

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

E. N. Tsyganov

*Cold Fusion Power, International
OSNovation Systems, Inc., Santa Clara, CA*

COLD NUCLEAR FUSION

*Joint Institute For Nuclear Research
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Joliot-Curie 6, 141980 Dubna, Moscow region, Russia. July 7, 2014*

1983 — on the JINR participation in DELPHI experiment



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Cold nuclear fusion. *Look beyond the horizon ...*



Flammarion, 1888,
based on the 16th
century vision

Julian Schwinger



Tried to “Look beyond the horizon ...”

“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 American Physical Society

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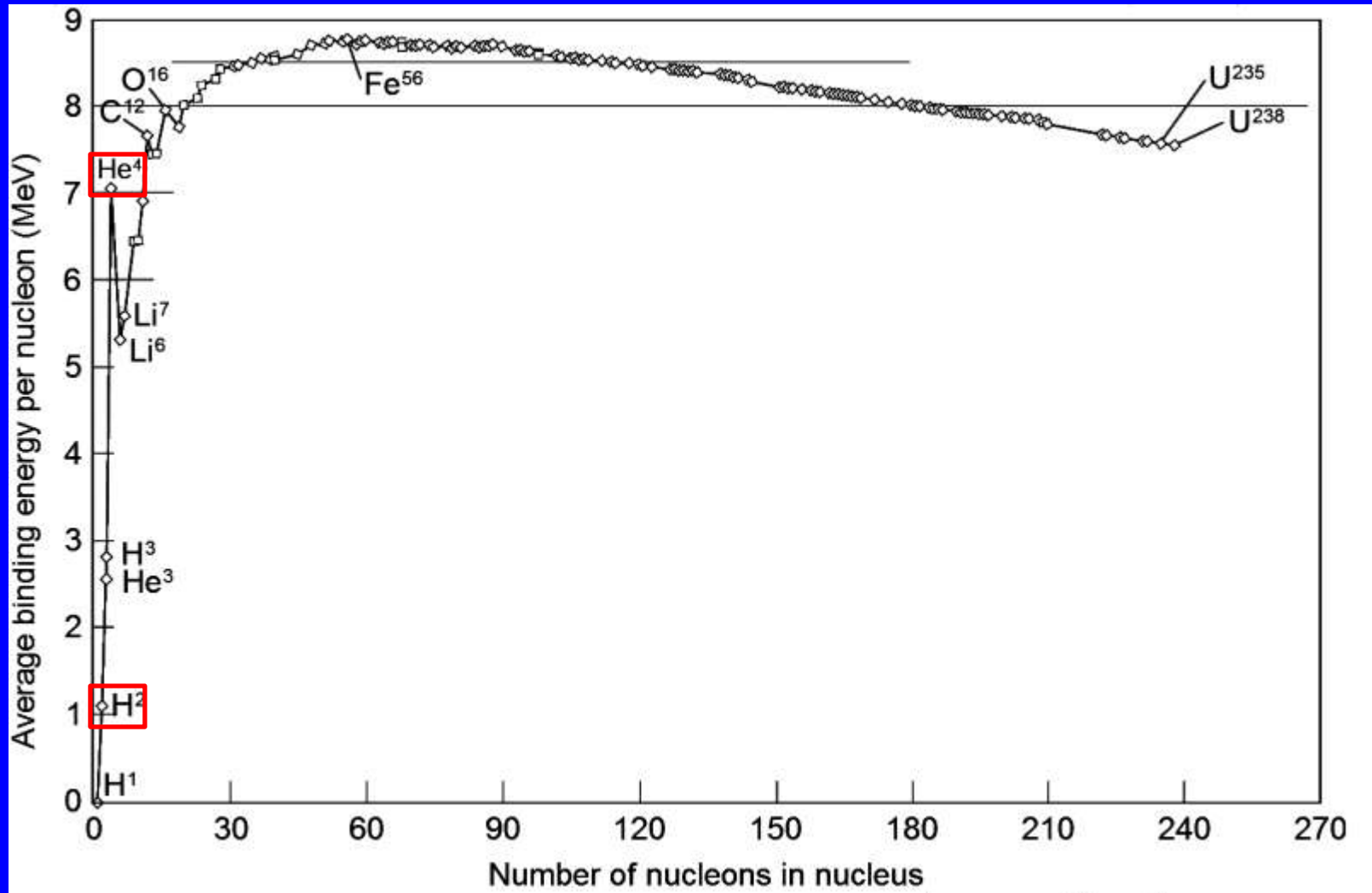
Richard Feynman



“Physics is the experimental science.”

