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# Cold nuclear fusion development

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ABSTRACT

Chemical energy sources (oil and gas) will run out in the next 30–50 years. In addition to the depletion of these sources, there is a so-called greenhouse effect, which imposes severe restrictions on the use of chemical fuel. Nuclear reactors use uranium and hope to use thorium reserves of fissile materials that will last for no more than 100–200 years. In addition to poor safety record of nuclear reactors, the problem of burying radioactive nuclear reactor waste for a period of thousands years has not have a reliable solution.

During the last 25–30 years, so called cold nuclear fusion processes in conductive crystals have been developed. This paper discusses the main features of such processes.



## 1. Introduction

Currently, humanity is facing a severe energy shortage and the effects of pollution. Nuclear power plants are based on fission reactions and are not safe enough, as seen in the accidents at Three-Mile Island (USA), Chernobyl (USSR), and Fukushima (Japan). Reliable preservation of nuclear power plants and disposal of their waste for thousands of years in our fast-changing world is simply unrealistic. In addition, the proven reserves of fissionable materials are drying up fast.

The history of controlled thermonuclear fusion (tokamaks and other devices) will soon celebrate 70 years, with the maximum support of governments of developed countries. However, due to inherent plasma instabilities, gigantic sizes of installations and their high cost controlled fusion is still only a distant dream.

## 2. Muon catalysis

The phenomenon of so-called $\mu$-catalysis was described in detail by Y.B. Zeldovich in 1954 [1]. In the ionized *DH* molecule prompt convergence occurs between the deuterium and hydrogen nuclei after replacing the only remaining electron by $\mu$-meson. This process is leading to *DH* fusion. The theory quite accurately describes the reaction of *d*-$\mu$-*p* synthesis. The first events of the process *HD*-fusion were observed in 1957 in the L. Alvarez hydrogen chamber [2].

The muon catalysis was reviewed in detail by A.A. Vorobiev, S.S. Gerstein, and L.I. Ponomarev on March 23, 2004 [3]. Fig. 1 presents the scheme of the energy levels of the rotational-vibrational states of the meso-molecule $dd\mu$. Here $m_\pi = 139.6$ *MeV*, $\pi \rightarrow \mu + \nu_\mu$, $\tau_\mu = 2.2 \times 10^{-6}$ c, $m_\mu = 105.7$ *MeV*, $m_e = 0.511$ *MeV*, $m_\mu/m_e \approx 207$. The phenomenon of muon catalysis was regarded for a while as a process applicable for use as an energy source, but the short lifetime of $\mu$-meson does not allow this.

## 3. The experiments with deuterium implanted in conducting crystals

A new method of nuclear fusion, the so-called cold nuclear fusion was discovered in 1989 by Martin Fleischmann and Stanley Pons [4]. The phenomenon of cold nuclear fusion in metal crystals today has been confirmed by numerous experiments [5]. There is a detailed description of the process of cold nuclear *DD*-fusion by us in [6]. The crystal structure of *fcc* – palladium, platinum is presented in Fig. 2.

In the explanation of cold fusion of deuterium in the crystals, it should be taken into account that all the Bohr atoms (***1s***) are not able to stay in the "deepest" niche in the center of conductive crystal cell, because it place is reserved for free conduction electrons. The energy threshold for this ban is about 10 *eV*. In the process of implanting the hydrogen atom in a metallic crystal, the hydrogen atoms are excited from the state ***1s*** to the states ***2p***, ***3p***, or above, by the value of 10–14 eV.

Normally, excited hydrogen atoms quickly return to their ground state. However, in a metal environment, hydrogen atoms are prohibited to be in ***1s***-state because of conduction electrons already assigned to the same area. However, the states ***2p*** and higher can easily survive with this inconvenience, due to their specific shape. The orbitals of the hydrogen atom ***1s*** and ***2p*** were presented in our publication [7]. Numerical solutions of the

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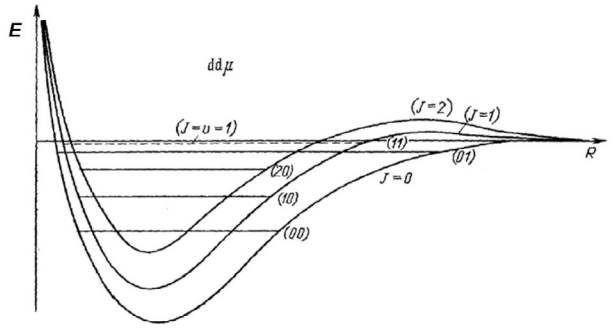


**Fig. 1.** The scheme of the energy levels of the rotational-vibrational states $(J,v)$ of the meso-molecule $dd\mu$.

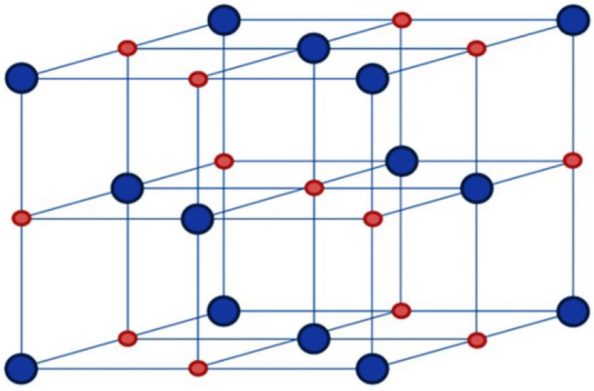

**Fig. 2.** (Color online) The crystal structure of *fcc* – palladium, platinum. Red circle denotes the deepest potential niches.

