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DD FUSION IN CRYSTALS

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Abstract

The article discusses the mechanism of $DD \rightarrow {}^{4}He$ fusion and so-called nonradiative thermalization of the reaction in crystals. The dynamics of this process is considered. The assumption that the decay time of the compound nucleus depends on its excitation energy makes experiments in crystals compatible with the acceleration data. We consider the processes in the crystals that increase the intensity of *DD* fusion in comparison to the amorphous media, and the yield of the reaction is estimated.

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1 – INTRODUCTION

In 1989, Fleischmann and Pons reported observing the production of heat of non-chemical origin in a palladium electrochemical cell, saturated with deuterium [1]. Since then, more than 1000 reports on the so-called cold fusion have been published. The most complete data on this subject are given in the report of M. McKubre et al. [2]. Results of experiments on cold fusion in the past 20 years have been severely criticized by the nuclear physics community as non-scientific and contradictory to fundamental scientific facts. The main objections of the scientists focused on the apparent contradiction of the experiments on cold fusion to the laws of thermodynamics, and to the absence of nuclear radiation in these experiments.

Recently, we considered the mechanism of the thermal acceleration of contaminant atoms of deuterium in crystals due to the interaction with long-wavelength vibrations of the crystal lattice in the deformed parts of the crystal [3, 4]. More recently, we described the hypothetical mechanism of *DD* fusion in crystals [5]. An important feature of this mechanism is the strict collimation of moving atoms of deuterium in hyper channels of a crystal lattice, which at very low energies limits the angular momentum of two colliding deuterium nuclei (*S*-wave). Such conditions are not typical in an amorphous medium and have not been studied in detail experimentally.

We will show below how all the experimental data on the reaction of $DD \rightarrow {}^4He$, including experiments [2], can be consistently explained.

2 – DD FUSION AT LOW ENERGIES

DD fusion at low energies has been widely discussed in cosmology and astrophysics in connection with the primordial nuclear synthesis in the early universe and the subsequent nuclear synthesis in stars. A good overview of the problem is given by Fowler [6]. Salpiter [7] and Bethe [8] proposed to extrapolate the cross sections for the fusion of two nuclei at low energies using the so-called astrophysical ***S***-factor equal to the product of the reaction cross section σ and the energy ***E*** of a particle in the center of mass, in order to avoid the singularity in the cross section at low energies. Taking into account a probability of penetration of a particle through Coulomb barrier (Gamov's factor), in the case of *DD* interaction

$$S(E) = E\sigma \cdot \exp\left(\pi \frac{e^2}{\hbar c}\sqrt{\frac{M_{\mathrm{d}}c^2}{E}}\right) = E\sigma \cdot \exp(31.41/\sqrt{E}) \quad ,$$

where E is in keV. The expression for the penetration is based on solving the Schrodinger equation for the Coulomb wave functions. The main uncertainty in this lies in the choice of the M_d parameter, which depends on the radius of the compound nucleus, but this parameter is well defined by measurements made at accessible energies. ***S(E)*** allows a more accurate extrapolation of experimental data to the region of very low energy, where direct measurement is impossible. In the case of pure *S*-wave the astrophysical function ***S(E)*** must be constant.

Fusion reactions of light nuclei were studied in details in accordance with the work on controlled thermo-nuclear fusion. The cross section of *DD* interaction with ${}^4He$ production has a so-called broad resonance at an energy of about 8 MeV [9]. The most complete data for the reaction ${}^2H(d,\gamma){}^4He$ are given in K. Sabourov et al. [10]. Figure 1 shows the data presented in [10].