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Binding energy



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.

Cross-section of synthesis in the collision of two deuterium nuclei:

$$\sigma(E) = S(E) E^{-1} \exp(-2\pi\eta(E))$$
$$2\pi\eta = 31.41/E^{1/2}$$

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 $\exp(-2\pi\eta(E))$, 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 $E_{\text{eff}} = E + U_e$, where $U_e = e^2/R_a$. For the unexcited hydrogen atom, $U_e = 27 \text{ eV}$.

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.

Zeldovich, Ya. B., Gerstein, S. S. (1960). U. F. N., LXXI(4), 1960, 581.
Consideration of piezo-fusion



Ya. B. Zeldovich



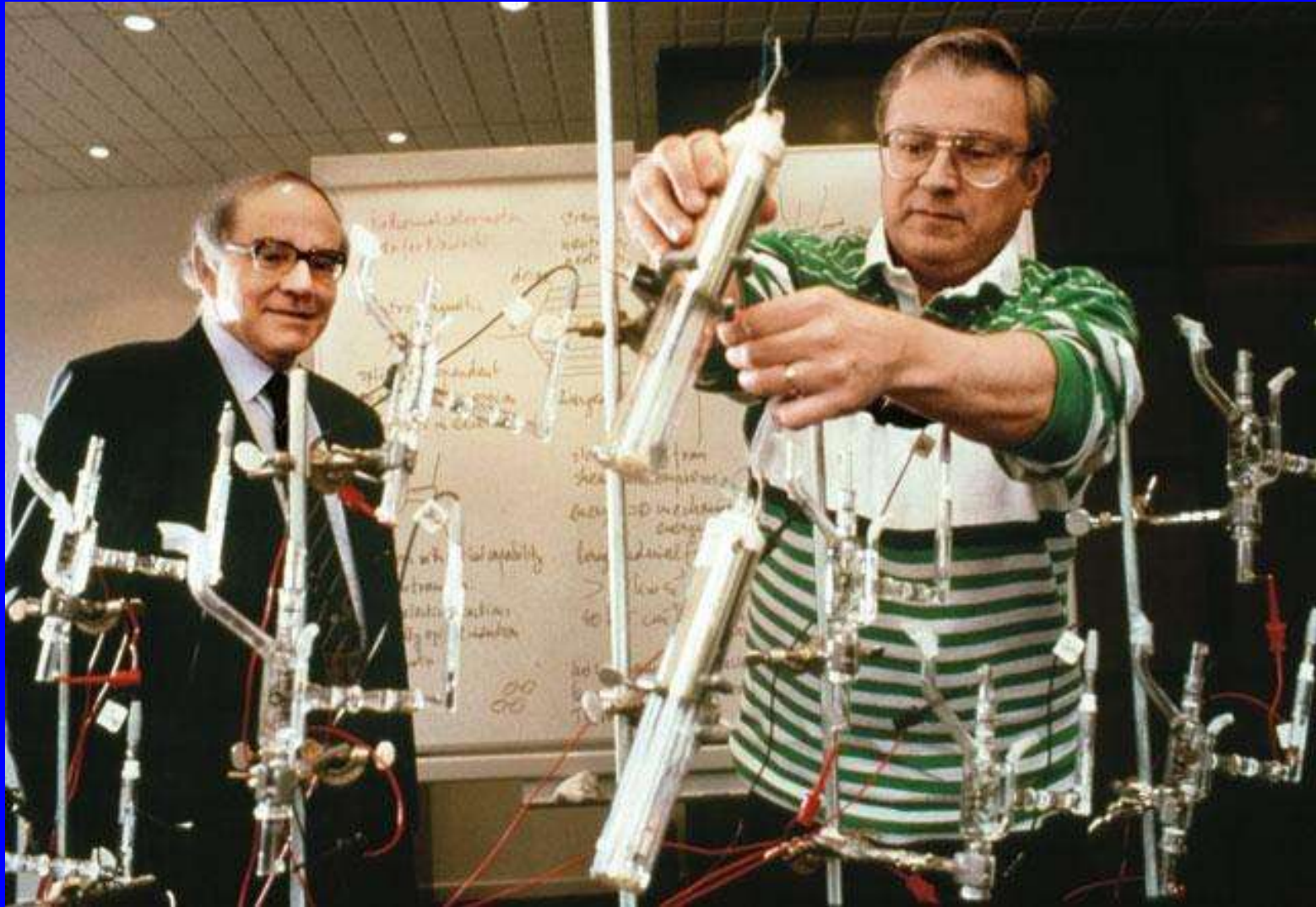
S. S. Gerstein

