There are more things in heaven and earth, Horatio,
Than are dreamt of in your philosophy.

– Shakespeare

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COLD NUCLEAR FUSION

Joint Institute For Nuclear Research
Bogoliubov Laboratory of Theoretical Physics
Joliot-Curie 6, 141980 Dubna, Moscow region, Russia. July
1983—on the JINR participation in DELPHI experiment
Cold nuclear fusion. Look beyond the horizon ...

Flammarion, 1888, based on the 16th century vision
“The pressure for conformity is enormous. I have experienced it in editors’ rejection of submitted papers, based on venomous criticism of anonymous referees. The replacement of impartial reviewing by censorship will be the death of science”.

Statement made while resigning from the

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“Physics is the experimental science.”

Richard Feynman
Binding energy

![Graph showing binding energy per nucleon versus number of nucleons in nucleus.](Image)
Currently, humanity has come to a stage of development when the struggle for energy resources is becoming especially important. All known sources of energy together will not be able to provide for our demand in the near future. Chemical energy is additionally limited by the so-called greenhouse effect.

Nuclear energy that based on the use of fissile materials is not the long-term solution to the problem, because stocks of these materials are limited. In addition, the required safe preservation of this radioactive waste for about 10,000 years is a serious problem.
Initial optimistic expectations of a transition to the controlled thermonuclear fusion process never materialized. Technical difficulties of obtaining viable super-hot plasma and the damaging effects of the enormous neutron flux arising as a result of thermonuclear reactions are pushing this development to the more distant and uncertain future.
The term “cold fusion” describes a number of processes at relatively low temperature, leading to the generation of heat due to the fusion of two nuclei. Under normal conditions, such processes are prevented by the Coulomb barrier, which precludes the convergence of nuclei. However, about 25 years ago, experiments were performed by Fleischmann and Pons that demonstrated the possibility of “cold” fusion, when nuclear reagents are implanted in metallic crystals.
Quickly rejected by most scholars as irreproducible and not having a consistent theoretical interpretation, these experiments, however, gradually began to give reproducible results. Classic examples are the experiments made by Dr. McKubre and his colleagues at the Stanford Research Institute, International. The results of these experiments demonstrated a reliable heat of nonchemical origin, whereby the effect exceeded about 100 experimental errors.
Dr. McKubre in his laboratory.
Excess heat in W, depending on the value of the electrochemical current, in the experiments of Dr. McKubre.
The success of the experiment depends on the concentration of deuterium.


“Achieve High Maximum D/Pd Ratio (Loading)”

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The fcc crystal structure. Small circles marked octahedral (the deepest) niches.
History of cold fusion “in vitro”

1. Martin Fleischmann 1989–2012

About 20–30 working groups in the US, Western Europe, Russia, Japan, and China.

During the last year, the first four patents were issued for cold fusion (US, Europe, China)
History of cold fusion—the main participants

Martin Fleischmann (1927–2012)
D + D in palladium
1989

Michael McKubre
D + D in palladium
1992–present

Yoshiaki Arata
D + D a palladium (ZrO2)
1998–2008

Proof of concept of cold fusion suddenly came from experiments performed with accelerators.
Consideration of piezo-fusion

The pressure needed to achieve the effect of piezo-fusion happens to be unusually high.

\[ B = \exp \left\{ -\frac{2}{\hbar} \int_{x_1}^{x_2} \sqrt{2M(U(x) - E)} \, dx \right\} = \exp \left\{ -\frac{2}{\hbar} \sqrt{2M\bar{U}} (x_2 - x_1) \right\} \]
In the quantum-mechanical consideration of the fusion process, electron screening potential $U_e$ is equivalent to the additional energy of particles involved (Assenbaum, Langanke, & Rolfs, 1987). “The penetration through a shielded Coulomb barrier at projectile energy $E$ is equivalent to that of bare nuclei at energy $E_{eff} = E + U_e$.”

The figure, taken from an Assenbaum paper, schematically depicts a collision of an incident deuterium nucleus with a deuterium atom. For the collision of two free deuterium atoms, this additional energy is equal to 27 eV.
The accelerator experiments have shown that the magnitude of the screening potential of the impurity atoms in metallic crystals can reach $300 \text{ eV}$ and even more. This means that in the DD reaction occurring in the medium of the metal crystal, the implanted deuterium atoms are excited and are no longer spherical. They have more sophisticated electronic orbitals, and they are oriented relative to each other in a certain crystallographic manner. In this case, the nuclei of these atoms can approach each other at a distance substantially less than for a nominal size of the atom without Coulomb repulsion.

