

Research Article

Cold Nuclear Fusion in Metal Environment

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Abstract

This paper discusses the mechanism of cold fusion with deuterium and other elements implanted in the potential sites of conductive crystals. Cold fusion in metals becomes possible due to the fact that the implantation of atoms in a crystal guides them to their excitation levels, which are determined primarily by the positioning of free conduction electrons in a zone of potential sites. The excitation energy of the p-states is about 10–14 eV. The excited atoms' orientation in the crystal is not random but dictated by the crystal lattice's electrostatic potentials. Calculations show that the transparency of the Coulomb potential barrier, for example, in the case of DD-fusion, increases by about 60 orders of magnitude if two deuterium atoms meet each other in the minima of the conductor's potentials in the *crisscross* orientation. Most of the papers are devoted to the process of DD-fusion in the electrolytic saturation by deuterium in crystals, a process that is extensively studied in these experiments. This paper also briefly comments on other experimental results related to cold fusion.

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Keywords: Deuterium, Excess power, Nickel, Palladium, Platinum

1. Introduction

There has been talk about the transition to controlled thermonuclear fusion for over 60 years. However, despite the initial expectation that the problem would soon be solved, a solution has not materialized yet. Technical difficulties

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related to obtaining sustainable superhot plasma ($\sim 10^9$ °C) and the damaging effects of the enormous neutron flux arising as a result of thermonuclear reactions have pushed the solution of this problem to the distant and uncertain future.

Fleischmann and Pons reported [1] an experimental result in which significant heat was observed in the electrolytic saturation of palladium crystal deuterium; this heat could not be quantitatively explained by chemical reactions. The authors concluded in these experiments that they were detecting nuclear DD-fusion occurring at room temperature. The orthodox physics community quickly decided that these experiments must be incorrect. However, after numerous subsequent confirmations, scientists appeared confident that the problem of controlled nuclear fusion had been solved. The most serious studies have been conducted by a group led by McKubre [2]. Nevertheless, the results of cold fusion experiments carried out in the past 25 years have either been completely ignored or met with great skepticism by the orthodox community of nuclear physicists. The two main objections put forward against the results of these experiments are as follows.

- (1) Numerous attempts have been unsuccessful in providing a scientific explanation for how, in the process of cold fusion, the so-called Coulomb barrier is overcome.
- (2) In DD cold nuclear fusion, in contrast to thermonuclear fusion, there are practically no other nuclear products except ^4He . This phenomenon has no clear explanation.

In the following sections, we have tried to answer these objections.

The heat release in cold fusion reactions is about 10^6 times greater than in any chemical reaction. Thus, we have discovered a new physical phenomenon that will undoubtedly change the whole course of human civilization. Some of the practical applications of this phenomenon (for ships, aircraft, and spacecraft) are simply not available for large cyclopean tokamaks or other hypothetical systems using conventional nuclear fusion.

2. Experiments on DD Fusion using Low-energy Accelerators

It has been shown in experiments with DD fusion accelerators that if the deuterium atom target is located in a conducting crystal, the fusion reaction at low energies is much more probable than in the case of free deuterium atoms. These experiments provide a direct explanation of the phenomenon of cold fusion.

Describing the collisions of atoms, one must properly modify the expression of the probability of penetration through the potential barrier, written for the collision of “naked” nuclei, because atomic electrons screen the repulsive effect of nucleic charges. Within the Born–Oppenheimer approximation, Assenbaum [3] and others have shown that introducing the so-called “electron screening potential” for a collision of free atoms is equivalent to introducing in expression of the transparency for the Coulomb barrier $P = e^{2\pi\eta}$, where $2\pi\eta = 31.41/E_{\text{eff}}^{1/2}$, $E_{\text{eff}} = E + U_e$, an additional energy $U_e = 27$ eV. In experiments at accelerators [4–13], the electron screening potential reaction of DD fusion in conducting crystals suddenly appeared to be very large – equal to $U_e \sim 300 - 700$ eV. Figure 1 shows the results of astrophysical function $S(E)$ from [11] for the case in which target deuterium atoms are embedded into the platinum crystal. Instead of approaching a value of about 50 keV-b with decreasing incident deuteron energy, as happens when deuterium targets are embedded in a substrate of semiconductors, insulators, or amorphous materials, the value of $S(E)$ begins to increase sharply.

The presence of the crystal’s conduction electrons, grouped in the conductor lattice’s potential sites, results in a ban for the hydrogen atoms’ s states to occupy these sites. The excitation of a hydrogen atom’s electron shell by only 10 eV translates to a deuterium atom in the state 2p, 3p, etc. and effectively removes the ban. This means that if one crystalline site in a conductive crystal contains two deuterium atoms, the distance between these atoms’ nuclei is equal to 1/10–1/20 of the nominal sizes of unexcited atoms. This drastically increases the probability of a fusion reaction.

We considered the processes of cold DD fusion in Refs. [14–18].

