Physics is the *experimental* science

Richard Feynman

E.N. Tsyganov

Cold Fusion Power International

Cold Nuclear Fusion Development

7th International Symposium on Energy,
13-17 August 2017 in Manchester, UK

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. Besides the 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 fusion processes in conductive crystals have been developed. This presentation discusses the main features of such processes.

Outline

1. Introduction
2. Muon catalysis
3. *Experiments with deuterium implanted in conducting crystals*
4. Experiments of Andrea Rossi and Giuseppe Levi
5. A.G. Parkhomov's experiments
6. Song-Sheng Jiang works (China)
7. *Interpretation of the experiments of Brillouin Energy Corporation*
8. Discussion and Conclusion

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 looks 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.

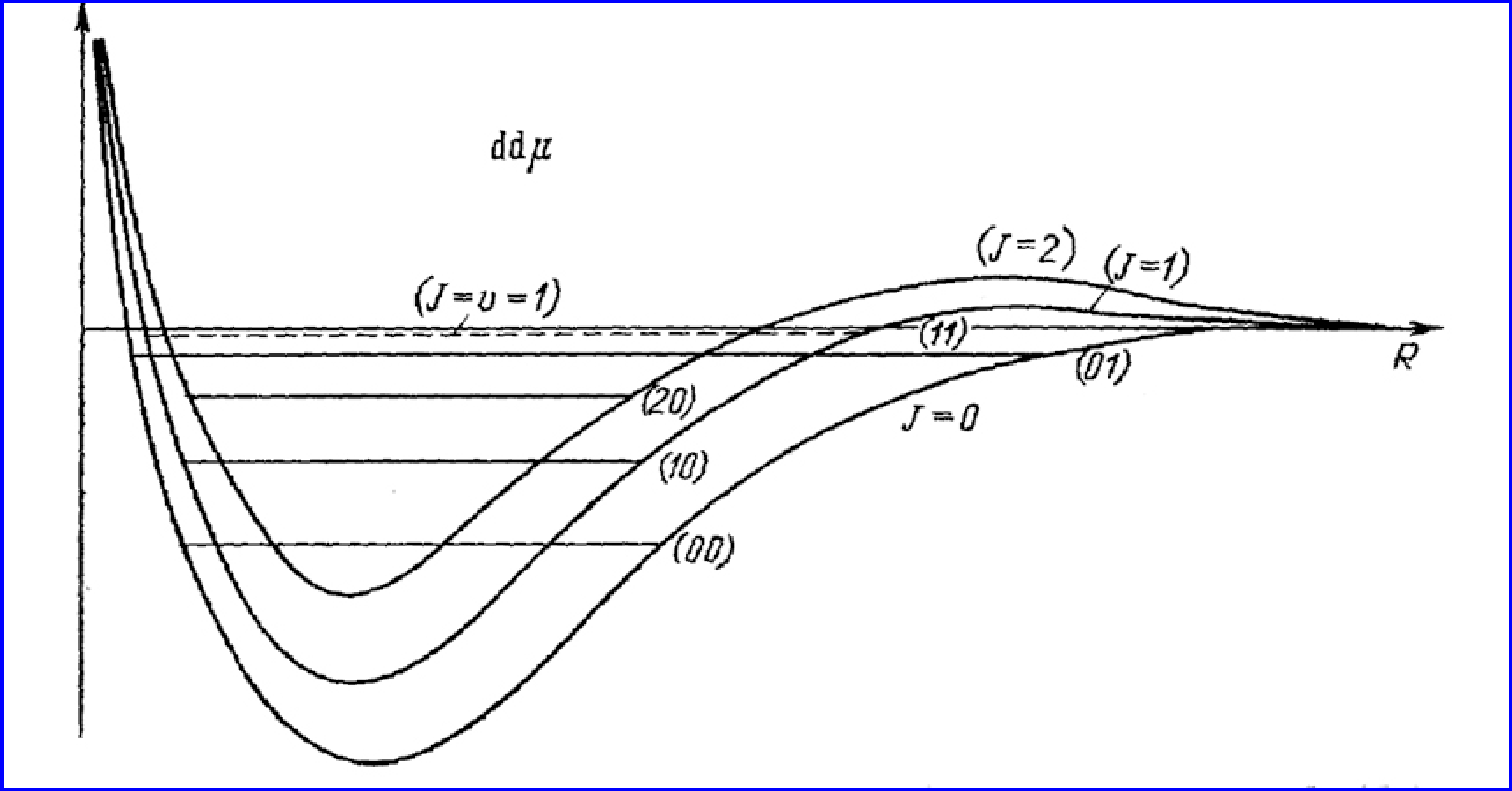
Chernobyl, April 26, 1986

2. Muon catalysis

The phenomenon of so-called μ-catalysis was described in detail by Ya.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 μ-meson. This process is leading to *DH* fusion. The theory quite accurately describes the reaction of d-μ-p synthesis. The first events of the process *HD*-fusion were observed in 1957 in 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]. Next Figure presents the scheme of the energy levels of the rotational-vibrational states of the meso-molecule $dd\mu$. Here $m_\pi = 139.6$ MeV, $\pi \longrightarrow \mu + \nu_\mu$, $\tau_\mu = 2.2 \times 10^{-6}$ s, $m_\mu = 105.7$ *MeV*, $m_e = 0.511$ *MeV*, $m_\mu/m_e \approx 207$.

The energy level scheme of rotational-vibrational states (J,υ) *in* meso-molecule *dd*μ

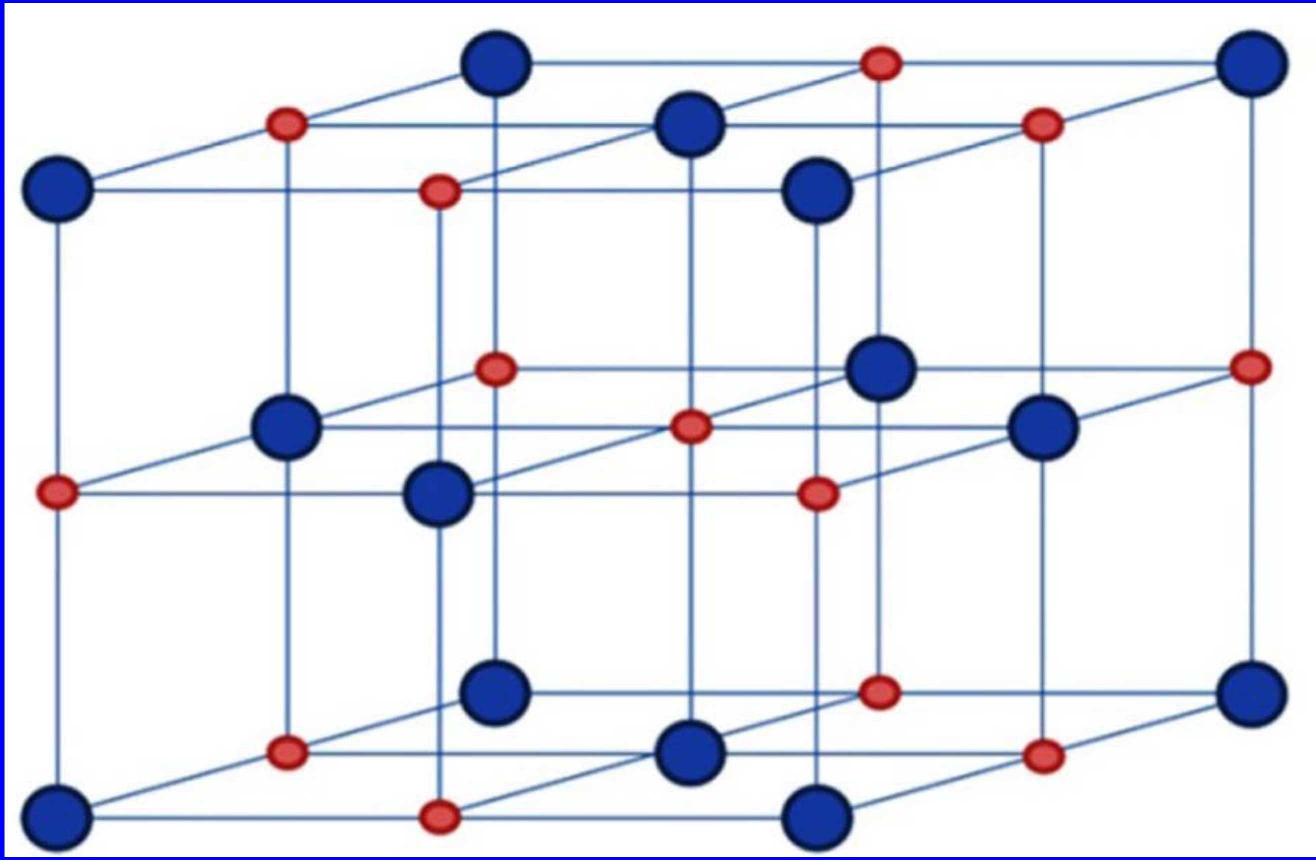


The phenomenon of muon catalysis was regarded for a while as a process applicable for use as an energy source, but the short lifetime of μ-meson does not allow this.