Such processes are known in chemistry and are the cause of chemical catalysis. Johannes Rydberg first described these processes in 1888.
Screening potential defines the distance to which the atoms are not experiencing Coulomb repulsion.
The main secret of cold fusion process—overcoming the Coulomb barrier—finally happened to be surprisingly simple. It was first noted by Professor Bressani in 1998 at ICCF-7 conference on the basis of a series of Japanese accelerator experiments performed since 1995. Unfortunately, the cold fusion community at that time did not follow the call of Professor Bressani.
When a solid state target is irradiated by a beam of charged particles, the incident particle captures an electron from the solid body and moves further like an atom, if its velocity does not exceed the so-called Bohr velocity. For deuterons this threshold energy is \(~50\) keV. This interesting observation was made in the work of Baranov, Y. A., Martynenko, Y. V., Tsepelevich, S. O., Yavlinsky, Y. N. (1988). “Inelastic sputtering of solids by ions”. Physics-Uspekhi, 156(3), p. 477.
Target deuterium atoms implanted into metals are no longer in s-state. The free electron cloud in a metal causes the electron of an implanted atom to occupy the excited p-state. The magnitude of the screening potential of 300 eV and above in experiments on DD-fusion accelerators indicates that the incident deuterium atoms in the conductor crystal are also moving in p-state.

These processes allow the two deuterium nuclei to get close without the Coulomb repulsion in the potential niche of the crystal cell at a very close distance.
One of the first DD experiments on accelerators.


ICCF-6, 13–18 October, Japan.
Yuki, H., Satoh, T., Ohtsuki, T., Yorita, T., Aoki, Y., Yamazaki, H., Kasagi, J. (1996). ICCF-6, 13–18 October, Japan. This is one of the early works on electron screening in metals.

Ratio of the yield of the reaction D(d, p)T in the thick target to the estimated yield value in ytterbium (Yb). The dashed line shows the value of electron screening potential of 60 eV.
"Anomalously enhanced d(d,p)t reaction in Pd and PdO observed at very low bombarding energies"

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The dotted and dashed curves are those with the screening potential $U_e = 250$ and 600 eV, respectively.


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Jirohta Kasagi, Hideyuki Yuki, Taiji Baba, Takashi Noda, Tsutomu Ohtsuki and Andrey G. Lipson

“Strongly Enhanced DD Fusion Reaction in Metals Observed for keV D+ Bombardment”

Czerski, K. et al., (2008). Physical Review C., 78, 015803, (Berlin). Normalized astrophysical factor $S(E)$ for DD-fusion, when the target is implanted in zirconium. Screening potential is about 10 times greater than for the free atoms of deuterium.
ZrD$_2$, $T=20$ °C

$U_0=205\pm37$ eV

$S$, keV.b

$\bar{E}$, keV

Thus, the convergence distance of two deuterium nuclei of impurity caught in the same crystalline niche of metal is an order of magnitude smaller than the size of the free atom of deuterium.

Although complete interpretation of this phenomenon is still lacking, many accelerator experiments leave no doubt to its existence. Coulomb barrier permeability in such conditions during the cold DD-fusion is very strongly (55–60 orders) increased as compared to the permeability of the barrier in the case of the free molecule of deuterium.
Orbitals of the hydrogen atom
Rydberg mechanism for the hydrogen atom. Electron orbital in 2p-state is no longer circular.
$2p$ orbital of the hydrogen atom by Dr. Winter
$7p$ orbital of the hydrogen atom by Dr. Winter
Structure of octahedral niche in platinum crystal.
Octahedral platinum crystal niche filled with a deuterium atom in \(2p\)-state
The case when two atoms of deuterium in $2p$-state are located in the same octahedral niche of conducting crystal.
Crystal cells of conductor. The simple, cubic structure is used as a didactic example. The shaded area shows the location of free electrons. Free electrons of conducting crystal are unwilling to vacate their positions completely, and the deuterium atom is transferred from $1s$-state to $2p$-state or higher.
1s, 2s and 2p orbitals of hydrogen atoms
$1s$ and $2s$ orbitals of hydrogen atom
Schrödinger equation for hydrogen atom
Accelerator experiments