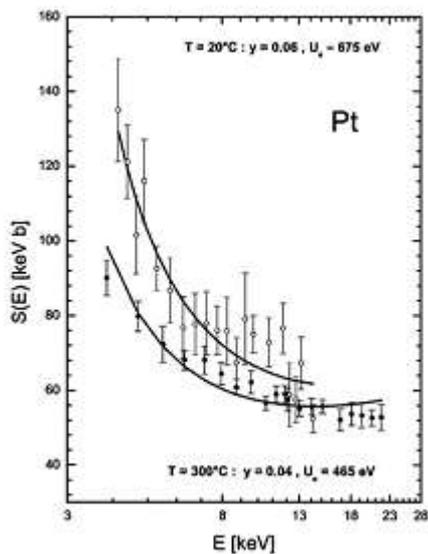
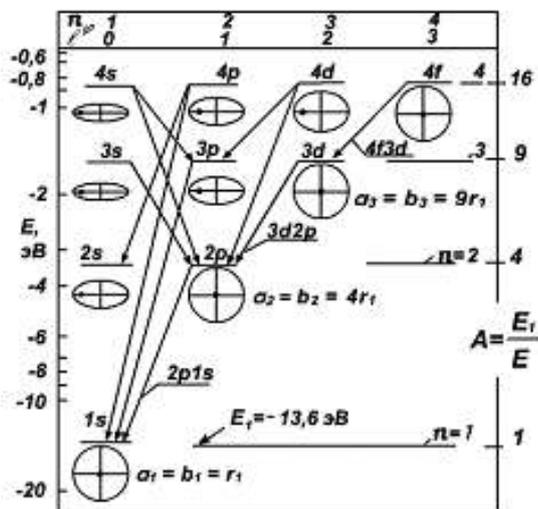


Figure 1. The astrophysical function value $S(E)$ in the case in which the target deuterium atoms are imbedded into the platinum crystal. At room temperature, the data fit well with the screening potential of 675 eV.

3. Physics of Cold DD Fusion

A diagram of a hydrogen atom's electron levels is shown schematically in Table 1.

Table 1. Scheme of a hydrogen atom's electronic excitation levels.



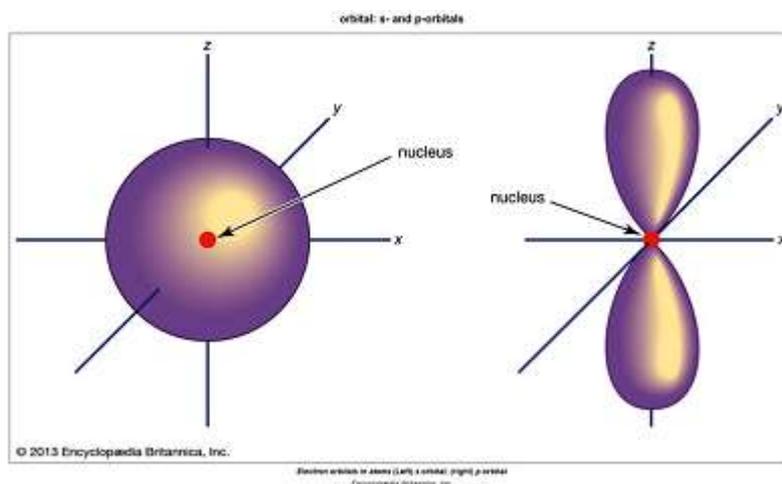


Figure 2. The hydrogen atom orbitals 1s (left) and 2p (right). This figure is taken from the Encyclopædia Britannica, 2013 [19]. The presented contours include 95% of the electron's possible positions.

We are interested in the second vertical column with the quantum numbers $n = 2$ and $l = 1$, and in particular, the levels 2p and 3p. Figure 2 [19] schematically illustrates the free hydrogen atom's electron density in the states 1s and 2p.

Winter [20] has developed an interesting representation of the free hydrogen atom's various orbitals. Figure 3 shows the function of hydrogen's electron density by the solution of the Schrödinger equation in the states 2p and 3p. Figure 4 shows the fcc crystal structure, of nickel, palladium, and platinum. Large circles indicate the atoms' location in the host crystal; small circles indicate the location of the deepest octahedral potential sites in the structure. The parameters of all octahedral sites are identical.

When the ratio of impurity atoms and deuterium atoms in a host crystal does not exceed the ratio of $D/Pd \sim 0.9$, the cold fusion process does not occur, as deuterium's impurity atoms are located in different octahedral sites and are quite distant from each other. However, when one such potential site has two deuterium atoms in an electron excitation state of 2p or above, the probability of penetration through the potential barrier of DD fusion increases sharply.

One of the cold fusion skeptics' most convincing arguments relates to these experiments' lack of nuclear decay products in the resulting compound nucleus. It was believed that "no neutrons – no fusion." However, a large international team of physicists, currently totaling about 200–300 people, continues to work in this direction. These researchers have considerable experience in cold fusion. The leading group of physicists working in this direction is led by M. McKubre [2]. Figure 5 shows a graph of excess heat (in watts), depending on the current, from these electrochemical experiments [21].