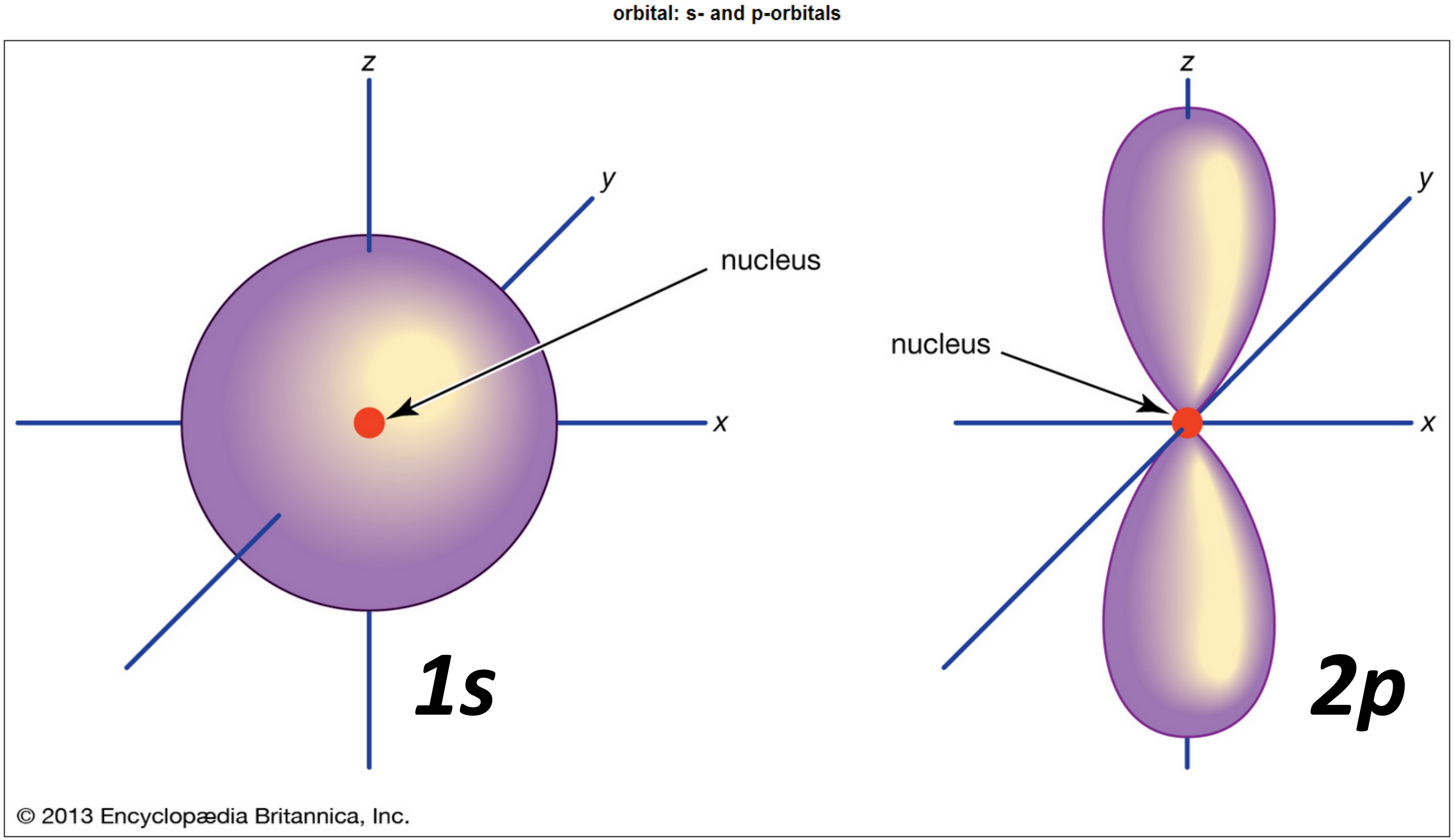
3. The experiments with deuterium implanted in conducting crystals

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 on the next Figure.

The crystal structure of *fcc* – palladium, platinum. Red circles denote the deepest potential niches.



Hydrogen atom orbitals ©2013 Encyclopædia Britannica, Inc.



Electron orbitals in atoms **(Left) *s* orbital; (right) *p* orbital**

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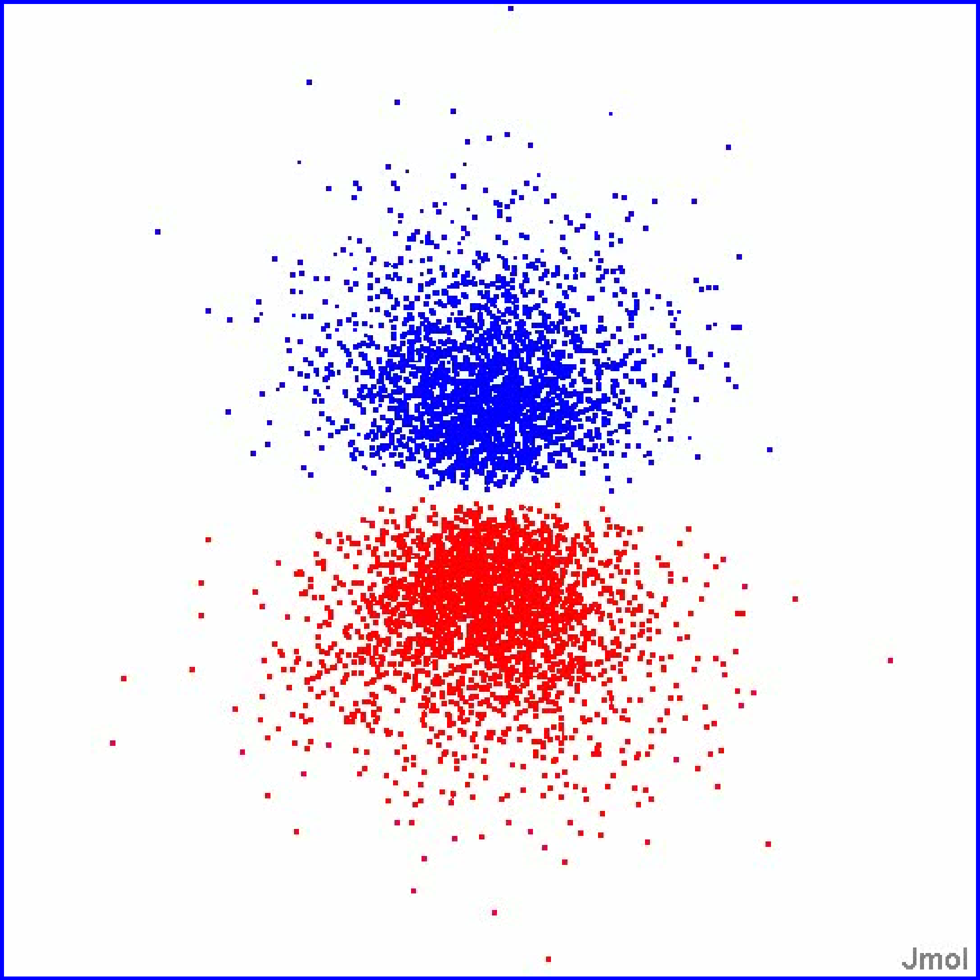
In the explanation of cold fusion of deuterium in the crystals, it should be taken into account that all the Bohr atoms (*1s*) are not able to stay in the "deepest" niche in the center of conductive crystal cell, because it place is reserved for the free conduction electrons. The energy threshold for 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 Schrödinger equation for the hydrogen according to the calculations of M. Winter [8] (the University of Sheffield, England) for *2p* state is shown below.

2p orbital of hydrogen atom

Dot-density plot of the *2p* electron density function ψ_{2p}^2. Blue represents negative values for the wave functions and red represents positive values.

