядерний DD-і HD-синтез. Запропоновано механізм стимулювання в умовах хемоядерного синтезу дейтерію реакцій слабкої взаємодії за рахунок реакцій сильної взаємодії. Розглянуті в роботі результати численних дослідів свідчать на користь достовірності хемоядерного синтезу. Робиться висновок про те, що сценарій хемоядерного синтезу дейтерію в тому вигляді, як він представлений в роботі, може служити підставою для розгортання робіт з глибокого вивчення й освоєння цього екологічно чистого джерела енергії. Показано, що система за участю природного водню, що містить 0.015 % дейтерію, також має серйозні перспективи для використання в якості джерела енергії. Процеси хемоядерного сценарію синтезу не вимагають для свого пояснення виходити за рамки традиційної фізики.