McKubre et al. [22] have demonstrated the success of cold fusion experiments in the *yes-no* embodiment vs. deuterium concentration in the palladium crystal (Fig. 6). After exceeding the ratio of $D/Pd \sim 0.9$, experimenters

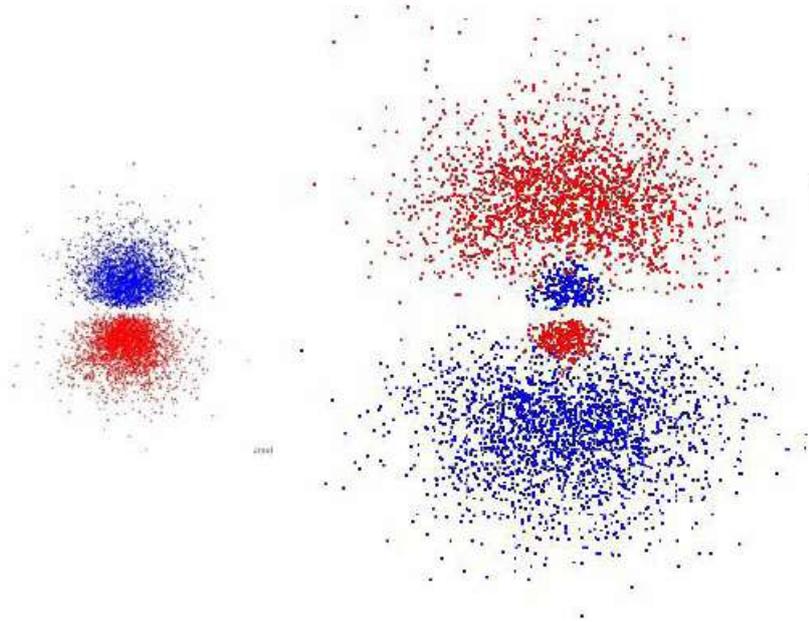


Figure 3. The functions of hydrogen's electron density in the states 2p (left) and 3p (right), from Winter [20]. Red and blue mark the density obtained for the positive and negative values, respectively, of the wave function ψ .

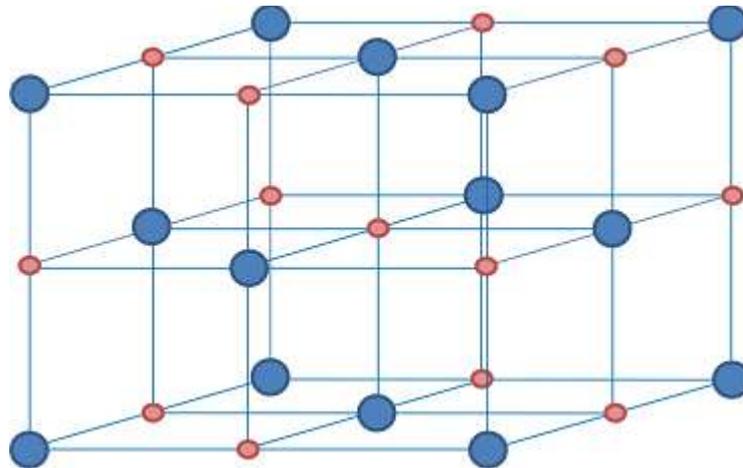


Figure 4. The crystalline structure of fcc (nickel, palladium, platinum). Small circles indicate the locations of the structure's deepest octahedral potential sites.

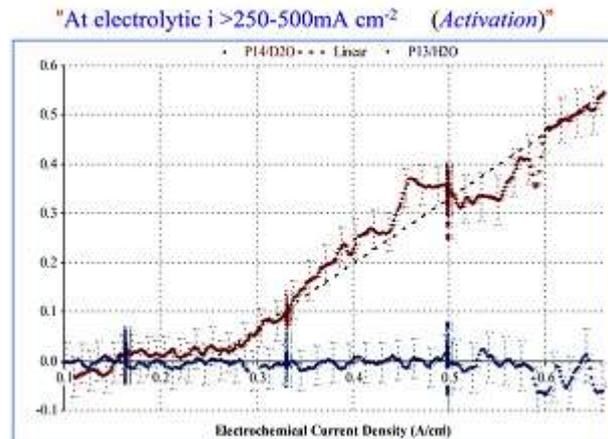


Figure 5. Excess heat (in watts) depending on electrochemical current in the experiments of McKubre et al. [21].

consistently observe DD fusion. In [16], we calculated the electric field in the volume of fcc crystals. Figure 7 shows the shape of the octahedral potential site in a platinum crystal.

The left-hand side portion of Fig. 8 shows the XY projection for the empty octahedral site. The center of the figure shows a possible arrangement of a single deuterium atom in the 2p state in this site. The right-hand side of the figure shows a possible combination of two such atoms in the same site. The color scale characterizes the electric field's potential in the cell of the crystal of platinum. The reader should keep in mind that there are some zero quantum vibrations of 2p deuterium atoms; this, however, does not deny their average location in the conductive crystal cell.