Schrödinger equation for the hydrogen according to the calculations of M. Winter [8] (the University of Sheffield, England) for ***2p*** and ***3p*** states are shown in Fig. 3 (***2p*** and ***3p***) of [6].

A schematic illustration of the influence of the free-electrons in conductive crystal for the shape of foreign hydrogen atoms is presented in Fig. 3. In Fig. 4, the energy levels of the hydrogen atom are shown (Rydberg states).

When all the deepest potential niches in the crystal are already filled by the hydrogen atoms in the states ***2p*** or higher, filling them further leads to the doubling of these clusters. In this ***2p***- or ***3p***-states, due to their non-sphericity, the niche is not occupied arbi-

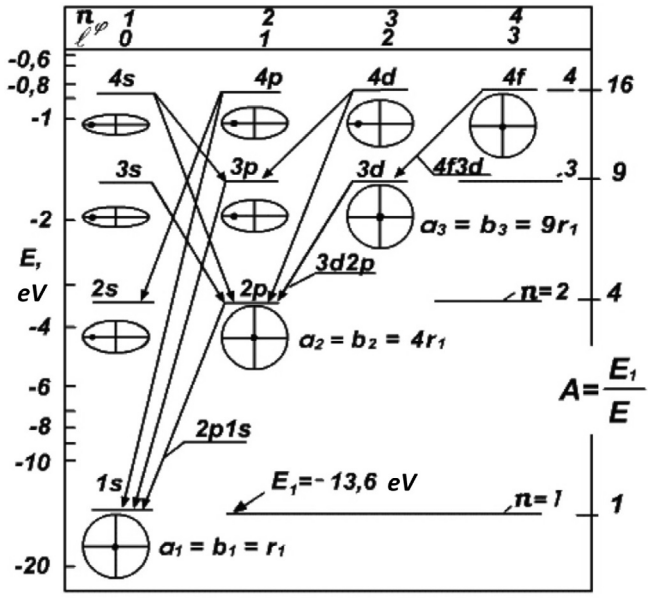


**Fig. 4.** The Rydberg energy levels of the hydrogen atom, 1885. Quantum numbers: $n$ – energy, l – the angular momentum.

trarily. It forms a certain "crisscross" spatial orientation in order to minimize the potential energy of the cluster in the crystal.

Fig. 5 shows ***2p*** states of the hydrogen atoms in the octahedral niche of platinum crystal in a horizontal plane *XY* in the "crisscross" orientation at $Z = 0$, and in the vertical axis by *Z*. The color scale represents the electric potential in crystal in volts. Fig. 6 shows the dependence of the probability of finding the electron in hydrogen atom *vs*. the radius. Here $a_o$ – Bohr radius = 52.9 pm. Fig. 7 presents *S(E)* – astrophysical factor for the reaction $D(d, p)^3H$ and $D(d, n)^3He$ from the work of S. Lemaitre et al. [9]. An astrophysical factor *S(E)* for the *DD* reactions in platinum from F. Raiola et al. [11] was discussed in our publication [10].

Transparency of the Coulomb barrier for *DD* fusion

$$P = e^{-2\pi\eta} (2\pi\eta = 31.41/E_{eff}^{1/2}, E_{eff} \text{ in keV})$$

Fig. 8 shows that the Coulomb barrier transparency increases by about 65 orders of magnitude with an increase in the so-called screening potential from 27 eV (deuterium molecule) to 300–700 eV for a cluster of two deuterium atoms in the platinum crystal in the ***2p*** state or above in the "crisscross" position (Table 1).

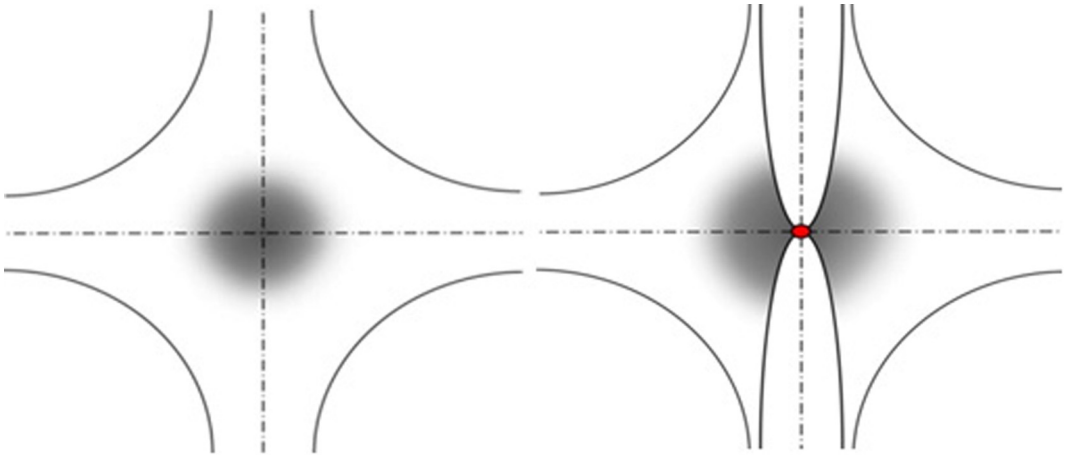

**Fig. 3.** (Color online) Schematic illustration of the influence of the free-electrons in conductive crystal for the implantation of foreign hydrogen atoms.