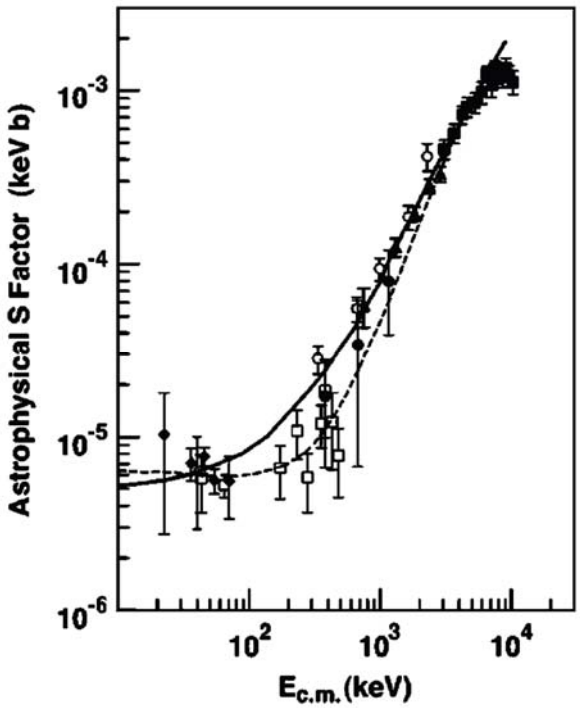

Figure 1. Data on DD fusion with the formation of ^4He from K. Sabourov et al. [10]. The solid line shows the fit of all known data for the reaction $^2H(d,\gamma)^4He$, taking into account the radiative transitions *E2*, *E1* and *M2* by the model RRGM. The dotted line shows the fit when accounting only for the *E2* transition.

This work also provides an analysis of all known data for the reaction $^2H(d,\gamma)^4He$. The Refined Resonating Group Model (RRGM) properly takes into account the scattering in the system of ^4He, using the variational principle of Kohn-Hulthen with the inclusion of some specific models. The results are supported by good agreement between the calculated binding energies of deuteron and ^3H and the experimental values. One of the interesting results of this work is the evaluation of the astrophysical factor $D+D \rightarrow {}^4He$ at zero energy, which is found to be $S(0) = 4.8 \times 10^{-6}$ keV b.

It seems interesting to compare the data obtained using particle beams with the experiments of M. McKubre et al. [2].

3 – DECAY OF COMPOUND NUCLEUS BY NUCLEAR REACTIONS

One of the paradoxes of *DD* fusion with the production of ^4He in crystals in experiments [2] is the apparent absence of the usual nuclear decay products of the compound nucleus.

Unfortunately, despite all the advances in nuclear physics, at the present time there is no coherent theory for making accurate calculations of nuclear reactions. Consequently, scientists are compelled to use simplifying models in these calculations. These models, such as the isotopic invariance model, the nuclear shell model, and others, describe many processes in nuclei fairly well. However, at very low energies these models are either not applicable or useless, and additional attempts to consider nuclear processes are required.

Due to identical boson character of entrance channel in *DD* system (Bose statistics) at very low collision energies, the orbital quantum number l is *0* and thus only two spin states are possible: $S = 0$ and $S = 2$.

In the *DD*-interactions at low energies, when penetrating through the Coulomb barrier and forming the compound nucleus, nucleons usually do not appear as separate objects. This is evidenced, for example, by the practically equal rate of proton and neutron emission when the compound nucleus decays. Thus, the deuteron penetrates the Coulomb barrier as a whole. In the case of S-wave, decay of the compound nucleus to the ^4He ground state is suppressed by the law of conservation of total angular momentum. For the compound nucleus with total spin $S = 0$ in the case of S-wave, decay to the ^4He ground state is therefore completely banned, and the disintegration of the compound nucleus must be carried out exclusively through the reaction $D+D \rightarrow {}^3He+n$ and $D+D \rightarrow {}^3H+p$. We need to understand why such decays are not observed in cold fusion experiments [2].

Let us consider possible dynamics of the fusion of two deuterons with zero angular momentum with the subsequent emission of nucleons through the reaction $D+D \rightarrow {}^3He+n$ and $D+D \rightarrow {}^3H+p$.

One approach to this problem is a quantum-mechanical calculations of matrix elements of reactions, which is usually associated with the name of Werner Heisenberg. However, in this approach the dynamics of the process are not considered. This approach usually ignores the spatial-temporal characteristics of a phenomenon in order to obtain energy spectra and probabilities of processes. This approach can be illustrated by the diagram shown in Figure 2.

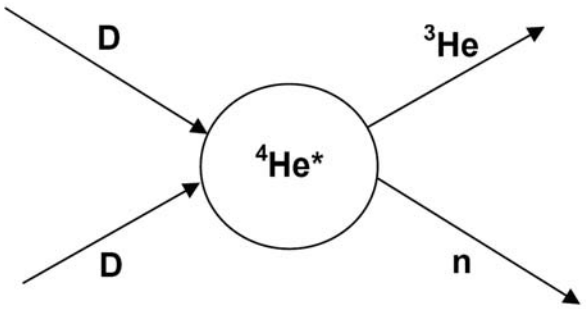

Figure 2. The diagram of the reaction $D+D \rightarrow {}^3He+n$.