$$B = \exp \left\{ -\frac{2}{\hbar} \int_{x_1}^{x_2} \sqrt{2M(U(x) - E)} dx \right\} = \exp \left\{ -\frac{2}{\hbar} \sqrt{2M\bar{U}} (x_2 - x_1) \right\}$$

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

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.

Martin Fleischmann and Stanley Pons, 1989



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Quickly rejected by most scholars as irreproducible and not having a consistent theoretical interpretation, these experiments, however, gradually began to give reproducible results.

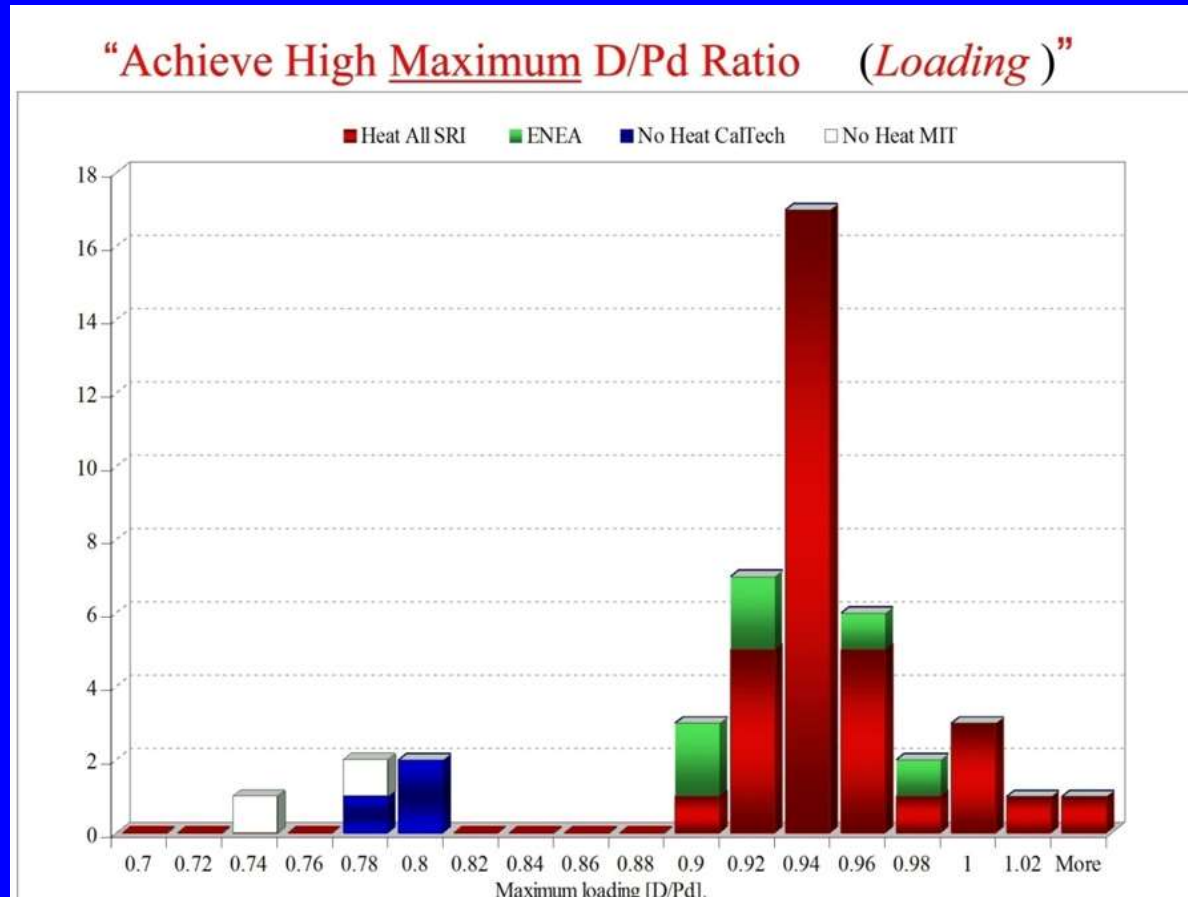
Classic examples are the experiments made by Dr. McKubre and his colleagues at the Stanford Research Institute, International. The results of these experiments demonstrated a reliable heat of nonchemical origin, whereby the effect exceeded about 100 experimental errors.