http://winter.group.shef.ac.uk/orbitron/AOs/2p/wave-fn.html



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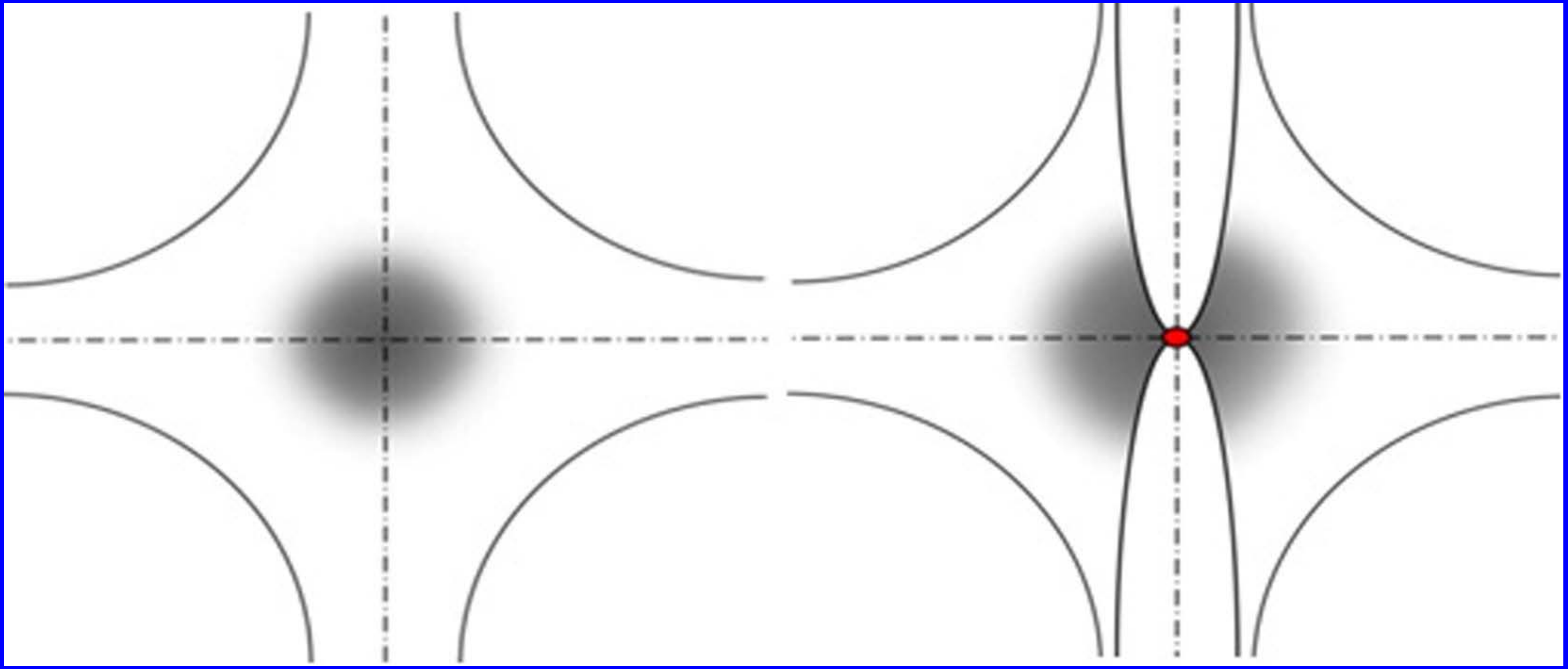
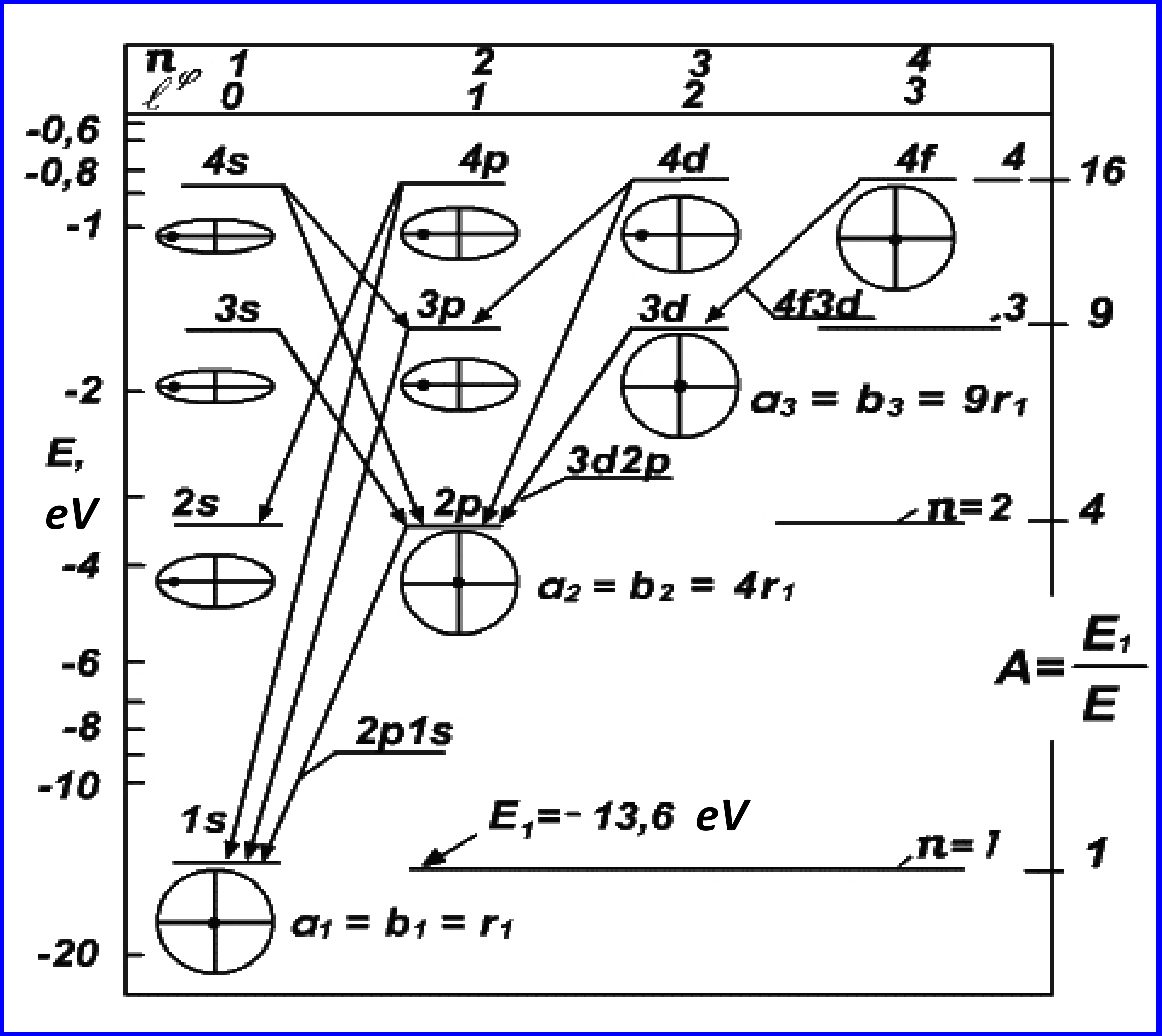
Schematic illustration of the influence of the free electrons in conductive crystal for the implantation of foreign hydrogen atoms.



Energy levels of hydrogen atom. Rydberg states, 1885.

Johannes Robert Rydberg
Sweden
1854 – 1919



Quantum numbers:

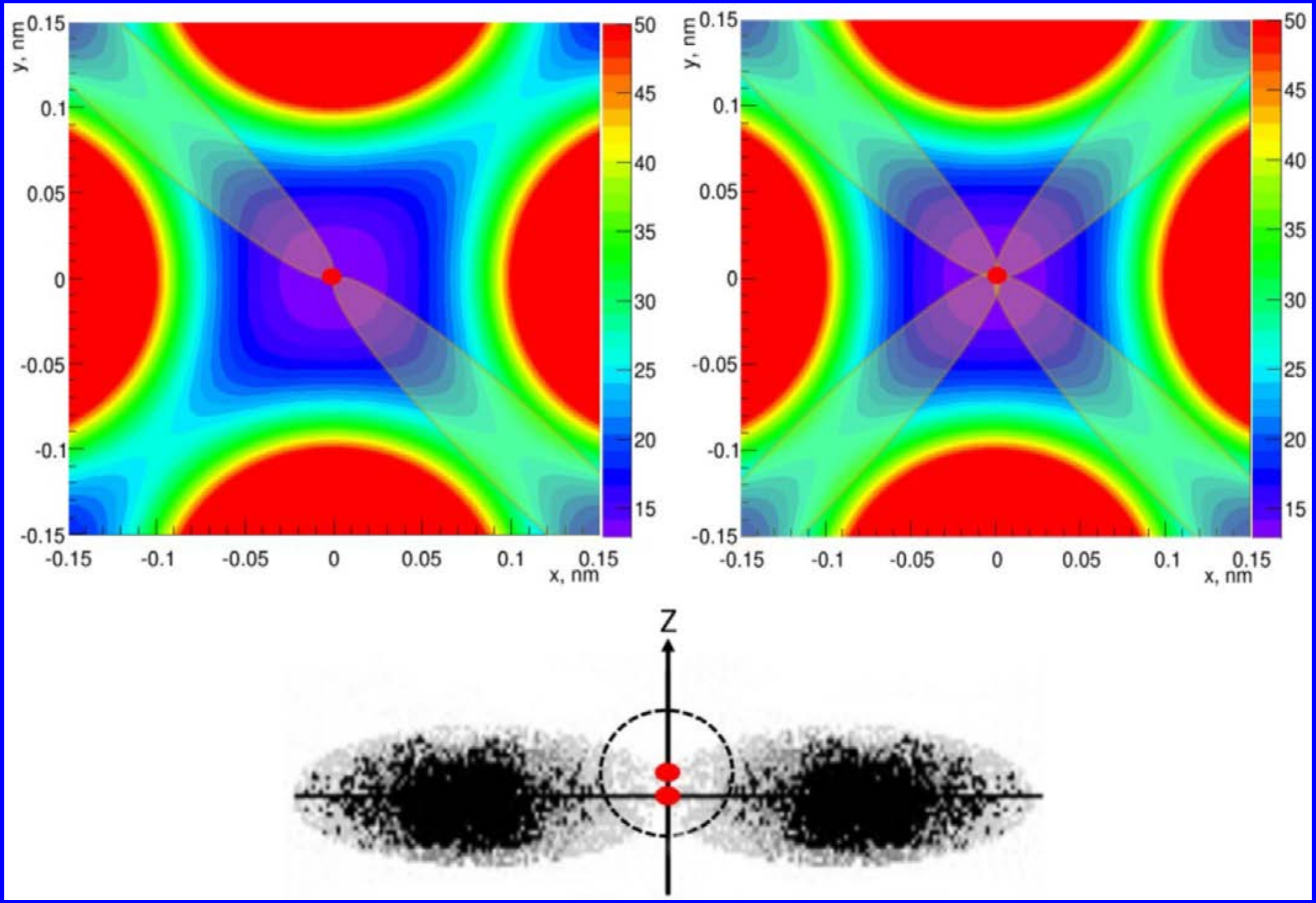
n – energy

ℓ – angular moment

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 arbitrarily, it forms a certain "crisscross" spatial orientation in order to minimize the potential energy of the cluster in the crystal.

Next Figure 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. Figure below shows the dependence of the probability of finding the electron in hydrogen atom *vs.* the radius. Here a_o – Bohr radius = 52.9 pm.

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.



Dependence of the probability of finding the electron in hydrogen atom *vs.* the radius. Here a_o – Bohr radius = 52.9 *pm*.