The dynamics of the process in this approach are not important for the particular results. This matrix approach which is very fruitful in the description of many quantum-mechanical phenomena, unwittingly served as the basis for the widely accepted opinion among physicists that all the strong processes, by definition, are very fast. We will show below that for the description of *DD*-fusion at low energies the finite speed of the nuclear processes is quite crucial.

Let us consider another figure of the same process $D+D \rightarrow {}^3He+n$, shown in Figure 3 in a form that emphasizes on the time in the element $^4He^*$. This diagram is inspired by the Schrodinger equation containing the space-time coordinates in an explicit form.

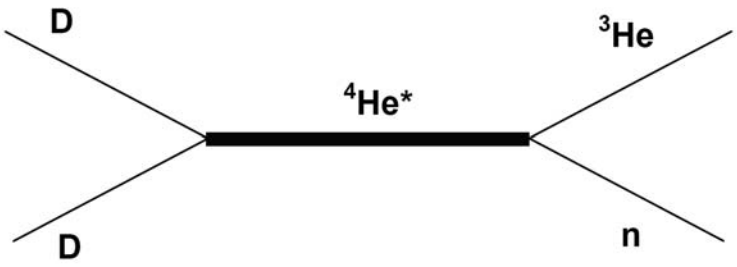

Figure 3. This diagram of the reaction $D+D \rightarrow {}^3He+n$ depicts the time involved in the process of $^4He^*$ decay.

Let us consider, by the very basic principles, the processes in the compound nucleus $^4He^*$ that take place after the merging of two deuterons at low energies. As we have already noted, the dominant contribution to the cross section for this reaction at low energies will be the *S*-wave, i.e. the state with zero orbital number. Nucleon decay modes of the compound nucleus require the restructuring of its nuclear structure. We believe that after penetration through the Coulomb barrier and materialization in a potential well with zero angular momentum, these two deuterons preserve for some time their own identities. This is the time that determines the frequency of further nuclear reactions.

It seems that in this process, a certain hierarchy of strong interactions is manifested. The peripheral nuclear field (pion exchange and so on) is strong enough to hold the two deuterons in the well of the strong interactions. However, the law of conservation of baryon number requires more radical intervention in the system for the implementation of nuclear reactions with the transfer of nucleons from one deuteron to another.

Figure 4 schematically illustrates the mechanism of this process. The left part of Figure 4 shows the *S*-states of the compound nucleus $^4He^*$ at two different excitation energies. The dash-dotted line shows the boundary of the potential well. In principle, this system is the dual "electromagnetic-nuclear" oscillator. In this oscillator, the total kinetic energy of deuterons is transferring to the potential energy of the oscillator, and vice versa. In the case of very low excitation energy, the amplitude of the oscillation of deuterons is small, and the reaction of nucleon exchange is suppressed. When the excitation energy increases, the region of overlapping of trajectories of oscillating deuterons (more correctly, their wave functions) increases and therefore the probability of exchanging nucleons increases. In high-energy physics, the mechanism usually associated with similar processes is called the phase volume of reaction. The right part of Figure 4 shows the possible form of the potential well for the *S*-state compound *DD* nucleus. The dashed lines represent the excitation energy.

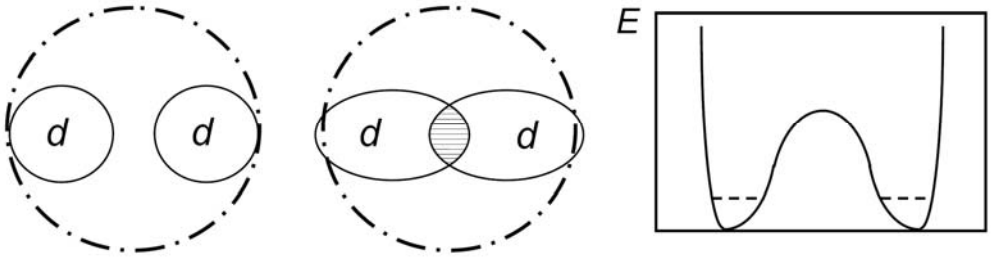

Figure 4. Schematic illustration of the mechanism of dependence of the nuclear transition frequency in the compound nucleus $^4He^*$ with the excitation energy. Left: the dash-dotted lines shows the boundaries of the potential wells. One diagram depicts the state of the compound nucleus at asymptotically low excitation energies, another diagram depicts the compound nucleus at higher energies. Right: a schematic illustration of the potential well of the compound nucleus $^4He^*$, the dashed lines represents the excitation energy.