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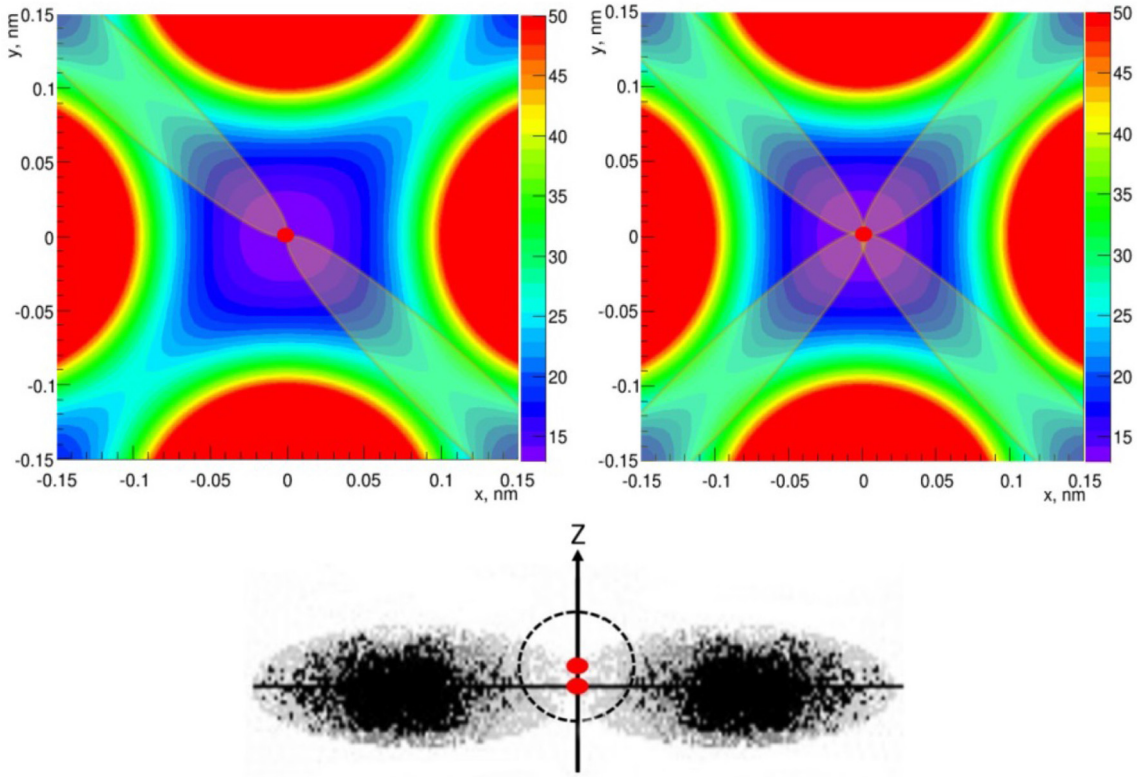


**Fig. 5.** (Color online) Hydrogen atoms in the state ***2p*** in octahedral niche of platinum crystal in the *XY* horizontal plane, on the left: a single atom; on the right: two atoms in the "crisscross" orientation at *Z* = 0. The lower figure shows two hydrogen atoms vertically, i.e. on the axis *Z*. The color scale the electric potential of the crystal in volts.

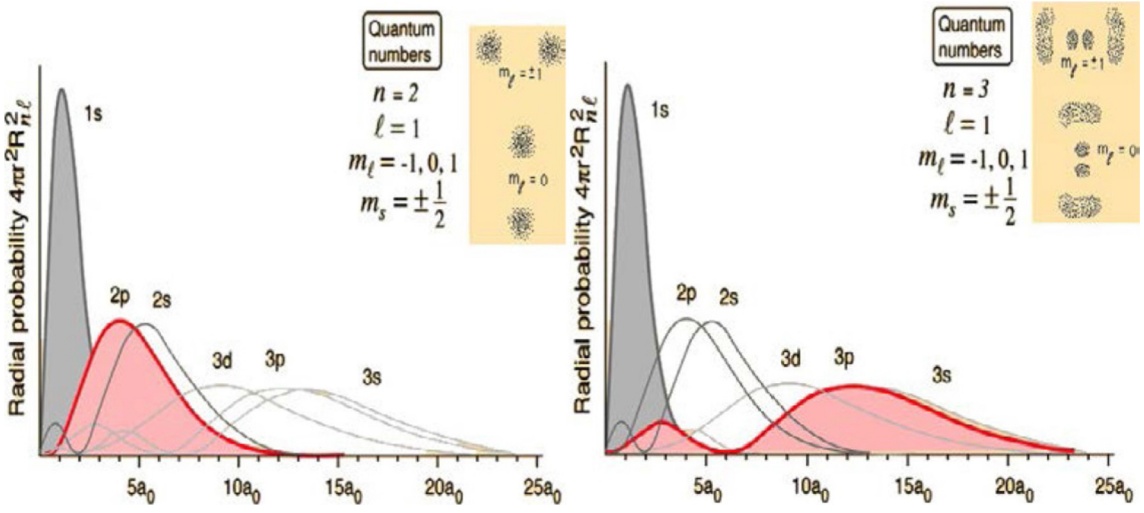


**Fig. 6.** (Color online) Dependence of the probability of finding the electron in hydrogen atom *vs.* the radius. Here $a_o$ – Bohr radius = 52.9 pm.