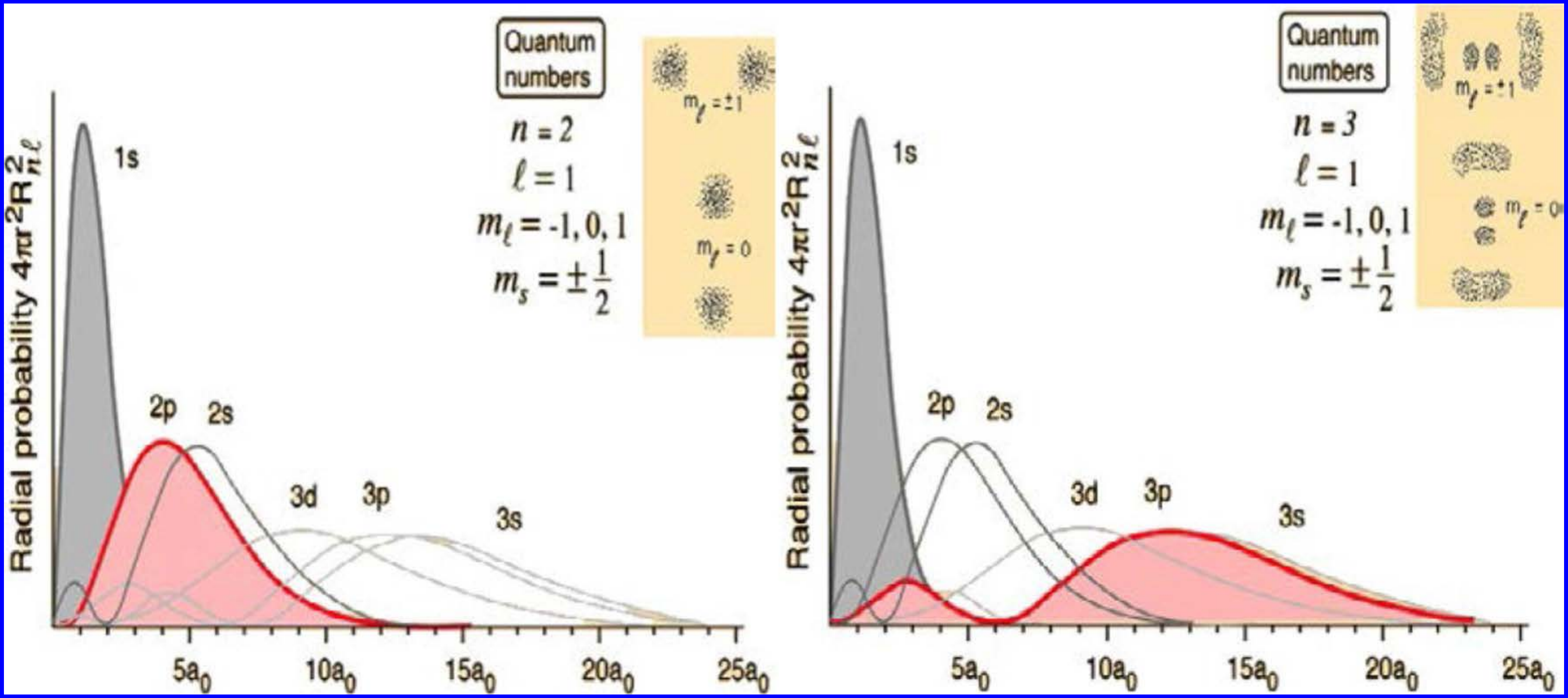
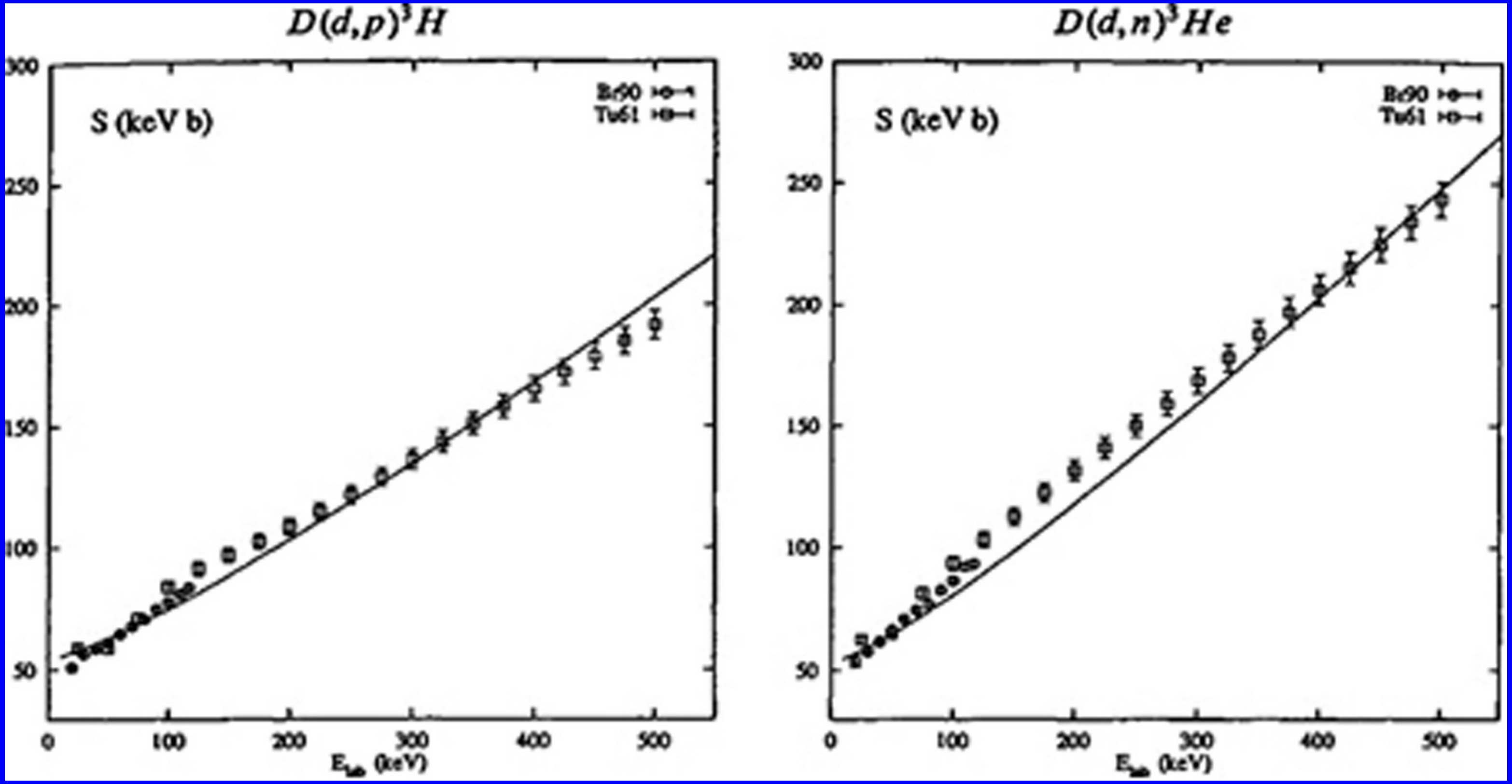


Figure below presents *S(E)* – astrophysical factor for the reaction $D(d,p)^3H$ and $D(d,n)^3He$ from the work of S. Lemaitre et al. [9]. An astrophysical factor *S(E)* for the *DD* reactions in platinum from F. Raiola et al. [10] was discussed in our publication [11].