The stability of the excited compound nucleus $^4He^*$ can be considered in the formalism of the usual radioactive decay. In this case,

$$N(t)/N_0 = e^{-t\nu}$$

where ν is the decay rate, i.e. the reciprocal of the time constant of decay τ. According to our hypothesis, the decay rate ν is a function of excitation energy of the compound nucleus E. Approximating with the first two terms of the polynomial expansion, we have:

$$\nu = \nu_0 + aE$$

Here ν_0 is the decay rate at asymptotically low energy excitation. According to quantum-mechanical considerations, the overlap of the wave functions of the deuterons does not disappear completely with a decrease in energy, as illustrated by the presence of the term ν_0. The second term characterizes the decay rate that depends on energy.

Characteristic nuclear rates are usually about 10^{22} per second. As mentioned above, the fusion reactions $D+D \rightarrow {}^4He$ has the so-called "broad resonance" at an energy of about 8 MeV. Simple estimates using the width of the resonance and the uncertainty relation give the lifetime of the compound nucleus at this energy of about 0.8×10^{-22} seconds. Then it increases approximately linearly with decreasing energy. It seems to us, McKubre group [2] works in a range of about 2 keV energy in the center of mass (the equivalent temperature is approximately 10^7 degrees Kelvin). Thus, in these experiments, the excitation energy is about 4×10^3 times smaller than in the resonance. We believe that the rate of nuclear decays in this case is approximately as many times less than at the resonance, and the corresponding decay time is about 0.3×10^{-18} second. This decrease in the nuclear reaction rate has a small effect on the ratio of output decay channels of the compound nucleus, but only to a certain limit. This limit is about 6 keV. Then the compound nucleus is no longer an isolated system, since virtual photons from ${}^4He^*$ can reach to the nearest electron and carry out some excitation energy of the compound nucleus. For the distance to the nearest electron, we have chosen the radius of electrons of a helium atom (3.1×10^{-11} m). From the uncertainty relations, the time of these processes is about 10^{-19} seconds. The total angular momentum carried by virtual photons can be zero, and therefore the process is not restricted. The process of the exchange by virtual photons without changing the total angular momentum, called *E0*, is known in nuclear spectroscopy and sometimes called photonless exchange [11].

We believe that after a few exchanges of virtual photons with the electrons of the environment, the relatively small excitation energy of the compound nucleus ${}^4He^*$ (the energy of two deuterons before the collision) is practically zero, and the decay rate of the compound nucleus with the emission of nucleons is determined only by the term ν_0. We assume, for convenience, that this term is not more than 10^{12}-10^{14} per second. In this case, in about 10^{-16} seconds the virtual photons carry off ~ 4 MeV, and then also the entire energy of the compound nucleus (24 MeV). After that, the nucleus ${}^4He$ is in the ground state. Calculations by quantum electrodynamics can provide more information about the process.

Figure 5 shows observations of the Astrophysical S Factor for the $D+D \rightarrow {}^4He$ reaction from the article of K. Sabourov et al. [10] with a somewhat expanded scale to the lower energies. The horizontal dashed line is the astrophysical factor at zero energy $S(0) = 4.8\times10^{-6}$ keV b, obtained in [10] with the analysis of all known data. The arrow indicates the energy at which the exchange of energy between the compound nucleus and surrounding electrons by virtual photons comes into effect.