Figure 9 shows the arrangement of two deuterium atoms in the 2p state in one crystallographic site along the vertical axis Z. Figure 10 schematically illustrates the mechanism of a deuterium atom transition to the 2p state during its implantation in a conductive crystal. Thus, the target deuterium atoms implanted into metals are no longer in the base 1s state, as the cloud of free electrons in the atom causes the implanted atom's electrons to take excited p states.

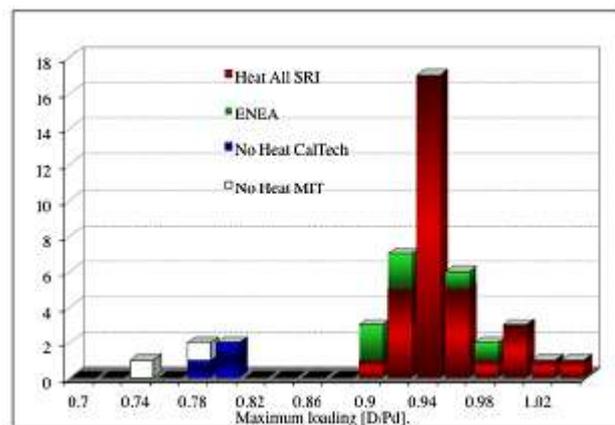


Figure 6. The success of cold fusion experiments, depending on the concentration of deuterium in the palladium crystal, from [22].

Table 2. Characteristics of cold fusion for palladium and platinum.

Crystal type	Screening potential (eV)	Oscillation frequency (ν , s $^{-1}$)	Transparency ($e^{-2\pi\eta}$)	Reaction rate (λ , s $^{-1}$)
Palladium	300	0.74×10^{17}	1.29×10^{-25}	0.95×10^{-8}
Platinum	675	1.67×10^{17}	2.52×10^{-17}	4.2

The screening potential of 300–700 eV in experiments on DD fusion at accelerators shows that incident deuterium atoms are also in the p states during their movement in a conducting crystal. These processes allow for the two deuterium nuclei in the crystal potential site cell to be close enough without feeling a strong Coulomb repulsion.

Figure 11 presents the sizes of different hydrogen orbitals, in particular 2p and 3p [23]. Note again, Figs. 2, 3, 9 and 11 are valid exactly only for separated atoms, and could be distorted during chemical bonding. We used them here as the first approximations. Figure 12 shows the Coulomb barrier transparency of the potential electron screening U_e for DD cold fusion.

$$P = e^{-2\pi\eta} (2\pi\eta = 31.41/E_{\text{eff}}^{1/2}, E_{\text{eff}} = E + U_e).$$

For cold fusion ($E \cong 0.040$ eV), the ratio of the deuterium atoms' Coulomb barrier transparency in the same crystal platinum site to the corresponding value for the transparency of the free deuterium molecule is $\text{Pt}/\text{D}_2 \cong 10^{65}$. Thus, the metal crystal penetration of deuterium nuclei through the Coulomb barrier becomes practically possible due to the system's zero quantum vibration of the system. Table 2 (taken from [15]) shows the characteristics of cold DD fusion for palladium and platinum crystals.

The pioneering work of Arata [24] was very fruitful; the detailed experiments of Swartz and Hagelstein [25] should be also mentioned here. Unfortunately, the brevity of this review does not allow further detail on these studies.

Below, we will show that the relaxation of the excited compound nucleus $^4\text{He}^*$ can be successfully explained by the exchange of this object with the crystal environment through the so-called *virtual photons*. This process has remained an intriguing mystery over the last 25 years.

4. The Discharge of $^4\text{He}^*$ Excess Energy by Virtual Photons

We have shown that the presence of free electrons in these crystals' saturated metal causes deuterium atoms to firmly occupy 2p orbitals or higher. When all octahedral sites are already filled with such deuterium atoms, sites with more than one such atom begin to appear. In this case, the probability that the DD system will penetrate the potential barrier increases dramatically. As we noted above, the rate of DD fusion in platinum crystals in such a site may reach 4 s $^{-1}$.

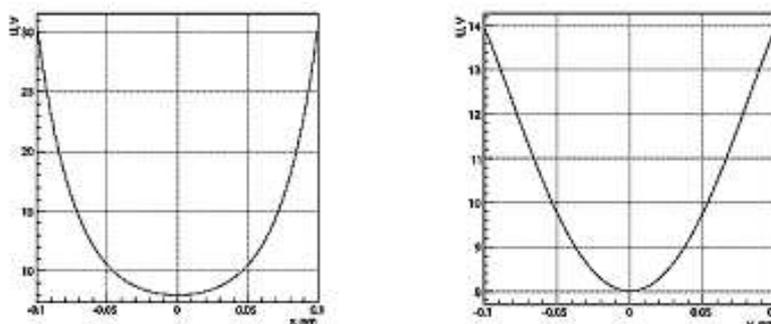


Figure 7. Electric potential behavior in the vicinity of an octahedral potential site in platinum crystal. The potential (in volts) at $Z = 0$ is shown in the crystal cell's horizontal plane (left) and diagonal plane (right).