***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].**

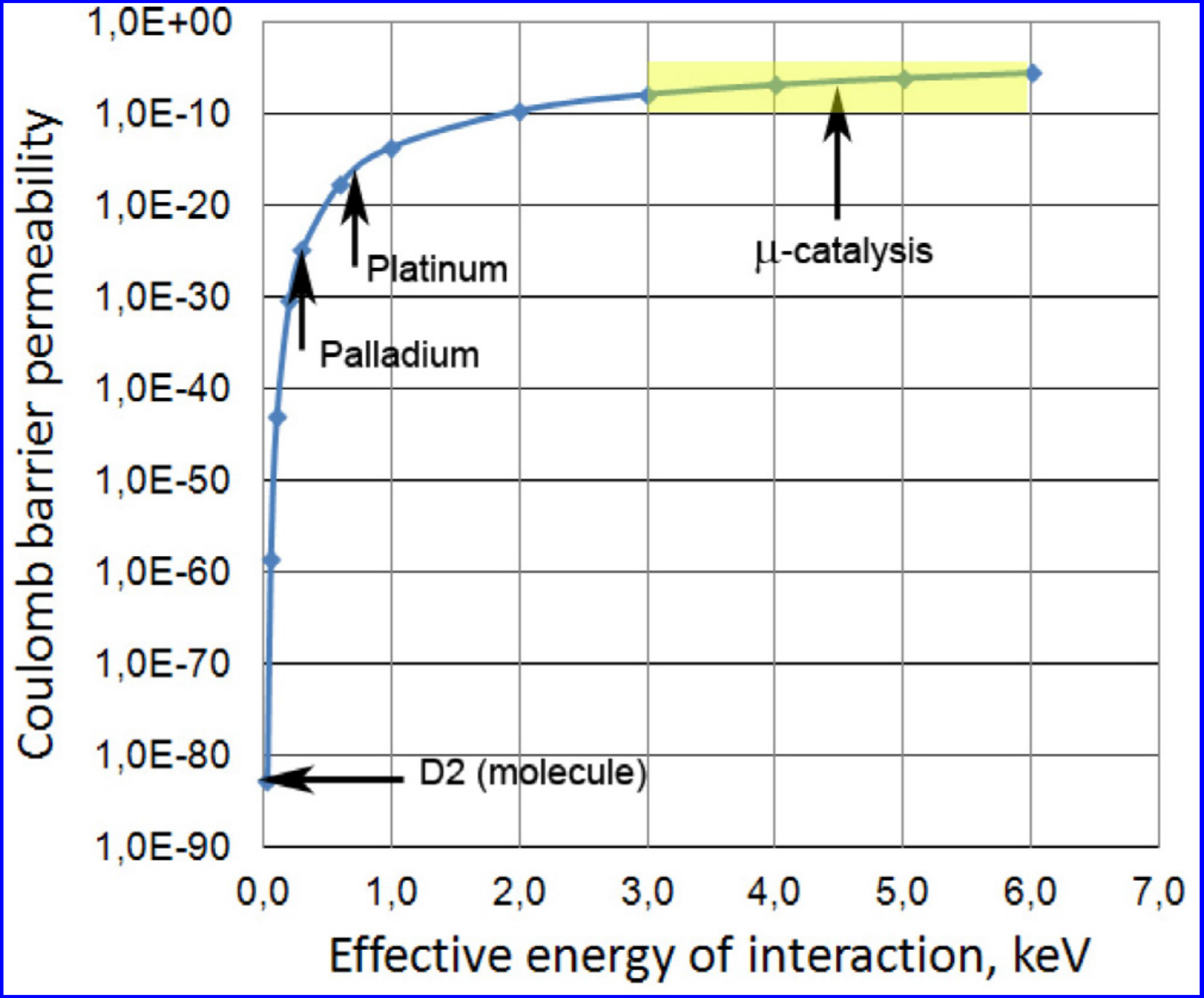


Next Figure shows how the Coulomb barrier transparency increases by about 65 orders of magnitude with an increase in the so-called screening potential from 27 *eV* (deuterium molecule) to 300–700 *eV* for a cluster of two deuterium atoms in the platinum crystal in the *2p* state or above in the “crisscross”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

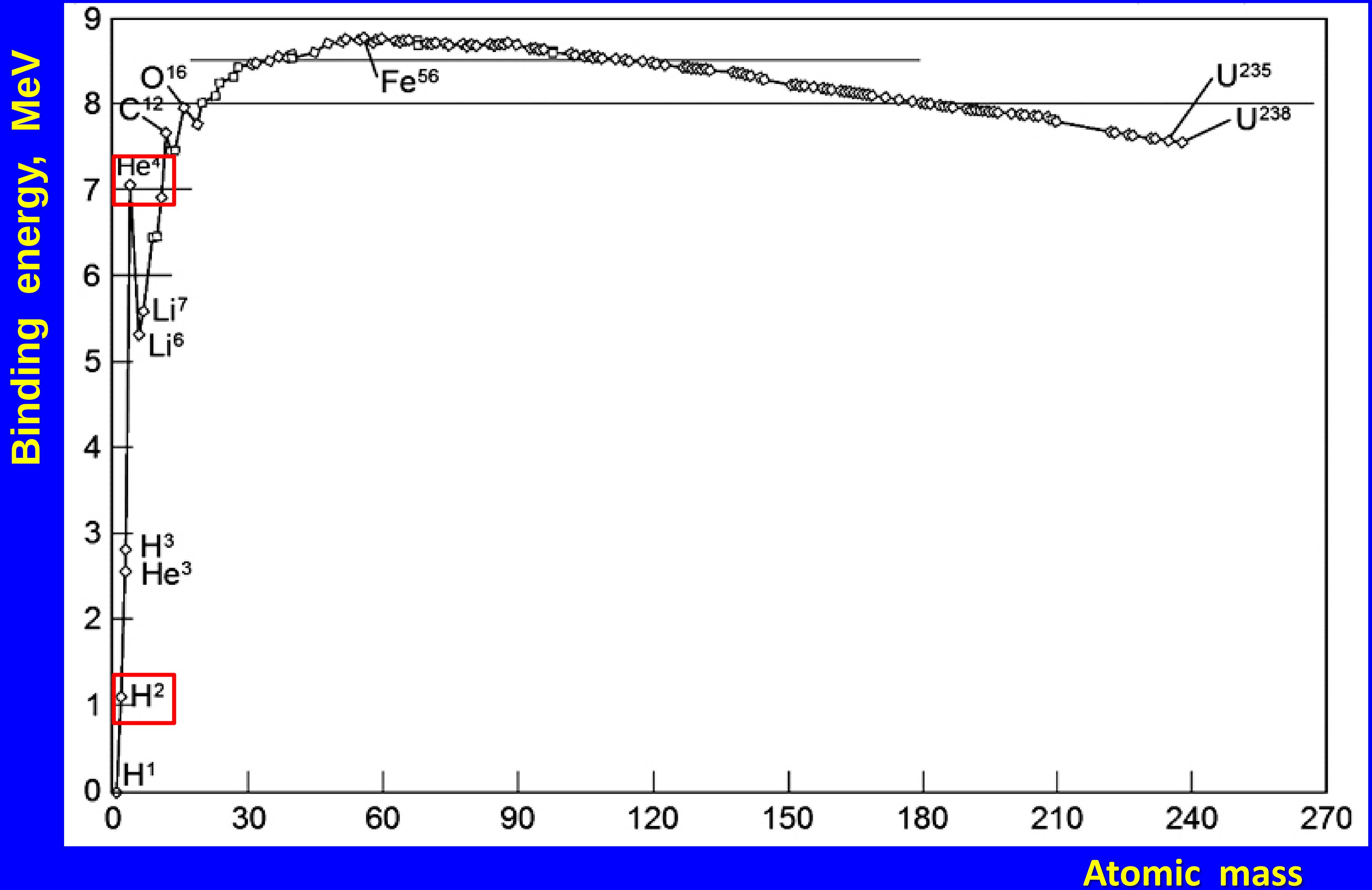
Transparency of Coulomb barrier for *DD* fusion:

$$P = e^{-2\pi\eta} \ (2\pi\eta = 31{,}41/E_{eff}^{\ 1/2},\ E_{eff} \text{ in keV})$$

Transparency of Coulomb barrier for *DD* fusion



Binding energy per nucleon



Rate of *DD*-fusion in a crystalline cell is presented in Table 1.

Crystal type	Screening potential, eV	Quantum vibration frequency ν, s^{-1}	Barrier permeability $e^{-2\pi\eta}$	Rate of *DD* fusion λ, s^{-1}
Palladium	300	$0{,}74\times10^{17}$	$1{,}29\times10^{-25}$	$0{,}95\times10^{-8}$
Platinum	675	$1{,}67\times10^{17}$	$2{,}52\times10^{-17}$	4,2

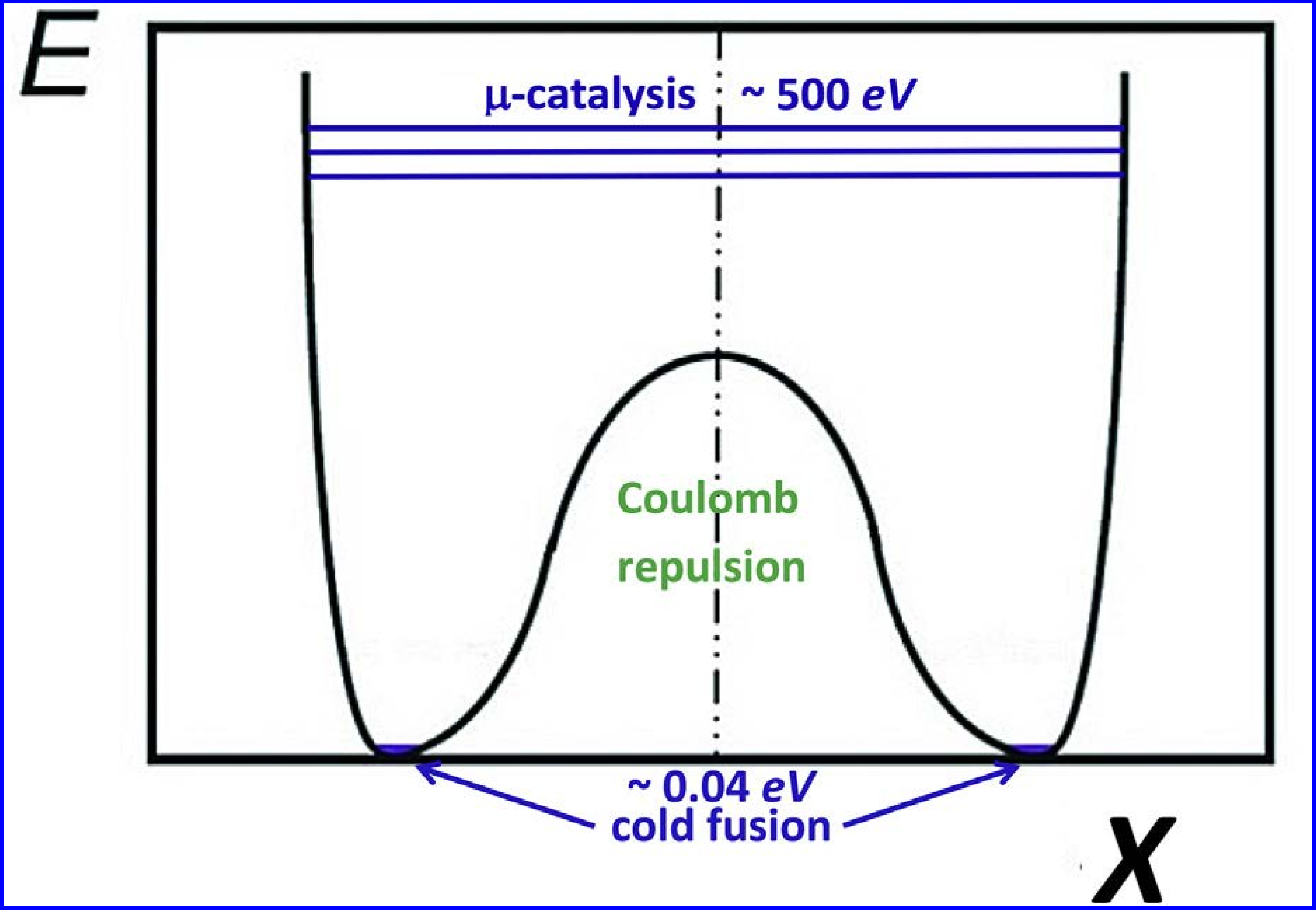
[12] E.N. Tsyganov, "Cold Nuclear Fusion", *Physics of Atomic Nuclei*, 2012, Vol. 75, No. 2, pp. 153–159

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 $\ell = 0$ 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.