The table is taken from [12].

The observed expressive reducing of the decay rate of the intermediate nucleus through the direct channels of nuclear decay ($^4He^*$) in cold fusion experiments can be explained by the existence of a residual Coulomb barrier (about 100–200 eV) already in the potential well of the strong interactions, after the reaction $DD \rightarrow {}^4He^*$ with the thermal excitation. Thermal deuterons, penetrated into the potential well of the strong interactions at low excitation energies, still separated by the relic of the Coulomb repulsion, and are on the opposite sides of this potential barrier. In this case, the energy discharge of the $^4He^*$ system having a projection of the orbital angular momentum 1 = 0 occurs through the emission the *virtual photons*. You can think of virtual photons more literally as Richard Feynman liked to do, imaging that spin of such photon is *directed along the time axis*. After a release of the energy of the system due to this mechanism by the 3–4 MeV and approaching the levels of reaction $3He + n$ and $^3H + p$, the rate of these reactions decreases sharply because the *phase space* of these processes becomes very small.

Fig. 9 presents a schematic view of the potential well of the strong interactions in fusion process $DD \rightarrow {}^4He^*$. This figure demonstrates that even inside the nuclear potential well, the Cou-

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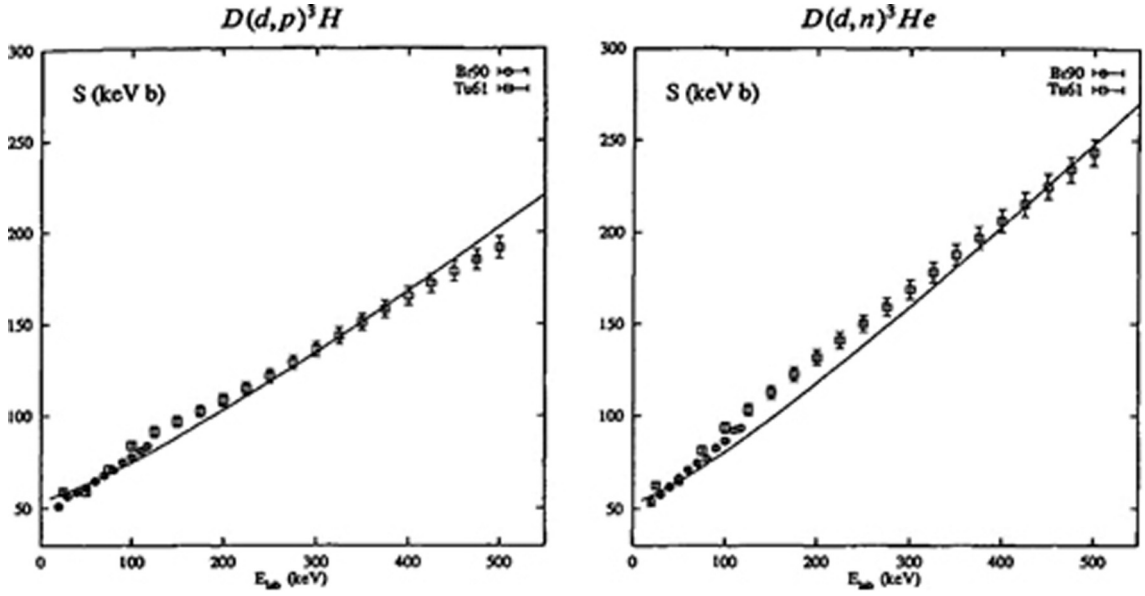


**Fig. 7.** *S(E)* – astrophysical factor for the reaction $D(d, p)^3$H and $D(d, n)^3He$ from the work of S. Lemaitre et al. [8].

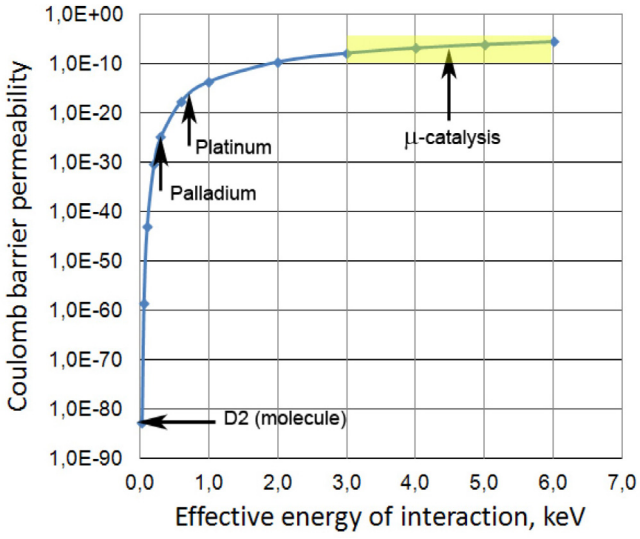


**Fig. 8.** (Color online) Transparency of the Coulomb barrier for *DD* reaction. Yellow mark indicates the region of *DDμ*-reactions.