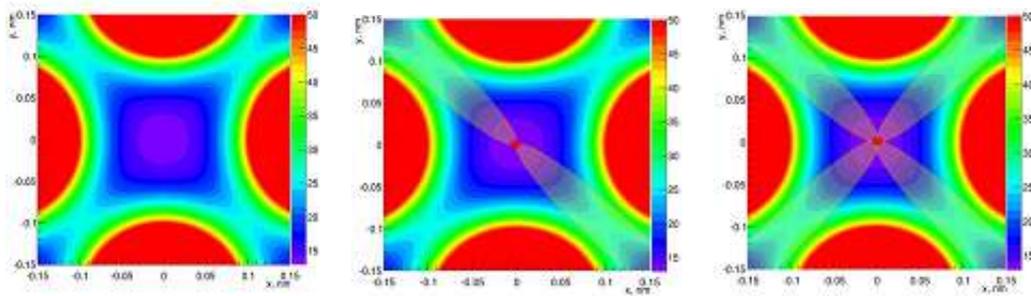


Figure 8. Left: the potential distribution in the empty octahedral site in the XY projection; center: a possible location of a single deuterium atom in the 2p state in this site; right: a possible combination of two such atoms in the same site. The color scale represents the electric field potentials in the platinum crystal cell.

Due to the very small (thermal) excitation energy of the compound nucleus reaction $DD \rightarrow {}^4\text{He}^*$, the compound nucleus's orbital angular momentum equals zero, which eliminates the possibility of real gamma ray emission. Figure 13 shows the potential well of strong interactions for the reaction $DD \rightarrow {}^4\text{He}^*$. Deuterons that have already penetrated into the potential well are still separated by the residual Coulomb barrier, the value of which, apparently, can reach hundreds of electron-volts. The nuclear decay rate of the compound nucleus ${}^4\text{He}^*$, by the standard nuclear decay channels ${}^3\text{H}+p$ and ${}^3\text{He}+n$, is significantly decreased. In this case, the exchange by the virtual photons with the external environment is still possible, as the spin of the virtual photons can be *directed along the time axis*. This residual Coulomb barrier acting between deuterium nuclei already in the potential well of the strong interactions can significantly slow down the rate of conventional nuclear decay channels.

In accordance with Fig. 13, we assume that the deuteron's penetration rate through the residual Coulomb barrier in the strong interactions' potential well is much less than 10^{-15}s^{-1} because of the very small (thermal) excitation energy of ${}^4\text{He}^*$. During this time, the excess energy of the excited nucleus ${}^4\text{He}^*$ is completely entrained into the environment.

Figure 14 shows the energy transfer of the excited ${}^4\text{He}^*$ state to surrounding electrons in the conducting crystal by virtual photons. In order for this mechanism to work, the ${}^4\text{He}^*$ metastable state must exist.

It can be assumed that after the fusion, the Coulomb barrier acts inside the strong interactions' potential well, and neutrons no longer have a retention factor, so they can almost freely move from one proton to another. However, the fact that this reaction is "almost free," not "completely free," means that extra energy of about 2 MeV is needed for

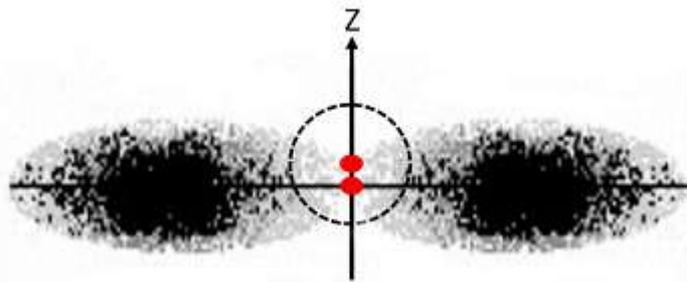


Figure 9. Location of two deuterium atoms in the 2p state in the same crystallographic site along vertical axis Z.