Next Figure 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 Coulomb repulsion between deuterons does not disappear. 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.

Schematic view of the potential well of the strong interactions after a cold fusion reaction *DD* → $^4He^*$.

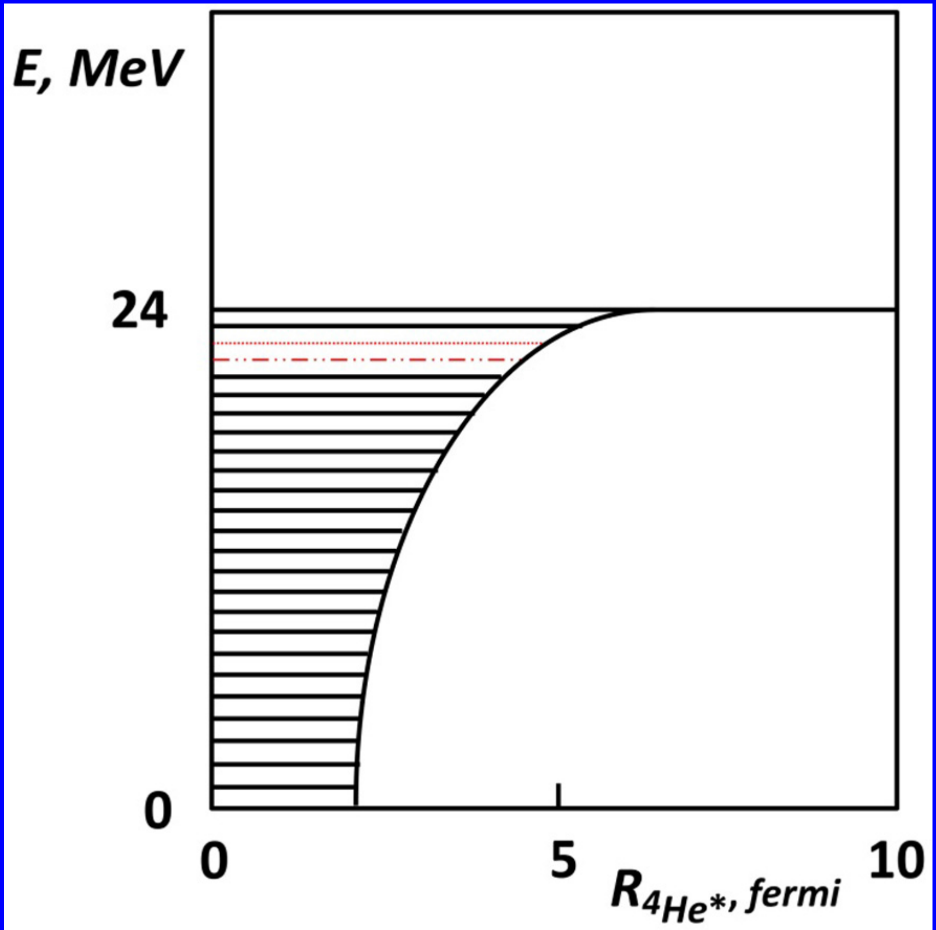


The Coulomb barrier between the deuterium nuclei that are already inside the strong interaction potential well significantly delays the mechanism of the compound nucleus decay *via* the nuclear channels $D + D \rightarrow {}^3H + p$ and $D + D \rightarrow {}^3He + n$. It has to be noted here, that the 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.

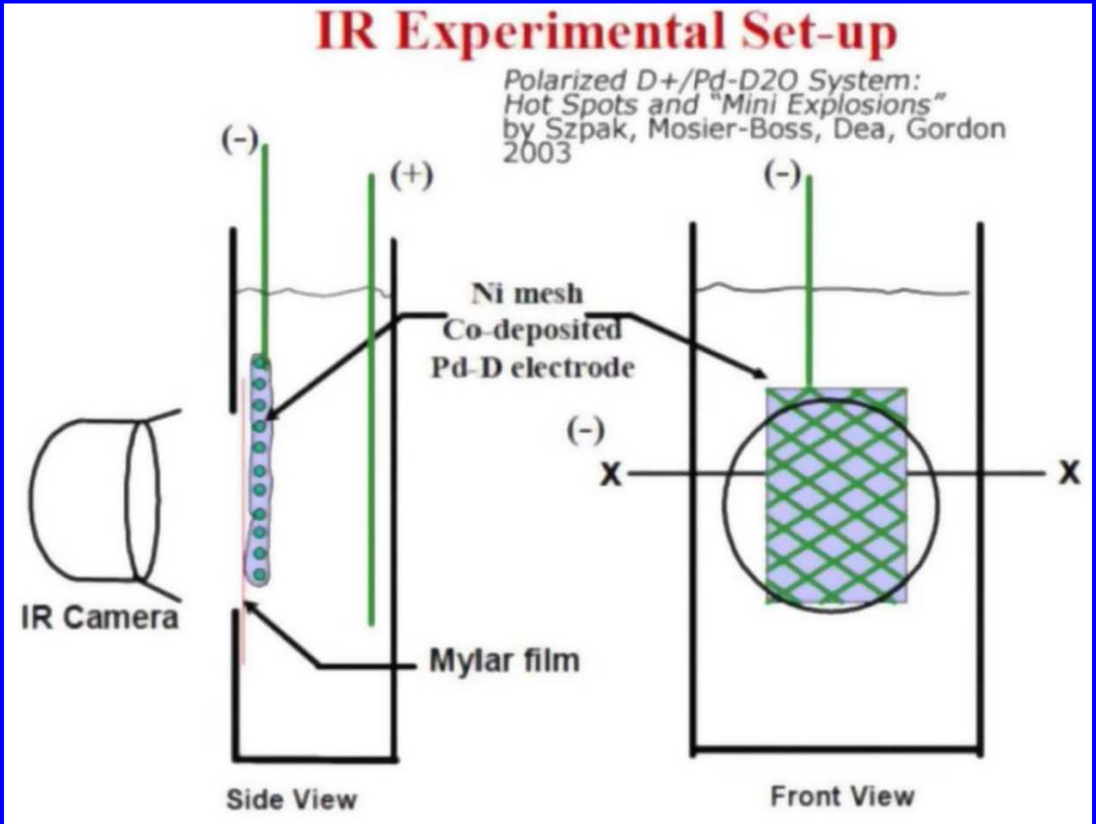
Next Figure represents the possible evolution of the size of intermediate metastable nucleus in the reaction *DD* → ^{4}*He in the process of the release of the bounding energy. Evolution of the size of intermediate metastable nucleus in the reaction *DD*→^{4}*He** in the process of the release of the bounding energy. The dotted line marks a prohibited level of *DD* →^{3}*He + n*.**

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.

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



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]. Figure below is a diagram of Stanislaw Szpak and his colleagues' experiment.



This slide presents one of an impressive result of Szpak' group. 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:

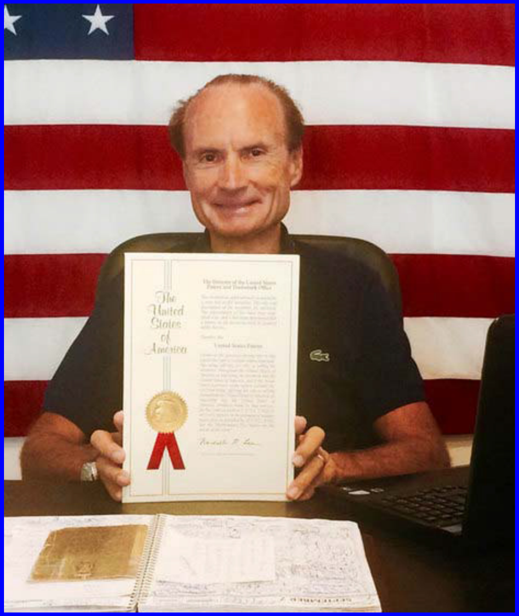
$$^{7}Li + {}^{1}H \rightarrow {}^{8}Be \rightarrow 2\ {}^{4}He + 17.3\ MeV$$

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].

Results of D. Levy et al. [15].