D-beam

D-target

Host metallic crystal
Cross section of synthesis in the collision of two deuterium nuclei:

$$\sigma(E) = S(E) \frac{E-1}{E} \exp(-2\eta(E))$$

$$2\eta = \frac{31.41}{\sqrt{E}}$$

Here, the kinetic energy of the deuteron $E$ is shown in the center of mass in keV. $S(E)$ — astrophysical factor at low energies; it can be assumed to be constant. The main energy dependence of the cold fusion cross-section is contained in the expression $\exp(-2\eta(E))$, which determines the probability of penetration of the deuteron through the Coulomb barrier in a single collision. In the event of a collision of atoms, the energy $E$ must be replaced by $E_{eff} = E + U_e$, where $U_e = e^2/R_a$. As we have noted, for the unexcited hydrogen atom, $U_e = 27$ eV.

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Coulomb barrier permeability for DD fusion:

\[ P = e^{-2 \pi \eta} \left( 2 \pi \eta = \frac{31.41}{\sqrt{E_{\text{eff}}}}, E_{\text{eff}} = E + U_e \right) \]

For cold fusion, \( E \cong 0.040 \text{ eV} \)
So, the first secret of cold fusion, which necessarily results in the fusion of deuterium nuclei at saturation deuterium in conducting crystal, can today be considered practically solved.

The second surprise of the cold fusion process: In these reactions, there are practically no standard nuclear decay products of 4He*. 

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A possible cause of slowing of nuclear decays with decreasing excitation energy: residual Coulomb barrier between the deuterium nuclei in the potential well of the strong interactions. “Statistical principle of correlation weakening with distance” (N. N. Bogolubov, Selected works on statistical physics, M., 1979) may be working for neutrons.
One can assume that the potential inside of the Coulomb barrier common well after the strong interactions of the fusion reaction is no longer a retaining factor for neutrons, and neutrons can almost freely move from one proton to another. In this case, the metastable $DD$-system goes into a metastable $PT$-system.
According to our *hypothesis*, the rate of nuclear decay of a compound nucleus $4\text{He}^*$ is a function of the excitation energy of the nucleus $E_k$. We assume that when the $E_k \sim 0$ (thermal energy), the compound nucleus $4\text{He}^*$ is metastable with a lifetime of about $10^{-15}$ s. After a time of $\sim 10^{-16}$ seconds, the compound nucleus is no longer an isolated system, since virtual photons from the $4\text{He}^*$ can reach the nearest electrons in a crystal, and carry away the excitation energy of the compound nucleus $4\text{He}^*$. It must be emphasized that the above hypothesis is merely an attempt to explain the well-established experimental fact of the virtual absence of nuclear decay channels of the intermediate compound nucleus $4\text{He}^*$ in the process of cold fusion.
Cold Nuclear Fusion*

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Abstract—Recent accelerator experiments on fusion of various elements have clearly demonstrated that the effective cross-sections of these reactions depend on what material the target particle is placed in. In these experiments, there was a significant increase in the probability of interaction when target nuclei are imbedded in a conducting crystal or are a part of it. These experiments open a new perspective on the problem of so-called cold nuclear fusion.
Rate of DD-fusion in the crystal cell


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In our recent articles, we discuss the possibility of experimental detection of the “cold” DD-fusion using low-energy electrons, which are the result of the fusion reaction of two deuterons in palladium crystals at very low (thermal) excitation energies of the compound nucleus $^4\text{He}^*$. This process is made possible by the exchange of the intermediate nucleus with electrons of the crystal lattice by the virtual photons.