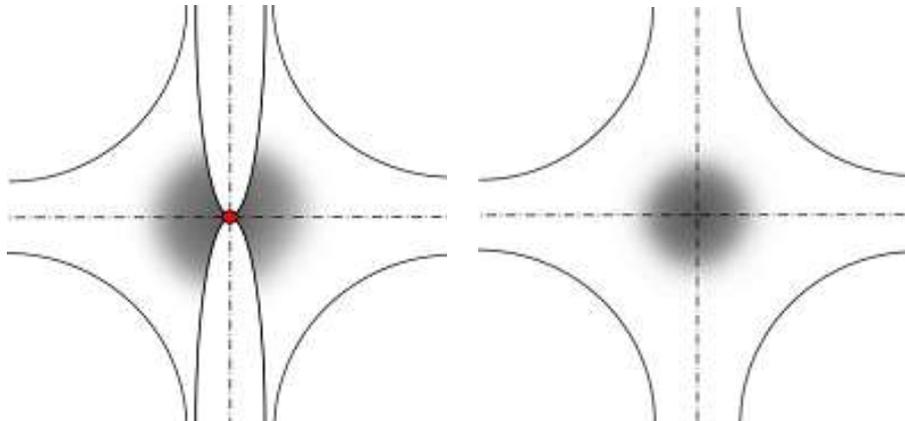


Figure 10. The conducting crystalline cell. A simple cubic structure is used as a didactic example. The shaded area shows the free electrons' location. The crystal's free conduction electrons do not completely leave their positions; as a result of this compromise process, a deuterium atom transits from the 1s state to the 2p state.

this process. Recall that in this case the kinetic energy of the deuterons in the strong interactions' potential well is very small, much less than 1 eV. The left-hand side of Fig. 15 shows Feynman's representation of a hydrogen atom. The right-hand side shows virtual photons carrying away the excess excitation energy in the reaction $DD \rightarrow {}^4\text{He}^*$, as it could have been represented by Feynman.

Figure 16 illustrates the process of transferring the electron energy to the environment. Figure 17 demonstrates changes of the compound ${}^4\text{He}^*$ nucleus during transition to the ground state ${}^4\text{He}$. The spatial separation of two deuterons in the intermediate nucleus ${}^4\text{He}^*$ produced in cold fusion must be large enough to ensure that the deuterons' residual Coulomb repulsion significantly delays the discharge ${}^4\text{He}^* \rightarrow {}^4\text{He}$ with virtual photons. This is dictated by the distance between the intermediate nucleus and the nearest electrons in the crystal lattice.

5. Design of the Experiment

A calorimetric approach does not allow us to understand in detail the specific mechanism of DD cold fusion. A special experiment is needed to shed light on the energy transfer mechanism in DD fusion without nuclear decay. We have

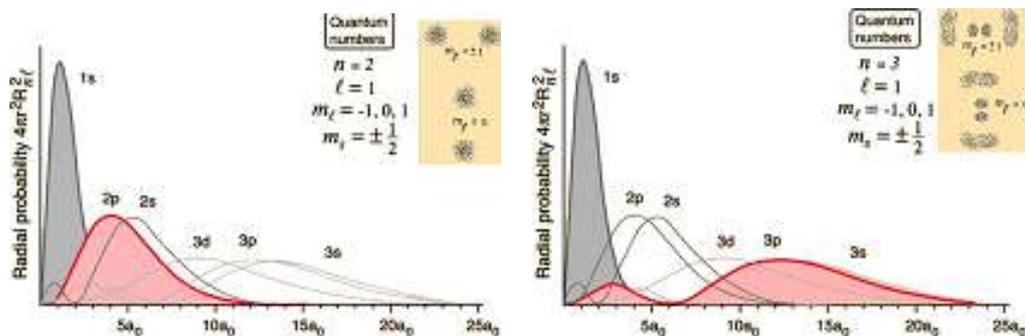


Figure 11. Radial probability for 2p and 3p states.

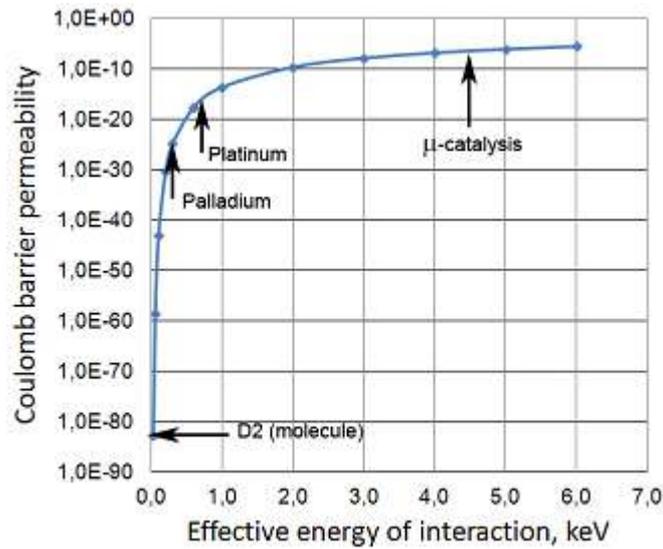


Figure 12. Coulomb barrier transparency for $E = 0$ in the potential U_e electron screening process of DD cold fusion.

formulated such proposals in Ref. [16]. As noted above, the effect of conduction electrons and the lattice of metallic crystals (suppression of 1s orbitals, excitation of 2p orbitals and these orbitals' definite spatial orientation in a crystal lattice) can significantly change the Coulomb potential barrier. The effective screening distance in this case could be an order of magnitude less than for non-excited atoms.

We calculated the process using the energy of the individual emission electron of 60 keV. In Fig. 18, we show the experiment's geometry, which would allow us to obtain additional information on cold DD fusion in conductive crystals.