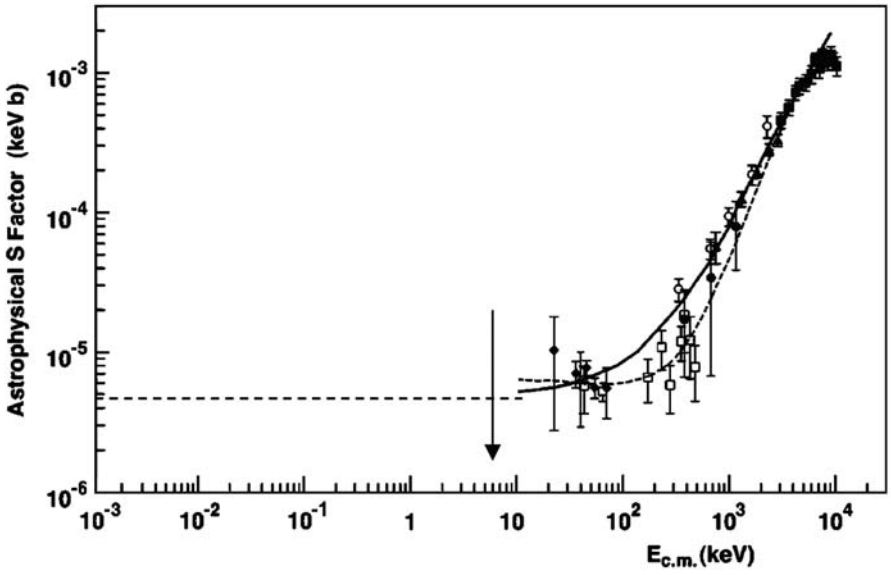

Figure 5. Observations of the Astrophysical S Factor for the reaction $d+d \longrightarrow {}^4He$ from the article of K. Sabourov et al. [10] with a somewhat expanded scale of energies. The dashed horizontal line indicates the value of the astrophysical factor at zero energy $\boldsymbol{S}(0) = 4.8 \times 10^{-6}$ keV b, obtained from the analysis of all known data. The arrow indicates the boundary between the established understanding of nuclear physics and the proposed explanation, which hypothesizes the exchange of energy between the compound nucleus and the electrons by virtual photons.

According to this theory, the main process which allows the relaxation of the excited compound nucleus ${}^4He^*$ to the ground state of ${}^4He$ is the transfer of energy by virtual photons between the nucleus and the nearest constituent electrons, including the electrons of the crystal lattice. In this case, the emission of virtual photons by the nucleus ${}^4He^*$, when the energy of the compound nucleus is transferred directly to the electrons of the lattice, is apparently the dominant process due to the fact that the amplitude of this process is proportional to the square of the electric charge. Full discharge time of the compound nucleus in this process is determined by the distances to the nearest electrons of the crystal lattice, and can be completed in approximately 10^{-15} seconds.

Figure 6 illustrates the processes that provide thermalization of *DD* fusion reactions in crystals.

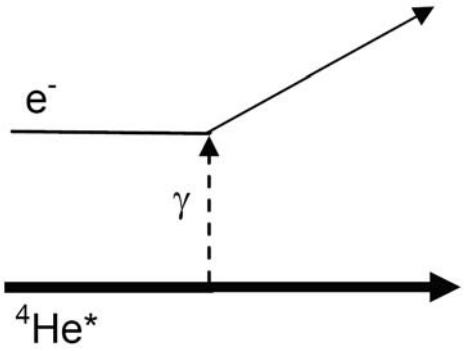

Figure 6. The diagram of the processes that provide thermalization of *DD* fusion reactions in crystals. Virtual photons are emitted by a compound nucleus ${}^4He^*$.

The mechanism of energy dissipation of the compound nucleus $^{4}He^{*}$ with virtual photons, discussed above, naturally raises the question of the electromagnetic-nuclear structure of the excited compound nucleus.

4 – ESTIMATES OF THE FUSION REACTION RATE OF DEUTERONS IN CRYSTALS

4.1 – Movement of Deuterons in Crystal

As we pointed out earlier [3, 4], our hypothesis is that at least some of the deuterium atoms which are impurities in the crystal lattice are not "settled" in certain niches of the lattice. Instead, these deuterium atoms travel almost freely along the axes of the crystal lattice in the so-called hyper channels of crystal, just as high energy particles are channeled in crystals.

A very unusual situation arises when atoms of deuterium are moving in a curved channel. If the particle moves in a curved channel with a static potential, its kinetic energy is conserved, and the particle moves along a certain equilibrium orbit. However, when the crystal lattice experiences collective thermal vibrations, the particle moving in the curved channel experiences successive transverse kicks from a group of atoms of the lattice, and therefore absorbs momentum and energy from the lattice. This small "thermal acceleration" of the deuterium atoms, in our view, is the origin of deuterium fusion in crystals. The limit on energy gain in this course is dictated by the beginning of the ionization process, which occurs at about 50 keV. It is obvious that the usual Maxwell thermal energy distribution of atoms in a crystal is not occurring. Especially strong anisotropy in the momentum distribution of the particles occurs for the moving contaminants.

We believe that this dynamic process in a crystal system which contains deuterium atoms as impurity is not in conflict with the fundamental principles of thermodynamics, which operates with the average values of temperatures. There are numerous naturally occurring phenomena resulting from dynamic processes in which the average temperature of bodies that are in thermal contact, can vary considerably, for example in the case of liquids with an open surface, reflecting objects, etc. There were more serious challenges to the laws of thermodynamics, such as superfluidity, superconductivity, the dissolution of liquid ^{3}He in ^{4}He, and many others, and the thermodynamics were adjusted to treat these processes accordingly. This list could be continued until even the inflation process in the early stage of our Universe is included. We believe that in the case of the phenomenon of "cold fusion" (below we show the possibility of this) an absolutely scientific explanation exists for the apparent paradox of "hot deuterium in cold palladium". It must not be forgotten that during the introduction of one deuterium atom in the crystal of palladium about 30 eV is spent in order to overcome the crystal potential, and that is about three orders of magnitude greater than the average thermal energy of an atom of the crystal. In the near future we will conduct the detailed thermodynamic consideration of the processes that lead to the fusion of deuterium in the crystals.