Dr. McKubre in his laboratory.



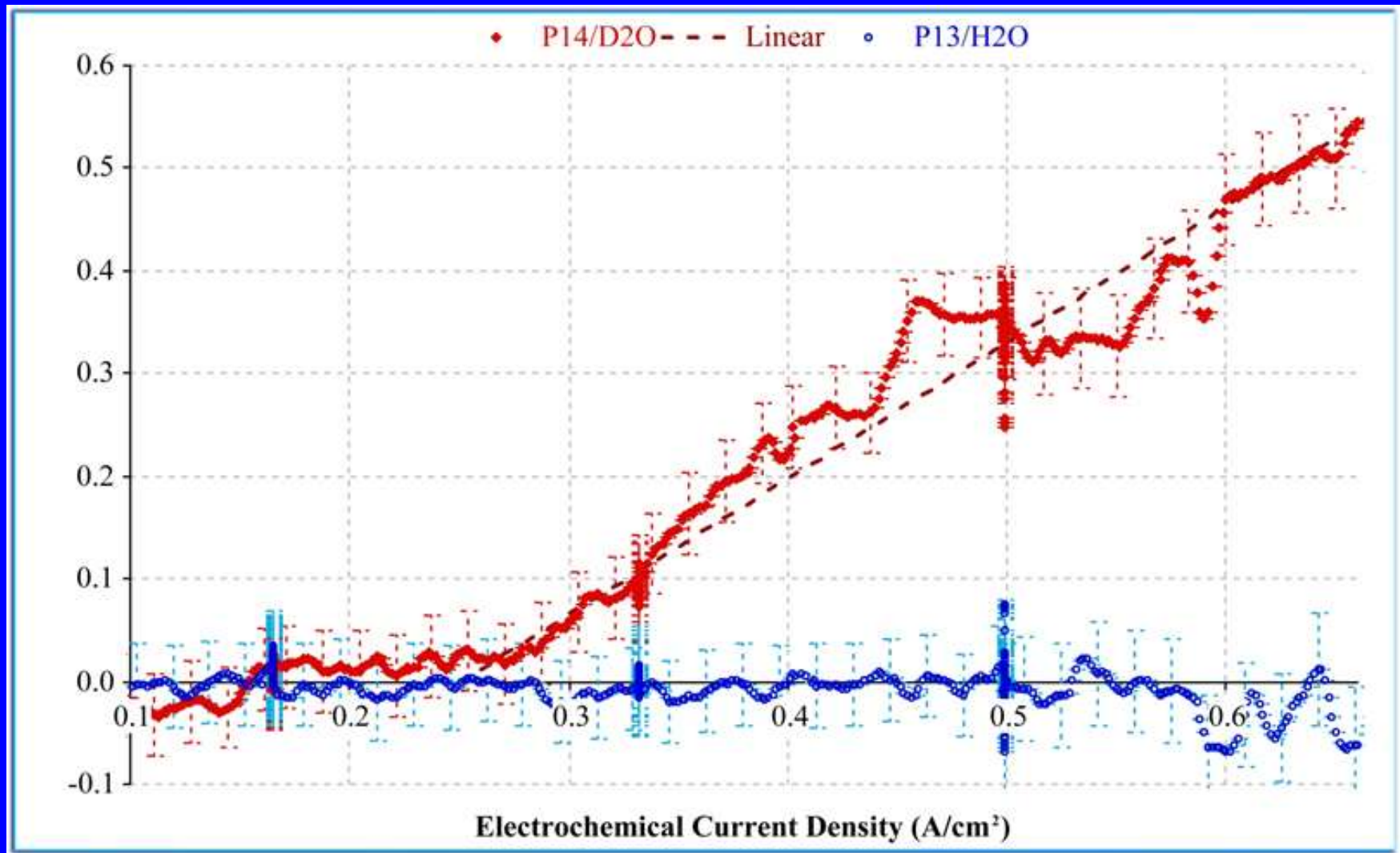
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The success of the experiment depends on the concentration of deuterium.