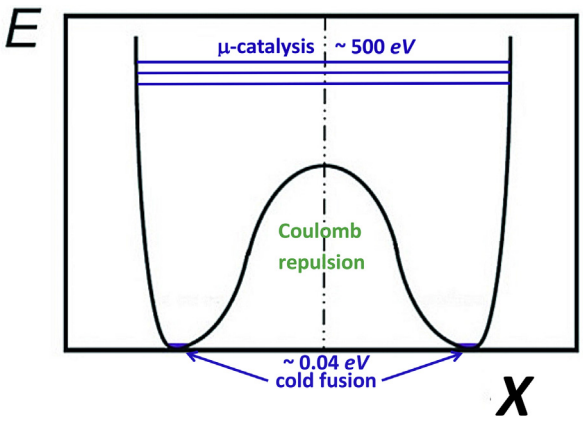


**Fig. 9.** (Color online) Schematic view of the potential well of the strong interactions after a cold fusion reaction $DD \rightarrow {}^4He^*$.

lomb repulsion between deuterons does not disappear completely. The explanation is given below why the nuclear decay proceeds rapidly for the muon catalysis and is practically forbidden in the case of cold fusion. The excitation thermal energy of the intermediate nucleus after the cold fusion process is approximately four orders of magnitude lower than in the case of muon catalysis. The Coulomb barrier between the deuterium nuclei that are already inside the strong interaction potential well significantly delays the mechanism of the compound nucleus decay via the nuclear channels $D + D \rightarrow {}^3H + p$ and $D + D \rightarrow 3He + n$. It has to be noted here, that the orbital momentum of the compound nucleus in the process of cold fusion is zero. Once reducing the excitation energy of the intermediate compound nucleus below 4 *MeV*, there are no other possible nuclear decay channels except the *virtual photon* mechanism, and the reaction $D + D \rightarrow 4He + 24$ MeV proceeds to the very end.

McKubre and others [5] repeatedly pointed out the presence of tritium accumulation in cold *DD* fusion process. It is necessary to develop further this issue, both experimentally and theoretically.

Fig. 10 represents the possible evolution of the size of intermediate metastable nucleus in the reaction $DD \rightarrow {}^4He^*$ in the process of the release of the bounding energy.

To conclude this section, it should be noted that the researchers of cold *DD* fusion, even in 1994, were very close to finding the key to this process [13]. Fig. 11 is a diagram of Stanislaw Shpak and his colleagues' experiment, and in Fig. 12 one of their impressive

**Table 1**
Rate of *DD* fusion in the crystal cell.

| Crystal type | Screening potential, eV | Frequency $\nu$, $s^{-1}$ | Barrier permeability $e^{-2\pi\eta}$ | Rate of DD reaction $\lambda$, $s^{-1}$ |
|---|---|---|---|---|
| Palladium | 300 | $0.74 \times 10^{17}$ | $1.29 \times 10^{-25}$ | $0.95 \times 10^{-8}$ |
| Platinum | 675 | $1.67 \times 10^{17}$ | $2.52 \times 10^{-17}$ | 4.21 |

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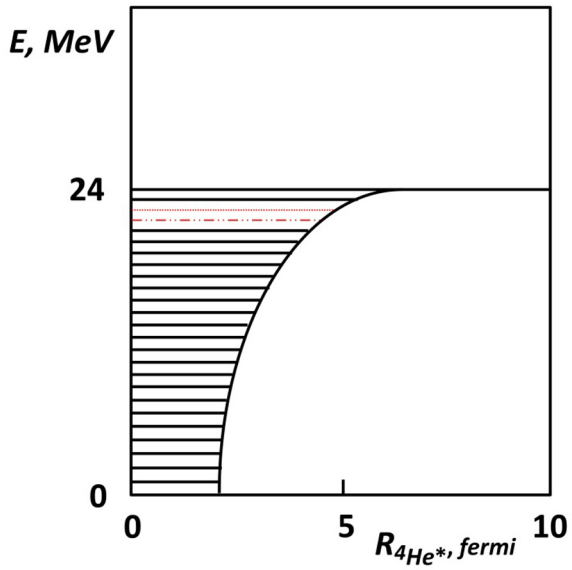


**Fig. 10.** (Color online) Evolution of the size of intermediate metastable nucleus in the reaction $DD \rightarrow {}^{4}He^{*}$ in the process of the release of the bounding energy. The dotted line marks a prohibited level of $D + D \rightarrow {}^{3}He + n$.

results is presented. Experiments with continuous deposition of deuterium in forming palladium crystal have observed the well localized bright light flashes.

### 3.1. Experiments of Andrea Rossi and Giuseppe Levi

Italian engineer Andrea Rossi in 2015 received a patent on cold fusion process (US9,115,913 B1) entitled "Fluid Heater" [14].

An interesting novelty in this patent is the use of $^{7}Li$ reaction with hydrogen element $^{1}H_{1}$:

$$^{7}Li + {}^{1}H_{1} \rightarrow {}^{8}Be \rightarrow 2{}^{4}He + 17.3\ MeV$$

These studies were carried out in parallel at the University of Bologna (Italy), led by Dr. Giuseppe Levi [15]. The results after about three months' work of this group are shown in Table 2.

When interpreting the results of these experiments, Rossi and his colleagues ignore the creation of positrons in the reaction H + Ni and mistakenly argue for the lack of ionizing radiation in the reaction. This was pointed out a few years earlier in our paper (E. N. Tsyganov, S.B. Dabagov, and M.D. Bavizhev) [16].