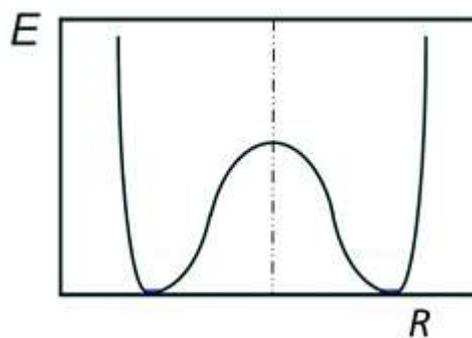


Figure 13. Schematic representation of the bottom of the potential well of the strong interactions for cold DD fusion in conductive crystals. The thermal excitation energy of ${}^4\text{He}^*$ is about 0.040 eV.

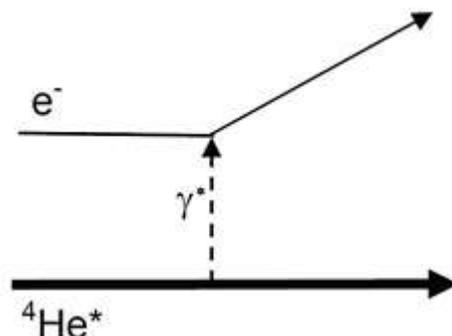


Figure 14. Scheme of excess energy discharge of the intermediate nucleus ${}^4\text{He}^*$ by a series of successive virtual photon exchanges between the nucleus and the environment.

At the preliminary stage of the experiment, we plan to measure the total energy of the electrons emitted from only one side of the palladium crystal. Sixteen semiconductor silicon detectors were placed on one side of the palladium crystal and included in the *coincidences*.

Total detected energy was calculated using a Monte-Carlo simulation (Geant4). For a detailed simulation of low-energy electromagnetic interactions [26], we used the Livermore Physics model (G4EmLivermorePhysics) of the GEANT4 package. We used the database and Livermore EPDL and EEDL.

It was assumed that, as a result of the fusion process occurring in a relatively short time (about 10^{-15} s), approximately 10^3 electrons enter into the detector with the energy of 60 keV; the total released energy is 24 MeV. Palladium foil is not an active element; this means that part of the electrons' energy resulting from the DD fusion is fading from the measurement. Calculations allowed the optimization of palladium foil thickness and detector geometry.

Figure 19 shows the results of calculations for the one-sided detector arrangement and the radiation of electrons with energy of 60 keV. Event selection can be done by triggering multiple detector coincidences on one side of the palladium foil.

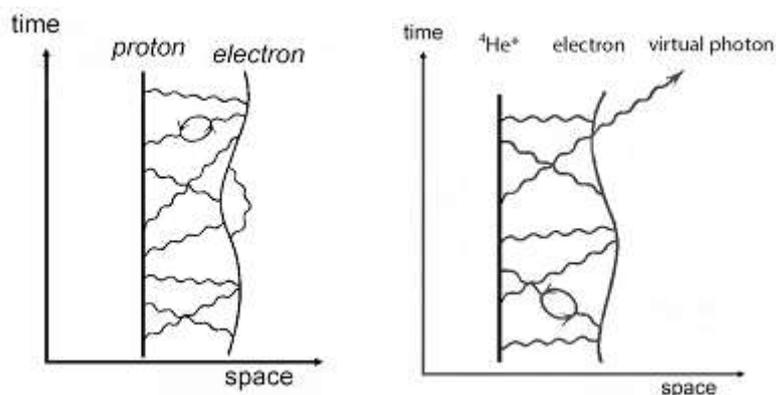


Figure 15. Left: Feynman's diagram of a hydrogen atom's steady state. Right: the virtual photons of the excited state ${}^4\text{He}^*$ in DD cold fusion, as they could have been represented by Feynman.

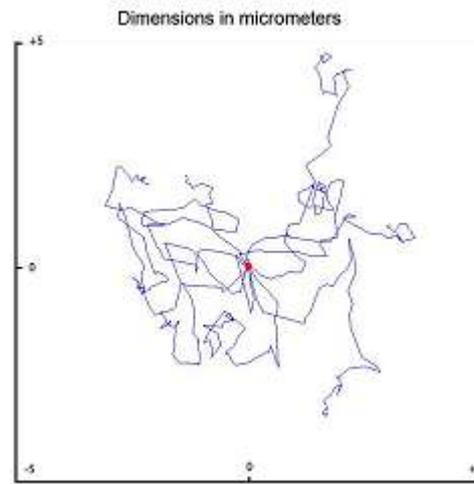


Figure 16. The trajectories of the first 10 electrons, generated to describe the cold DD fusion process in palladium using the Monte Carlo method [16]. Dimensions are in micrometers.

About 75% of the Monte-Carlo events were completely absorbed in the sample palladium. The resulting energy spectrum extends to about 14 MeV, which is explained by the backscattering of electrons in palladium fraction at angles up to 180° .