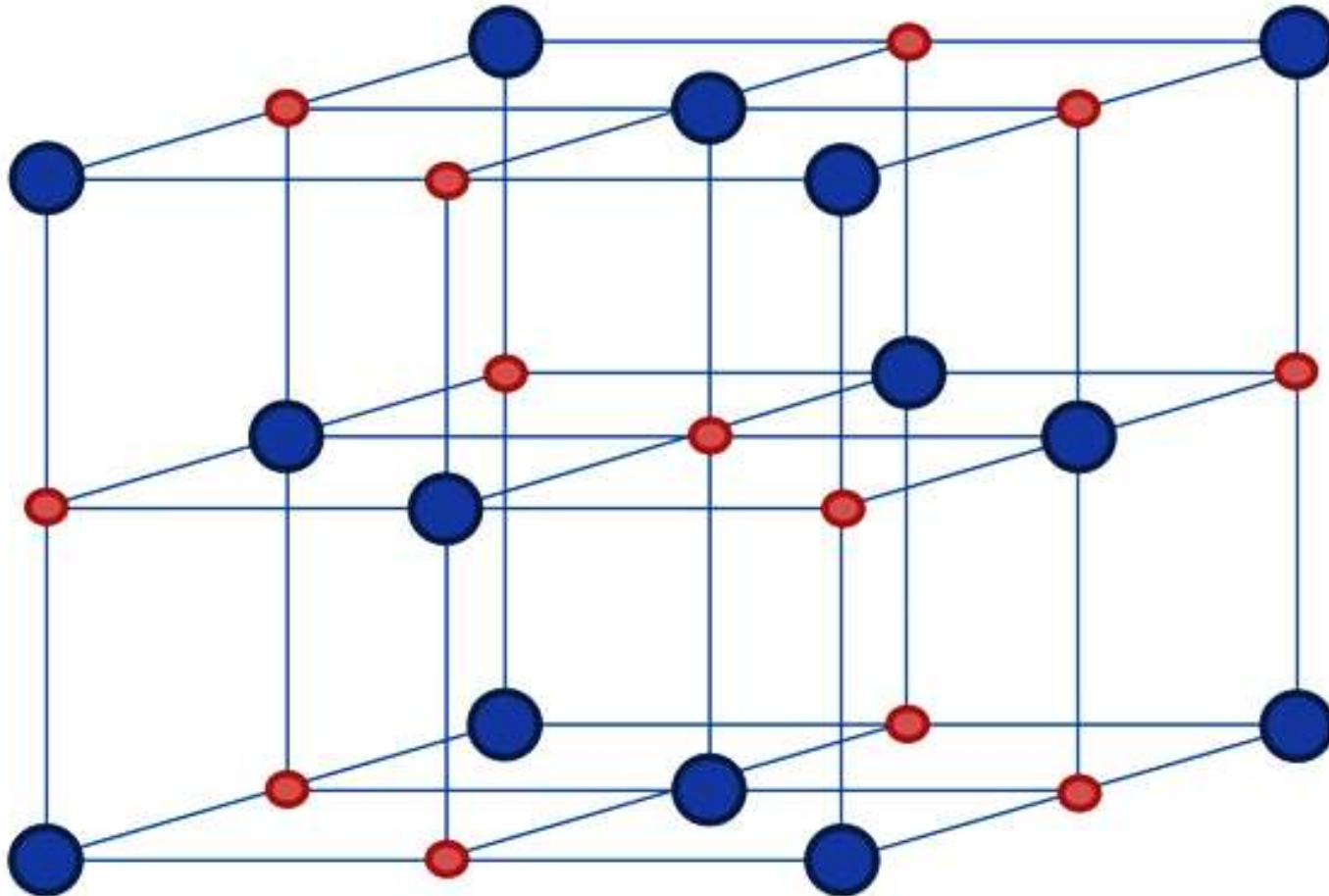


Michael C.H. McKubre, Francis L. Tanzella, and Vittorio Violante, Journal of Condensed Matter Nuclear Science, Volume 8, May 2012, p. 187
Joint Institute For Nuclear Research
Bogoliubov Laboratory of Theoretical Physics
Joliot-Curie 6, 141980 Dubna, Moscow region, Russia. July 7, 2014

Excess heat in W, depending on the value of the electrochemical current, in the experiments of Dr. McKubre



The fcc crystal structure. Small circles marked octahedral (the deepest) niches.



History of cold fusion “in vitro”

- | | | |