### 3.2. A.G. Parkhomov's experiments

At the 2015 International Conference on Cold Fusion, ICCF-19, the research of A.G. Parkhomov and E.O. Belousova from the Moscow State University titled "Investigation of heat generators,

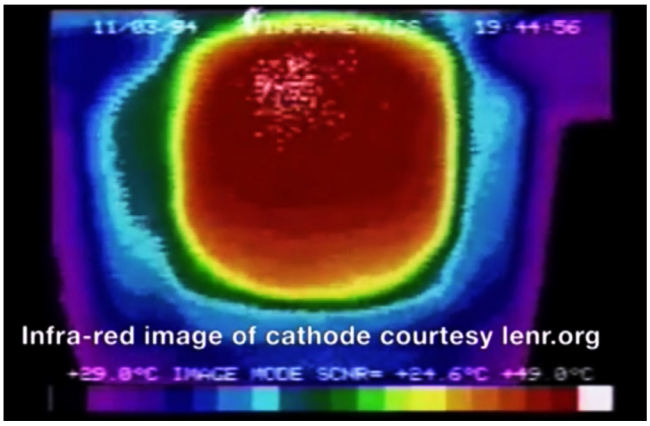


**Fig. 12.** (Color online) The images captured by the infrared camera in experiment of Stanislaw Shpak and others, 1994.

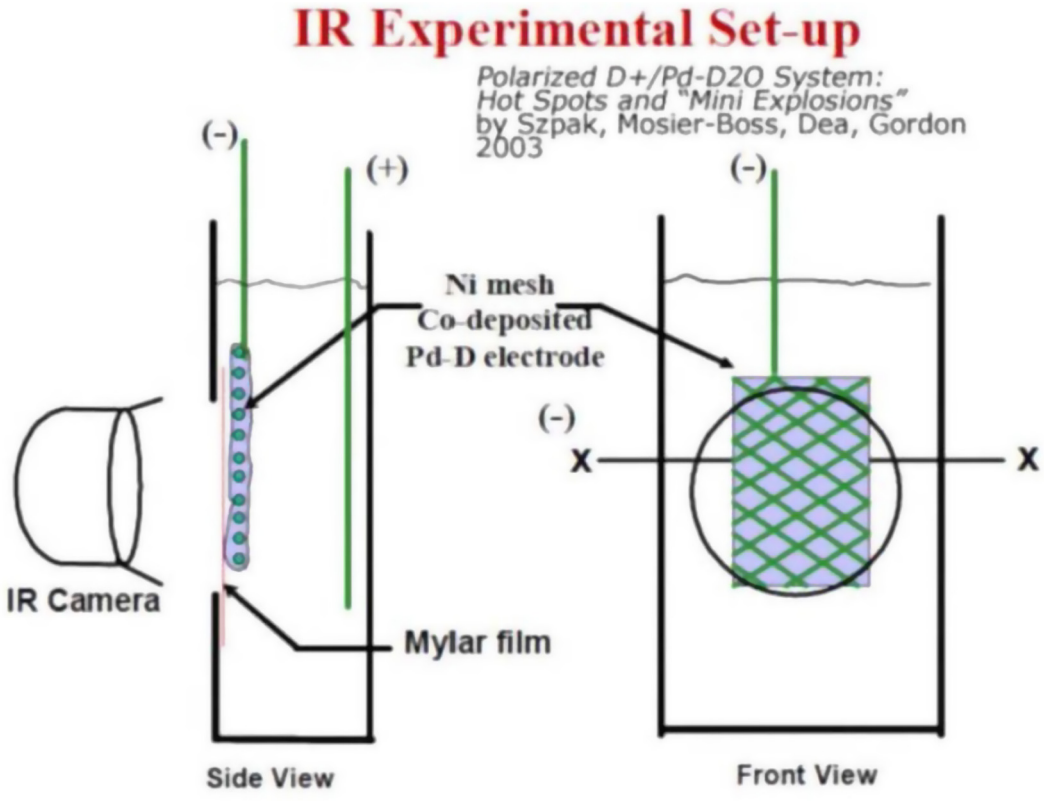


**Fig. 11.** (Color online) Stanislaw Shpak's experiment, 1994.

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**Table 2**
Results of D. Levy et al. [15].

| Ion | Fuel | | Ash | | |
|---|---|---|---|---|---|
| | Counts in peak | Measured abundance [%] | Counts in peak | Measured abundance [%] | Natural abundance [%] |
| $^{6}Li^{+}$ | 15,804 | 8.6 | 569,302 | 92.1 | 7.5 |
| $^{7}Li^{+}$ | 168,919 | 91.4 | 48,687 | 7.9 | 92.5 |
| $^{58}Ni^{+}$ | 93,392 | 67 | 1128 | 0.8 | 68.1 |
| $^{60}Ni^{+}$ | 36,690 | 26.3 | 635 | 0.5 | 26.2 |
| $^{61}Ni^{+}$ | 2606 | 1.9 | ~0 | 0 | 1.8 |
| $^{62}Ni^{+}$ | 5379 | 3.9 | 133,272 | 98.7 | 3.6 |
| $^{64}Ni^{+}$ | 1331 | 1 | ~0 | 0 | 0.9 |

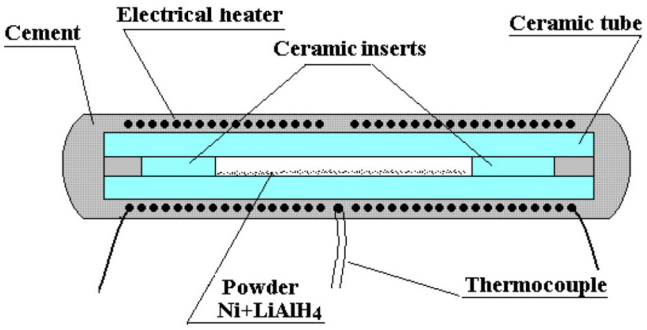


**Fig. 13.** (Color online) The scheme of A.G. Parkhomov's reactor.

similar to a high-temperature reactor Rossi" [17] was reported. Fig. 13 presents a scheme of A.G. Parkhomov's reactor.