For an explanation of the process, Figure 7 presents a diagram of the average electrical potentials in the silver crystal [12].

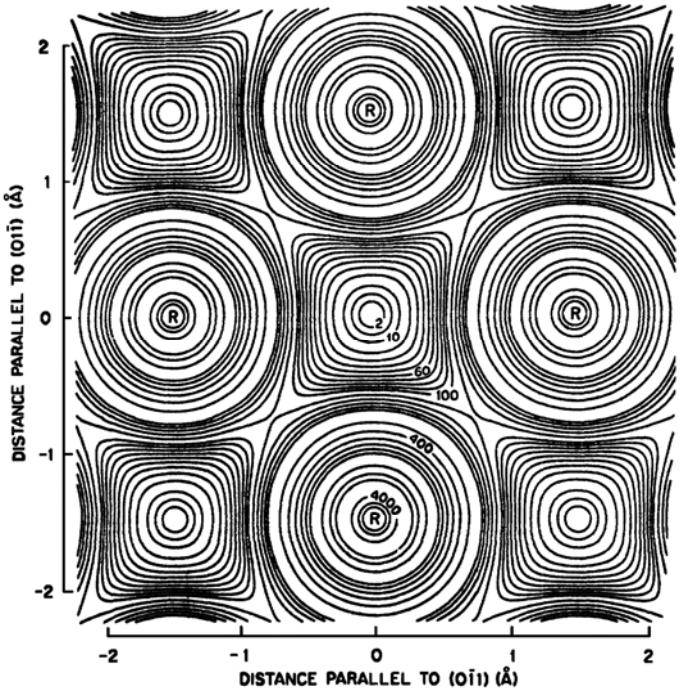

Figure 7. Averaged electrical potentials in silver crystals contain hyper channels as in the center of this diagram. Contaminant atoms of deuterium in such a structure will be located on the axes of these hyper channels (in the figure these areas are square shaped).

We believe that the crystal structure of palladium is similar to that shown in Figure 7. The numbers in Figure 7 represent the value of potential in electron-Volts. Obviously, all the contaminant atoms of deuterium in such a structure will be located in the hyper channels (in the figure these areas are square shaped), and the coordinates of their centers coincide with the axis of the hyper channel up to the value of thermal lattice vibrations. As already mentioned, at very low collision energies the dominant contribution to the deuterium reaction is *S*-wave. The strong mutual collimation of the deuterons in the crystal lattice further intensifies the demand for *S*-wave dominance.

Although the probability of *DD* fusion in a single collision at energies of about 2 keV is extremely low because of very low probability of penetration through the Coulomb barrier (the equivalent temperature is only of about 10^7 degrees), collimation of deuterium projectile and target significantly increases efficiency of the process.

In addition, the kinematics of elastic Coulomb scattering for the case of zero angular momentum in the hyper channels leads to the fact that because of the saturation of the palladium lattice with deuterium, *DD* interactions occur in virtually every cell of the crystal, resulting in about 3×10^7 interactions per cm for each deuterium atom moving in the crystal. Simplifying the process, you can imagine that the fast deuterium atoms moving along hyper channels face deuterium atoms that are at rest. As a result of a head-on collision, the incident deuterium atom stops, and the resting atom begins to move along a channel with a speed of the incident one (a peculiar effect, which we would call the "round domino"). This situation is repeated in each successive cell of the crystal, until either the *DD* fusion reaction occurs (the probability of this is very small), or a moving atom meets with a dislocation in the crystal. The process of channeling deuterium atoms in the crystal hyper channels strongly stabilizes this process of the "round domino".

A very important parameter of the process is the ratio of fast moving deuterons to the number of stationary ones. This parameter of the process is apparently determined by the mechanism and the degree of deformation of crystalline elements of the "reactor", and this was not controlled in the experiments [2]. We believe that this ratio could have reached about 10^{-5} in the experiments [2].