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СОДЕРЖАНИЕ

ФИЗИКА АТОМНОГО ЯДРА
И ЭЛЕМЕНТАРНЫХ ЧАСТИЦ

Цыганов Э.Н., Бавижев М.Д., Головатюк В.М.,
Дабагов С.Б., Лобастов С.И.
Механизм выделения энергии в реакции D+D→^4He*
в проводящих кристаллах (моделирование эксперимента) .......... 3
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DD FUSION IN CONDUCTING CRYSTALS

The paper presents a brief background on cold fusion leading to a discussion on some aspects of atomic physics. We are explaining the selection of the only permitted orbitals of deuterium atoms in conducting crystals when saturated with deuterium. Conduction electrons in metallic crystal are grouped in potential niches of the crystal lattice, resulting in a ban for s-states of hydrogen to occupy these same niches. At the same time, the filling of these niches with deuterium atoms is allowed for the excited atomic states of level 2p and above. As has been shown in experiments on deuterium-deuterium (DD) fusion with low-energy accelerators, if an atom of deuterium target is located within a conducting crystal, this reaction is much more probable than in the case of free atoms of deuterium. When a single crystal niche gets two such atoms of deuterium, the distance between the nuclei of these atoms becomes equal to 1/10...1/20 of the nominal size of these atoms. Theoretical calculations show that this is equivalent to the additional energy 300...700 eV for the fusion reaction $^2$He$^+ \rightarrow ^4$He*. We believe that this process of excitation of atomic states to the $2p$ level and above explains the first stage of the so-called cold fusion.
Atomic potentials of the cluster of 5×5×5 cells in the platinum crystal.
Diagonal XV plane of fcc crystals. Signs O marks octahedral vacancies; signs T, tetrahedral ones.
Potential contours in the diagonal XV plane for platinum.
Potential in the vicinity of the center of octahedral niche of platinum crystal cell along the V direction
Diagram of the process, providing “thermalization” of DD fusion with the formation of 4He* in conducting crystals. In order for this process to work, the existence of a metastable state of 4He* is necessary.
Virtual photons in the hydrogen atom (Richard Feynman)
The trajectories of electrons (Monte Carlo) generated in the process of DD cold fusion in palladium. Dimensions are in micrometers.
One-side scheme of the experiment. Several silicon detectors are placed on the same side of the palladium foil and included in coincidence. Left — side view, right — the relative positions of the aperture and detectors.
Energy emitted by 60 KeV electron in detectors placed on one side of the palladium foil. The spectrum extends up to 14 MeV, because some of the electrons are scattered in palladium at angles up to 180 degrees.


Claus Rolfs – Gran Sasso, 2002 – 2006


Tomsk Collaboration, 2012 - 2013

V. M. Bystritsky et al, National Scientific Research - Tomsk Polytechnical University, Russia, Nuclear Physics, 2013 (in press)

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Conclusion (1)

1. Existence of the phenomenon of cold fusion now is conclusively proven by the experiments, including experiments on low-energy accelerators.

2. The absence of nuclear products observed in cold fusion experiments can be explained by slowing down the decay speed of a compound nucleus $^4\text{He}^*$ via nuclear channels with decreasing energy of its excitation. Energy release is due to virtual photons.

3. Prejudice of many nuclear physicists toward the cold fusion phenomenon is associated with this unusual nuclear process. In the cold fusion process, the resulting intermediate compound nucleus $^4\text{He}^*$ is in a metastable state.
4. The accumulated empirical rules of nuclear physics are considered by the nuclear physics community as indisputable, while the range of application of these rules is limited.

5. Cold fusion provides many more practical opportunities than the expected traditional thermonuclear fusion. Some of the applications of cold fusion (ships, aircraft, and space travel) are simply unavailable for devices of cyclopean scale—tokomaks and other hypothetical facilities using thermonuclear fusion.
Холодный синтез сегодня

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История ядерного синтеза

1. Мартин Фейнман
2. Михаил Мак-Керр
3. Йоханнес Арата
4. Хейнольдс и Шварц (ИМТ)

1989 – 2012
1992 – сегодня
1998 – 2008
1992 – сегодня

См. примерно 30 групп работают в США, Европе, России, Японии, Китае. За последние несколько месяцев ведутся исследования по ядерному синтезу (США, Европа, Китай).
The way to a benign and limitless new energy source

Since the 1930s, thousands of scientists have been inspired by the sight of billions and billions of fusion furnaces—stars, like our own sun—that flare across the heavens, releasing vast amounts of light and energy. ITER is the latest experiment to tap fusion power and its name means “the way” in Latin. The hope is that fusion could solve our energy needs by generating electricity from water, with no carbon dioxide emissions during operation and with relatively little nuclear waste.
Thank you for your attention!