In the case when the detectors are located on one side of the Palladium, the maximum detected energy is about half of the decay energy of ${}^4\text{He}^*$. In our view, these measurements are conclusive evidence that excitation energy is transferred from the compound nucleus ${}^4\text{He}^*$ to the host crystal by means of virtual photons.

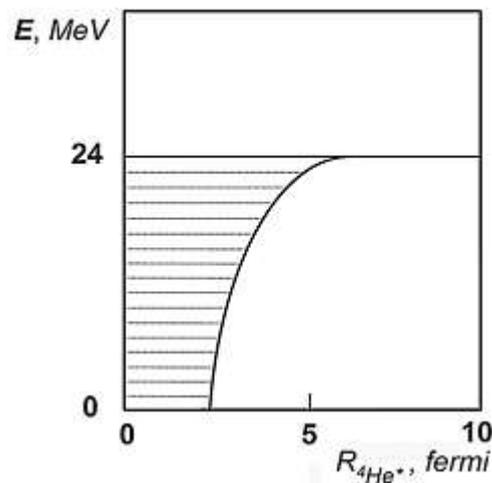


Figure 17. The size of the intermediate compound nucleus ${}^4\text{He}^*$ during discharge of the excited nucleus's excessive binding energy. The horizontal scale is quite conditional.

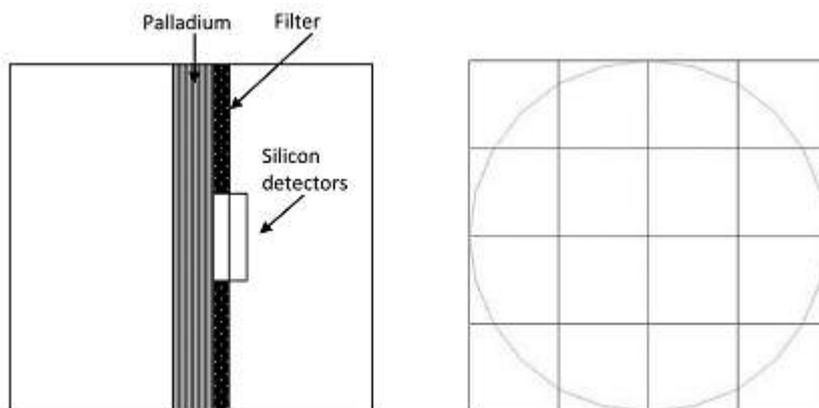


Figure 18. One-sided experimental scheme. Several silicon semiconductor detectors are located on one side of the palladium crystal and included in the coincidences. The left-hand side shows the detector; the right-hand side shows the mutual arrangement of the holes in the filter and the detectors.

6. Discussion

The scientific community's adaptation of new knowledge has never been easy. The current paradigm in nuclear physics does not support such effects as cold fusion even though this phenomenon does not contradict the fundamental laws of nature. This is complicated by the fact that attempts to find a solution to controlled thermonuclear fusion, which have taken place for more than half a century, have gone too far.

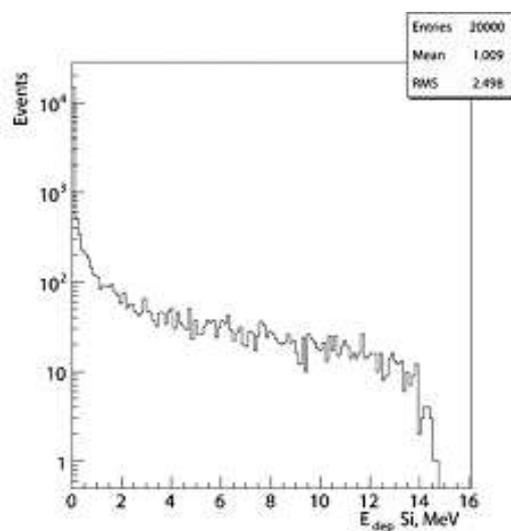


Figure 19. The total energy of the emitted electrons with energies up to 60 keV in the detectors located on one side of palladium. The thickness of the palladium foil was set at 20 μm .

The most advanced attempt in this direction is the international project ITER – Tokamak. Currently, the project, which is in the construction stage, is enormous and extremely expensive. Realists estimate that construction of the reactor and the possible start-up will be completed no earlier than 35–50 years from now. This project is considered as pure research, and if it can work, it will only do so in a cyclic mode. After its launch, the construction of an even more gargantuan structure – Industrial Tokamak DEMO – is planned. Huge financial and material costs will continue for another half-century.

The global fuel and oil–gas industries welcome these projects. Such a development could lead to climate change, the reduction of the global population, and other social cataclysms.

Cold fusion is a viable alternative to this tragic scenario. We believe that, in the coming years, there will be public recognition of cold fusion and that this research will cause radical changes in the practical applications of nuclear research.

Acknowledgements

One of the authors (E.T.) thanks Dr. A.G. Parkhomov for discussion.

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