A 1 cm^2 cross-section of the crystal has about 10^{15} hyper channels. Based on the evaluation of cross section of the $D+D \rightarrow {}^4He$ reaction at low energies, given in K. Sabourov et al. [10], our

calculations give a value of about 2.5×10^{13} $D+D \rightarrow {}^4He$ reactions per second per 1 cm^3 of palladium in the experiments [2]. As already noted above, we assumed the effective energy of fast deuterons to be about 2 keV relative to the center of mass. Taking into account the fact that the parameters of the process are still largely uncertain, these estimates can be considered very encouraging (the numerical calculations are given below).

In our opinion, these factors result in the certainty of deuterium fusion in the crystals. Collimation of the incident particle and target particle increases the probability of their interaction by a factor of about 10^4 compared with a substance in an amorphous state, such as high-temperature plasma, whose density (in addition) is significantly lower than the density of deuterium in the crystal. The "round domino" effect makes it possible to produce the reaction practically at room temperature since the proportion of fast deuterium atoms remains negligible, while at the same time the effective reaction temperature is high, about 10^7 degrees. Finally, the hypothesis of a decrease in the rate of nuclear decay of the compound nucleus ${}^4He^*$ at low energies opens up the possibility of nonradioactive thermalization of the energy released. Experiments [2] support of this hypothesis and provide evidence for this new phenomenon in nuclear physics.

4.2 – Numerical calculations

For simplicity, we consider the processes in a cubic element of palladium with the size of $1\text{cm}\times1\text{cm}\times1\text{cm}$.

Consider the motion of fast deuterium along a hyper channel in the direction of one of the main crystal axes and its interaction with other contaminant atoms of deuterium. Let us calculate the cross section for fusion of two deuterium nuclei to form a compound nucleus, assuming that the energy of the colliding deuterons is equal to 2 keV in the center of mass. From K. Sabourov et al. [10] the value of an astrophysical factor for this reaction at zero energy is **S**(0) = 4.8x10^{-6} keV b. Let us assume that for deuterons with an energy of 2 keV the astrophysical factor is equal to this value. We have ignored a further consideration of the possible shielding of deuterium by their electrons, which could increase the probability of penetration through the Coulomb barrier. From the work of C.A. Barnes et al. [9] for the energy of 2 keV, we get the following:

$$\sigma = \frac{S(E)}{E} e^{-2\pi\eta}$$

where

$$e^{-2\pi\eta} = e^{-31.4(E)^{-1/2}} = 1.86\times10^{-10}$$

$$\sigma(E = 2\ \text{кэВ}) = (1.86\times10^{-10}\times4.8\times10^{-6}\times10^{-24})/2 = 0.45\times10^{-39}\ \ \text{см}^2$$

As expected, this cross section is catastrophically low. However, there are some circumstances connected with the structure of the crystal which largely compensate for the smallness of this cross section.

It should be kept in mind that the density of deuterium in the hyper channels is significantly increased, compared to an amorphous substance. In one hyper channel of 1 cm length (3x10^7 atoms of deuterium), with a transverse dispersion of deuterium atoms 10^{-10} cm (~1% of the transverse size of a hyper channel) the total density of deuterium is about $10^{10}\times10^{10}\times3\text{x}10^7$ = 3x10^{27} cm^{-2}. As noted above, the kinematics of elastic Coulomb deuteron-deuteron scattering for the case of small angular momentum in hyper channels of the crystal leads to a peculiar effect of the "round domino." The process of channeling of deuterium atoms in the crystal hyper channels strongly stabilizes the process. The number of interactions in one hyper channel for a "single" fast deuterium path of 1 cm is

$$N = \sigma \times n_d = 0.45 \times 10^{-39} \times 3 \times 10^{27} = 1.34 \times 10^{-12}$$

By a "single" fast deuterium path, we refer to a "single domino" process in a full channel. If we take the proportion of fast deuterons ~ 10^{-5} to the total number of deuterons (i.e., 3×10^2 in one hyper channel), the total path of the deuterons along one hyper channel of a length of 1 cm gives approximately 4.0×10^{-10} interactions. The speed of fast deuterons (4 keV in lab system) is 6.2×10^7 cm/sec, time of flight distance of 1 cm is 1.6×10^{-8} seconds, so from one hyper channel we obtain $4.0 \times 10^{-10}/1.6\ 10^{-8} = 2.5 \times 10^{-2}$ interactions per second . Of course, fast deuterium atoms are moving in the hyper channel in both directions, but it does not change the results of these calculations.