During the four sessions of the device in 2015 at temperatures above 1100 °C and above, an additional heat was observed, exceeding the energy spent on heating it in **1.92**, **2.74**, **1.77**, **1.73** times. According to the measurements of A.G. Parkhomov, during these experiments, as also in the similar Rossi experiments, ionizing radiation exceeding the background level was not observed.

### 3.3. Song-ShengJiang works (China)

In 2015, work was reported of should Song-Shen Jung and others from the Institute of Atomic Energy of China, called "Anomalous heat production in hydrogen-laded metals: Possible nuclear reactions occurring at normal temperature" [18]. The authors of this paper make the statement that additional heat is generated in a fuel mixture consisting of nickel and LiAlH4 powders, which was then placed in a sealed stainless steel chamber. In the first session, excess heat lasted for seven days. In the second session, additional heat was continued for 120 min after the additional heating of the chamber was turned off. Fig. 14 presents the scheme of Song-Sheng Jiang and his colleagues' installation from the Institute of Atomic Energy of China. Fig. 15 shows the results of the first session of the Song-Sheng Jiang group.

### 3.4. Interpretation of the experiments of Brillouin Energy Corporation

On November 18, 2015, the Brillouin Energy Corporation, a developer of technologies based on thermal energy of low-energy nuclear reactions (LENR), announced that its research has been presented to U.S. Congress. According to Dr. M. McKubre, a gain in power by about factor of four was achieved at the impressive industrial operating temperature of about 640 °C.

In our consideration, the following mechanism may be assumed as a possible interpretation of the Brillouin group's results.

Earlier, it was observed that the electron capture (the weak interaction) for a light element, $^{4}Be_7 + e^{-} \rightarrow {}^{3}Li_7 + \nu_e$, runs for a lifetime of about 53 days. Experiments have shown that the electron

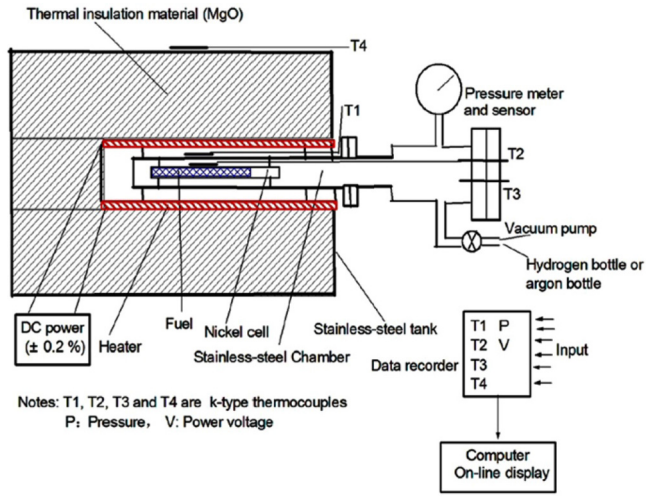


**Fig. 14.** (Color online) The scheme of Song-Sheng Jiang and his colleagues' installation from the Institute of Atomic Energy of China.

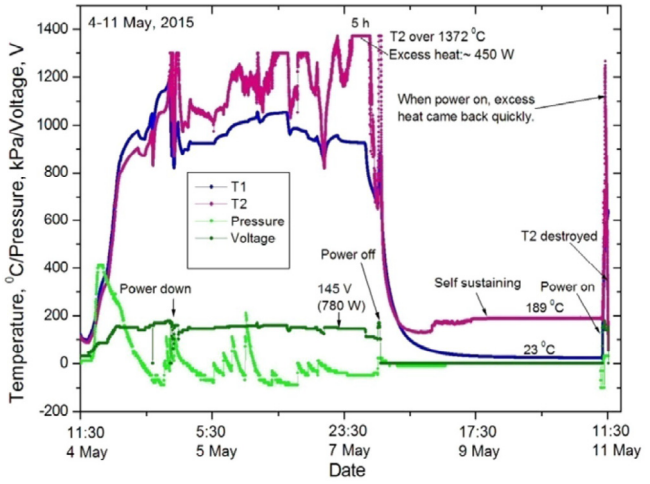


**Fig. 15.** (Color online) The results of the first session of the Song-Sheng Jiang group.

capture rate depends on the electron's proximity to the nucleus. The reaction rate of the weak interaction $^{4}Be_7 + e^{-} \rightarrow {}^{3}Li_7 + \nu_e$ in the case if this process occurs in a metal happens to be higher than in the case when this process occurs in the insulator, see the work of B. Wang et al. [19]. It *can be assumed* that a similar reaction, $^{1}H_1 + {}^{1}H_1 \rightarrow {}^{2}He_2^{*} \rightarrow {}^{2}He_2^{*} + e^{-} \rightarrow {}^{1}H_2 + \nu_e$, in the case of hydrogen implantation in metals in a "crisscross" configuration, without any apparent energy release, can run rapidly.