Ion	Fuel		Ash		Natural abundance [%]
	Counts in peak	Measured abundance [%]	Counts in peak	Measured abundance [%]	
$^{6}Li^{+}$	15804	8.6	569302	92.1	7.5
$^{7}Li^{+}$	168919	91.4	48687	7.9	92.5
$^{58}Ni^{+}$	93392	67	1128	0.8	68.1
$^{60}Ni^{+}$	36690	26.3	635	0.5	26.2
$^{61}Ni^{+}$	2606	1.9	~0	0	1.8
$^{62}Ni^{+}$	5379	3.9	133272	98.7	3.6
$^{64}Ni^{+}$	1331	1	~0	0	0.9

Andrea Rossi



Tom Darden

https://animpossibleinvention.com/2017/07/18/heres-the-settlement-getting-the-license-back-was-rossis-top-priority/

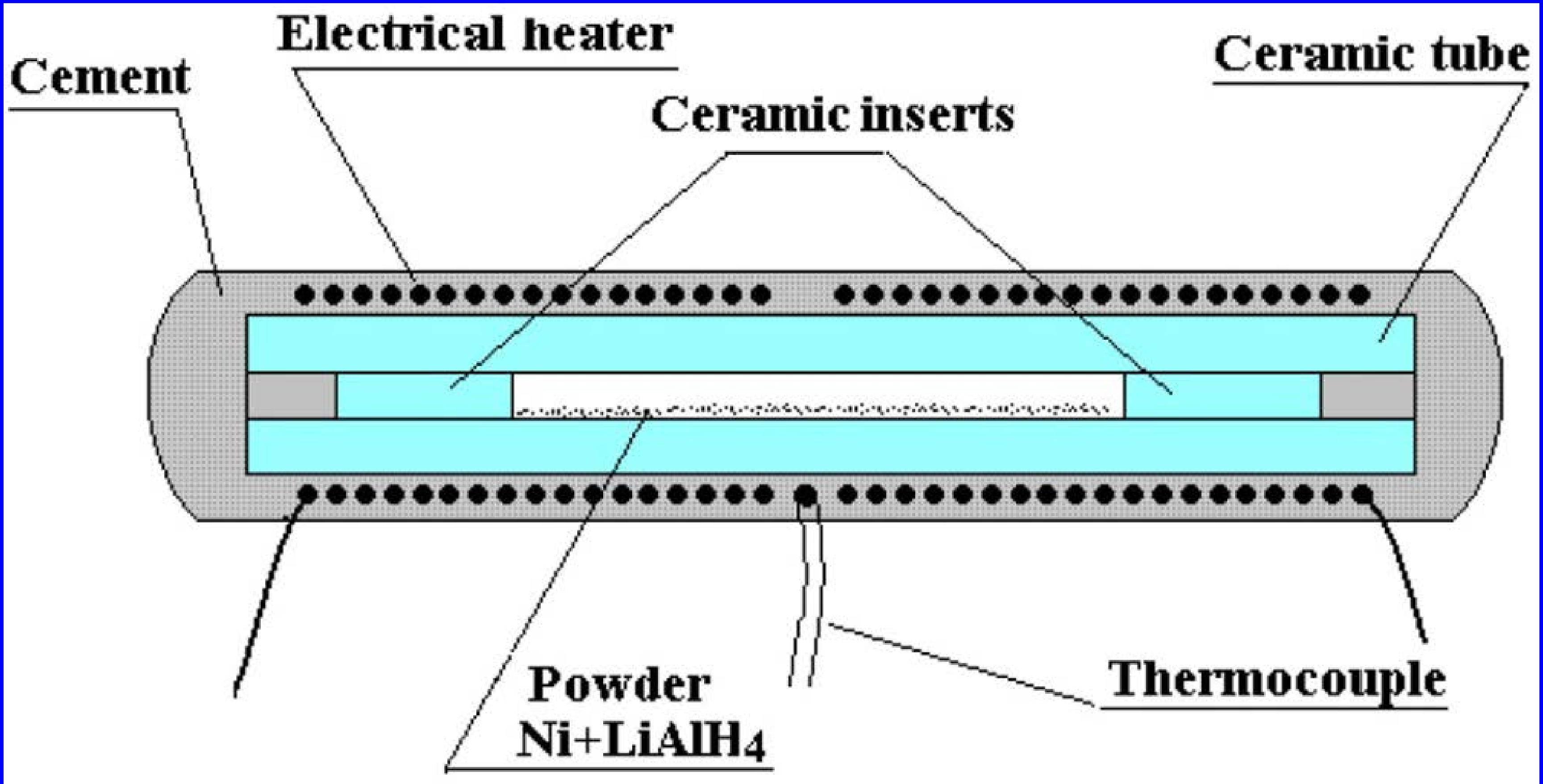
Mats Lewan Interview with Rossi posted on July 22, 2017:
http://e-catworld.com/2017/07/22/interview-with-andrea-rossi-on-current-and-future-developments-of-the-e-cat/

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, 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.