The number of hyper channels per 1 cm^2 is approximately $3 \times 10^7 \times 3 \times 10^7 \approx 10^{15}$. Thus, the total number of interactions in the palladium element of 1 cm^3 will be $2.5 \times 10^{-2} \times 10^{15} = 2.5 \times 10^{13}$ per second.

It should be noted that in this consideration hyper channels of other directions were not included, and this may increase the yield of the reaction. Of course, these estimates should only be considered as very preliminary.

It should be noted that there is an extremely high sensitivity of the yield of the reaction to the energy of the fast deuterons. This is due to the influence on the yield of the probability of penetration of deuterons through the Coulomb barrier. This sensitivity to the energy of the fast deuterons, apparently, was the main reason for the poor reproducibility of the experimental results[2]. As already noted, heating of the drifting fraction of deuterons occurs in the deformed parts of the crystals. If you decide to control the deformations, for example using crystalline undulators [13], the energy of the drifting fraction of deuterons can be increased. Figure 8 (not to scale) presents several options: 1– a bad sample of palladium, 2– a good sample, 3 – a future sample with controlled deformations. Here the spectrum of drifting atoms of deuterium is plotted against the left axis and the cross section of the reaction is plotted against the right axis. Indeed, the difference between the yields of these options is several orders of magnitude. According to our calculations, deuterons having an energy of 1 keV in the center of mass system yield 0.43×10^{10} events per second, or 16.5 mW, at 2 keV the yield of the reaction is 2.5×10^{13} events per second, or 96 watts, and at an energy of 3 keV the yield is 1.45×10^{15} events per second, or 5.6 kilowatts. At a deuteron energy of 1 keV the reaction D+D$\rightarrow {}^4$He in the experiments [2] could not be registered, because the volume of the palladium element in the experiment was about 0.1 cm^3, and the measurement error was about 60 mW.

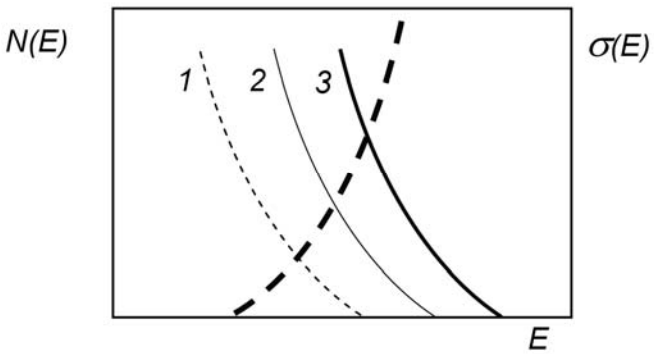

Figure 8. The cross section for the reaction and three examples of the spectrum of the drifting fraction of deuterons are shown in one graph (not to scale). The spectra of drifting atoms of deuterium are plotted againt the left axis while the cross section for the $D+D \rightarrow {}^4He$ reaction (heavy dashed line) is plotted against the right axis. For the spectra of the drifting fraction these three options are presented: 1 — a bad sample of palladium, 2 — a good sample, 3 — a future sample with controlled deformations. The difference in the yields of the reaction can be several orders of magnitude.

The effective energy of fast deuterons ~2 keV in our calculations was chosen to fit the reaction yield actually obtained in the experiments [2]. The aim of our numerical calculations was to show that the mechanism we propose, in principle, can explain the experiments.

5 – DISCUSSION

We believe that the physics of the decay of the compound nucleus $^4He^*$ resulting from collisions of deuterons is changing completely near 6 keV in the center of mass. In our view, the considerations presented in this article restore the compatibility of all the experiments related to the reaction $D+D \rightarrow {}^4He$, including [2], and elevate these experiments [2] to the rank of legitimate science. The results of these experiments indicate that at low excitation energies of the compound nucleus $^4He^*$ the frequency of decays with emission of nucleons does not exceed 10^{16} per second and cannot compete with the processes of energy exchange with the nearby electrons by virtual photons. Peculiarities of behavior of deuterium atoms in a crystalline environment provide a gross increase in the probability of deuteron fusion and open up the possibility of practical application of this process.

It should be noted that an increase in the efficiency of the thermal acceleration of contaminant atoms of deuterium (as with the use of crystalline undulators, for example), along with the sharp increase in the yield of fusion, may open unwanted nuclear channels.

The new nuclear physics at low energies could have unexpected implications for the customary practice with nuclear reactions. For example, the rate of certain nuclear reactions excited by thermal neutrons may be environmentally dependent.

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