The released energy in this reaction is 0.93 MeV. Since the deuteron $^{1}H_2$ is quite a heavy particle, almost all this energy is taken

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by the neutrino. Upon further saturation of this conductive crystal cell with more $^{1}H_{1}$ hydrogen, as a result of the cold fusion process, $^{2}He_{3}$ is formed, then $^{2}He_{4}$, etc. As we can see, the first step in the synthesis of two ordinary hydrogen atoms $^{1}H_{1}$ in the electron capture reaction in the conductive crystals causes no recorded energy release.

Apparently, this fact was the basis for the statement of McKubre and other researchers [5] that the fusion reaction $^{1}H_{1} + {}^{1}H_{1}$ in their very first experiments does not go.

Further *HD* and *DD* cold fusion reactions in Brillouin case take place through the channels of the strong interaction, without the emission of neutrinos.

## 4. Discussion

The scientific community's adaptation to new knowledge is never easy. The current paradigm of physics does not support effects such as cold nuclear fusion. The situation is complicated by the fact that the ambitious and expensive attempts to find a solution to the problems of controlled thermonuclear fusion, which have lasted for more than half a century, have gone too far for a quiet termination.

The most famous attempt for thermonuclear fusion is an International Project ITER. Currently, the Project is huge and extremely expensive. Realists have estimated that construction of the ITER reactor and the possibility of its launch will be completed no earlier than 35–50 years. The ITER project is seen as a purely scientific investigation, and if it can work, then it would only be in a cyclic mode. After its launch, there are plans to build an even more enormous structure— an industrial tokamak DEMO. In this case, the huge financial and material costs will continue for another half century. Global fuel and the oil and gas industry welcome this development. This situation, however, can lead to climate change, a reduction of the population of the planet, and other painful social cataclysms.

Cold fusion is a real alternative to this tragic scenario. We are confident that the public recognition of the process of cold fusion will happen in the coming years. There are real scientific basis for it.

## 5. Conclusion

Power plants using the principles of cold nuclear fusion potentially have quite unique advantages over the still hypothetical thermonuclear fusion. Compact cold fusion devises will be successfully used on ships, in aircrafts, and in near and outer space travels. That, in principle, is inaccessible for the giant thermonuclear installations.

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## References

[1] Я.Б. Зельдович, Доклады Академии Наук СССР, том 95, стр. 493 (1954).
[2] Luis W. Alvarez et al., Phys. Rev. Series II 105 (1957) 1127–1128.
[3] А.А. Воробьев, С.С. Герштейн и Л.И. Пономарев, доклад на Президиуме РАН 23 марта 2004 года.
[4] M. Fleischmann, S. Pons, M.W. Anderson, L.J. Li, M. Hawkins, J. Electroanal. Chem. (1990) 287–293.
[5] M.C.H. McKubre, F.L. Tanzella, I. Dardik, A. El-Boher, T. Zilov, E. Greenspan, C. Sibilia and V. Violante, in: J. Marwan (Ed.), Low-Energy Nuclear Reactions Sourcebook, ACS Symposium Series 998, Oxford University Press, Oxford, 2008, p. 219.
[6] E.N. Tsyganov et al., J. Condensed Mater. Nucl. Sci. 17 (2015) 96–110.
[7] E. Tsyganov et al., Nucl. Instrum. Methods Phys. Res., Sect. B 355 (2015) 333–339.
[8] M. Winter, http://winter.group.shef.ac.uk/orbitron/AOs/2p/wave-fn.html.
[9] S. Lemaitre et al., Ann. Physik 2 (1993) 503.
[10] E. Tsyganov et al., Nucl. Instrum. Methods Phys. Res., Sect. B 309 (2013) 95–104.
[11] F. Raiola, for the LUNA Collaboration, B. Burchard, Z. Fulop, et al., Eur. Phys. J. A27 (2006) 79.
[12] E.N. Tsyganov, Physics of Atomic Nuclei, 2012, Vol. 75, No. 2, pp. 153–159, Э.Н. Цыганов, Ядерная Физика, 2012, том 75, No 2, с. 174–180.
[13] S. Szpak, et al. SPAWAR Systems Center-Pacific Pd: D Co-Deposition Research: Overview of Refereed LENR Publications in ICCF-14 International Conference on Condensed Matter Nuclear Science. 2008. Washington, DC.
[14] Andrea Rossi, United States Patent US 9,115,913 B1 "Fluid Heater", Aug. 25, 2015, http://ecat.com/ecat-science/the-rossi-effect.
[15] Giuseppe Levi et al., "Observation of abundant heat production", Preprint 2014, University of Bologna Digital Library, in press.
[16] E.N. Tsyganov, S.B. Dabagov, M.D. Bavizhev, "XI International Scientific Conference: Solid State Chemistry", Nanomaterials, Stavropol, Russia on 22-27 April 2012, p. 51-57.
[17] A.G. Parhomov and E.O. Belousova "Researches of the Heat Generators Similar to High-Temperature Rossi Reactor", ICCF-19, 2015.
[18] Song-Sheng Jiang et al., "Anomalous heat production in hydrogen-loaded metals: possible nuclear reactions occurring at normal temperature", China Institute of Atomic Energy, PO 275 (49), Beijing 102413, 2015.
[19] B. Wang et al., Change of the $^{4}Be_{7}$ electron captures half-life in metallic environments, Eur. Phys. J. A 28 (2006) 375–377.

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