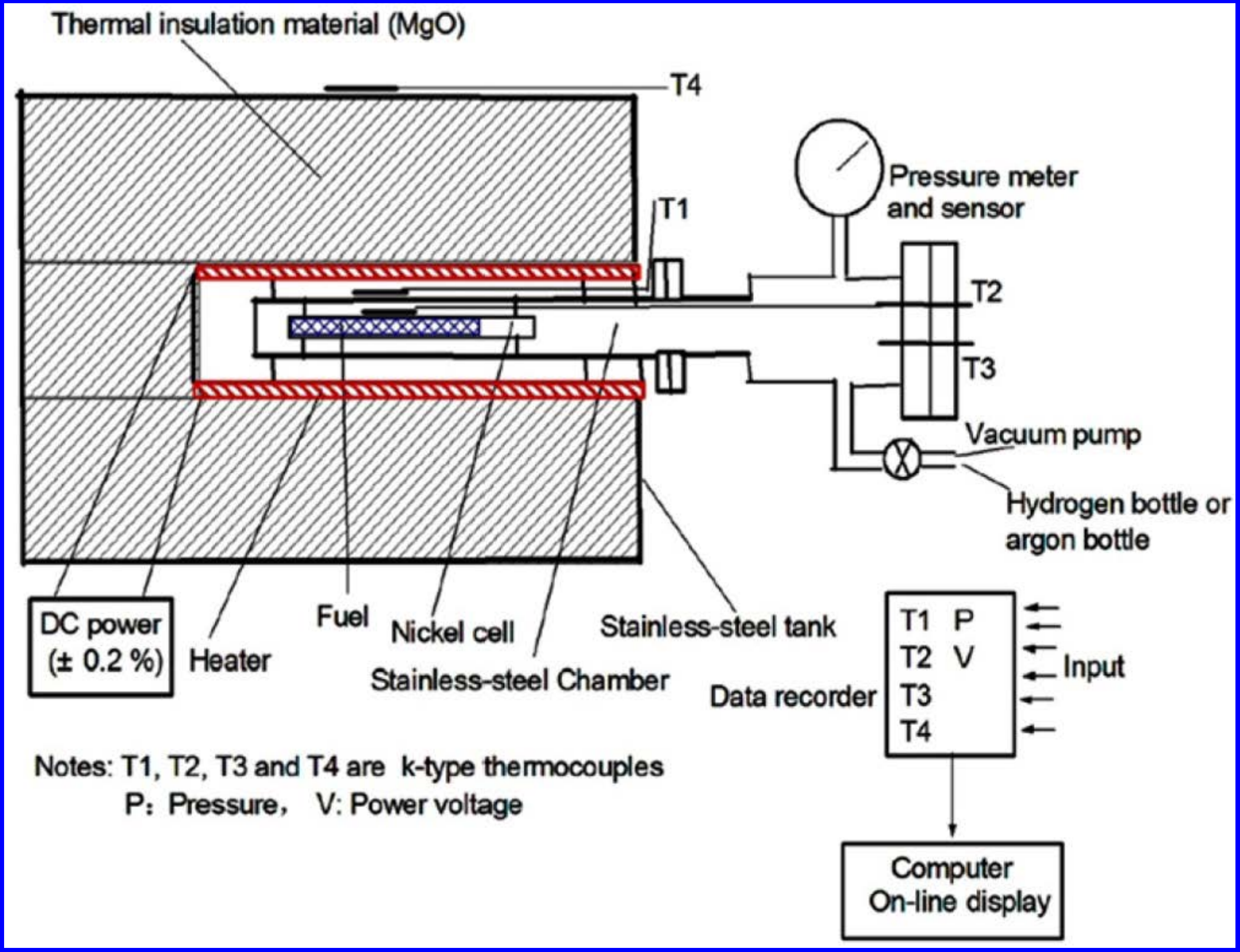
The scheme of A.G. Parkhomov's reactor



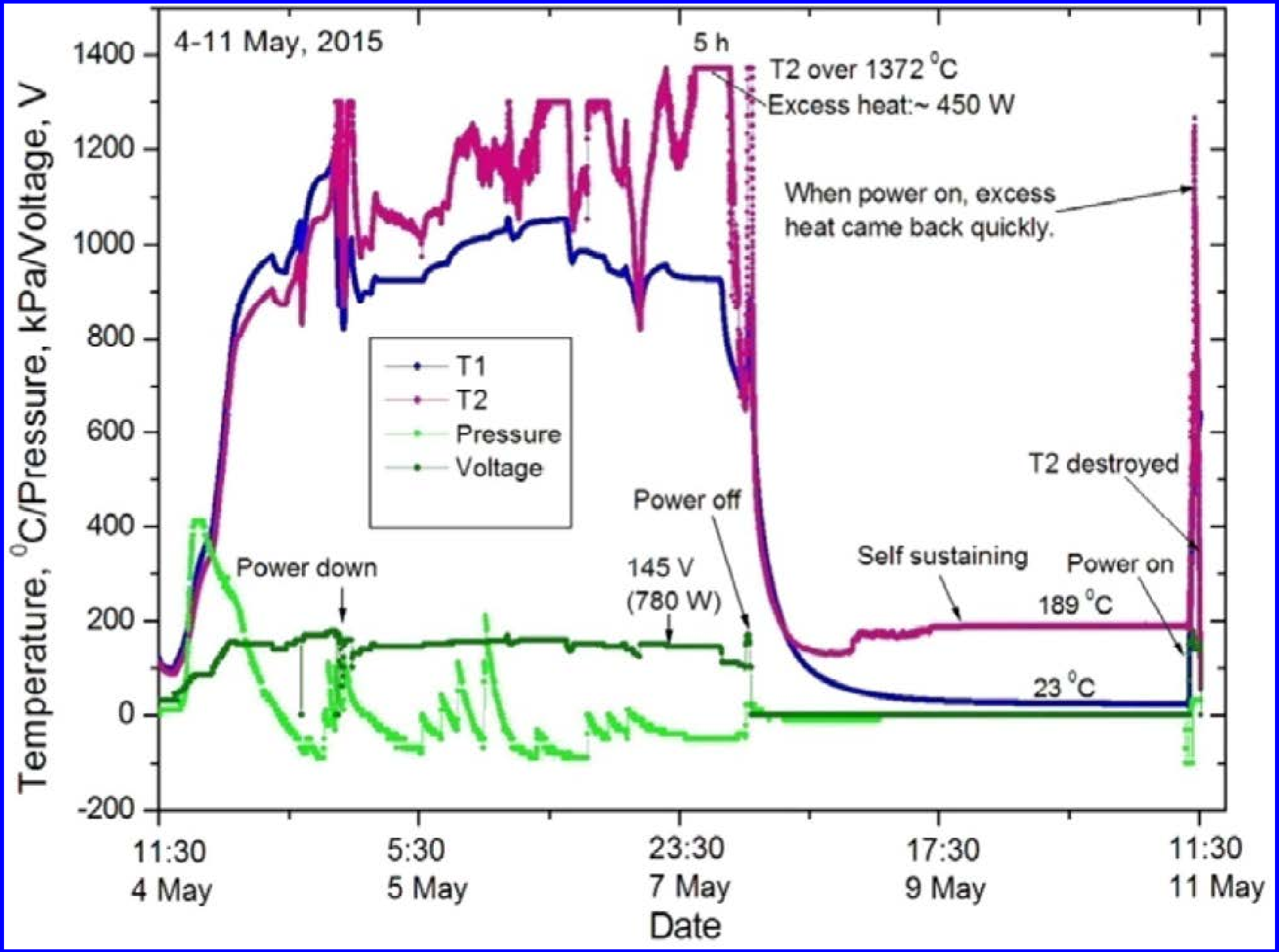
3.3. Song-Sheng Jiang works (China)

In 2015, work was reported of Song-Shen Jiang and others from the Institute of Atomic Energy of China, called "Anomalous heat production in hydrogen-loaded 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. Next slide presents the scheme of Song-Sheng Jiang and his colleagues' installation from the Institute of Atomic Energy of China.

The scheme of Song-Sheng Jiang and his colleagues' installation from the Institute of Atomic Energy of China



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, the 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^o 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 (weak interaction) for a light element, $^7Be + e^- \rightarrow {}^7Li + \nu_e$, runs with a lifetime of about 53 days. Experiments have shown that the electron capture rate depends on the electron's proximity to the nucleus. The reaction rate of a weak interaction $^7Be + e^- \rightarrow {}^7Li + \nu_e$ *(electron capture),* in the case when 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].

Press Release Brillouin Energy

BERKELEY, CA, 18 November 2015 **- Brillouin Energy Corporation, developer of renewable energy technologies capable of producing commercially useful *amounts of thermal energy (heat) based on controlled low energy nuclear reactions (LENR),* announced today that its WET™ and HHT™ Boiler System reactor core modules were presented to Congress on Capitol Hill.**

The member of the team Dr. Michael McKubre said, "It is very clear that something on the order of *four times (4x) and potentially more gain power* (and therefore ultimately energy) was achieved at an impressive and industrially significant operating temperature of around 640° C. This had not been achieved before in the LENR field. The Brillouin Energy Q-Puls™ control system is capable of triggering the excess power on and off 's also highly significant.

A possible interpretation of Brillouin results

Again, it was observed that the electron capture *(i.e. weak interaction)* for light element $^7Be + e^- \rightarrow {}^7Li + \nu_e$ runs with a lifetime of about 53 days *[19].* Experiments have shown that the electron capture rate depends on the electron proximity to the core. The reaction rate of the weak interaction $^7Be + e^- \rightarrow {}^7Li + \nu_e$, in the case when this process occurs in a metal, is expected to be higher than in the case where this process takes place in the insulator.

It can be *assumed* that a similar reaction

$$^{1}H+^{1}H \rightarrow {}^{2}He^{*} \rightarrow {}^{2}He^{*}+e^{-} \rightarrow {}^{2}H+\nu_e$$

of *2p*-hydrogen implantation in metals is very rapid. Please note that in *crisscross configuration* this reaction with no visible energy release can take place extremely fast.

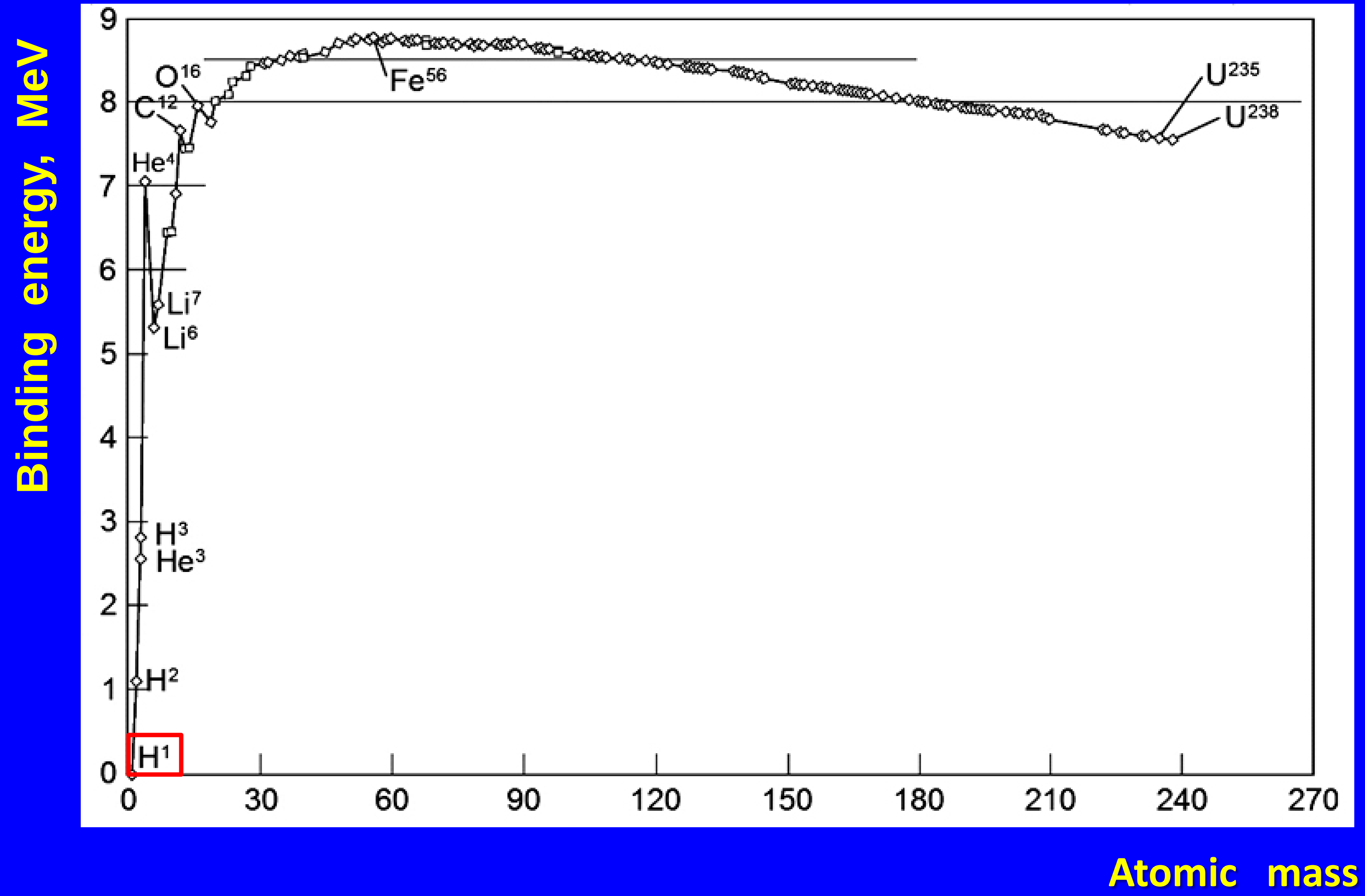
The energy released in this reaction equals 0.93 *MeV*. Since the deuteron ^{2}H is quite a heavy particle, almost all of this energy is taken by the neutrino. Upon further saturation of the conductive crystal cell with ^{1}H hydrogen, ^{3}He is formed as a result of cold fusion processes, then ^{4}He , etc.

As we can see, the first step in the fusion reaction of two ordinary hydrogen atoms ^{1}H in the conductive crystals with the electron-capture reaction causes no recorded energy release.

Apparently, this circumstance was the basis for the statement of the McKubre and others than the fusion reaction $^{1}H+^{1}H$ in their first experiments does not go.

Further *HD* and *DD* cold fusion reactions in Brillouin case take place through the strong interactions, without neutrino emission.

Binding energy per nucleon



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4. Discussion

The scientific community's adaptation to new knowledge was 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 already almost 70 years, have gone too far for the quiet termination.

The most famous attempt for thermonuclear fusion is the International Project *ITER*. Currently, the Project is huge and extremely expensive. Realists have estimated that construction of the *ITER* reactor and the attempts of its launch could be completed no earlier than 35–50 years from now. The *ITER* project is seen as 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 oil and gas industries welcome this development. This situation, however, can lead to a climate change, reduction of the population of our planet, and other painful social cataclysms.

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