|----|-----------------------------|------------|
| 1. | Martin Fleischmann | 1989–2012 |
| 2. | Michael McKubre | 1992–today |
| 3. | Yoshiaki Arata | 1998–2008 |
| 4. | Hagelstein and Swartz (MIT) | 1992–today |

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

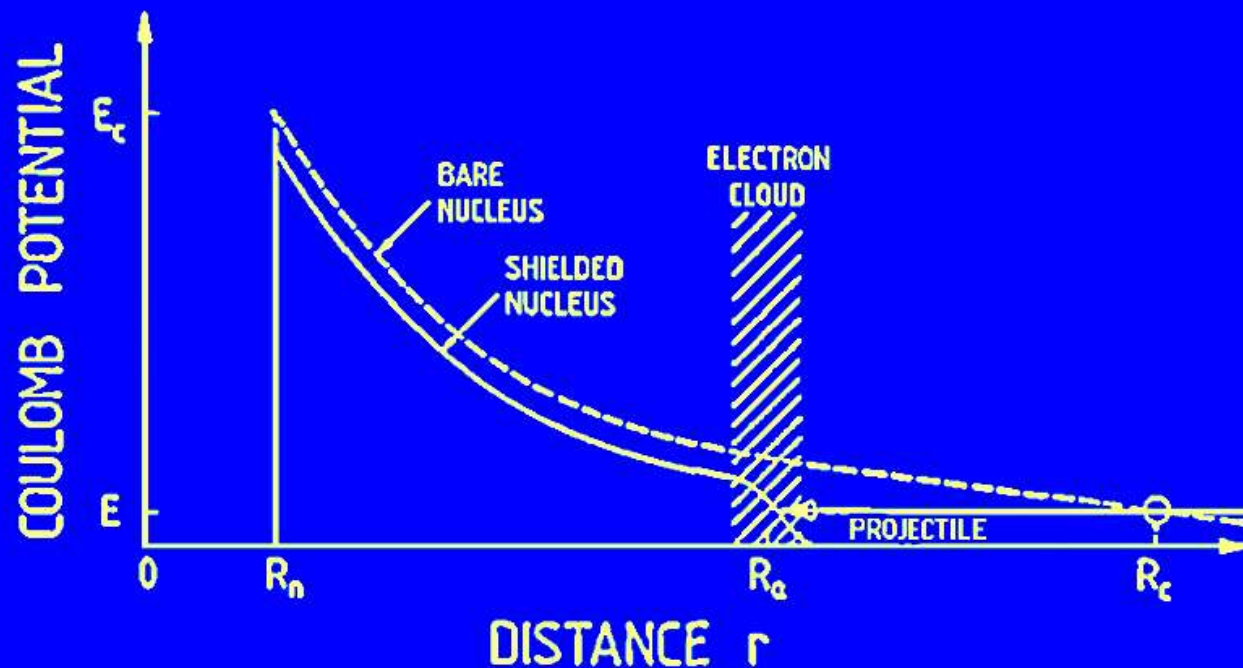
Michael McKubre
D + D in palladium
1992–present

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

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

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 $E_{\text{eff}} = E + U_e$.”

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**.

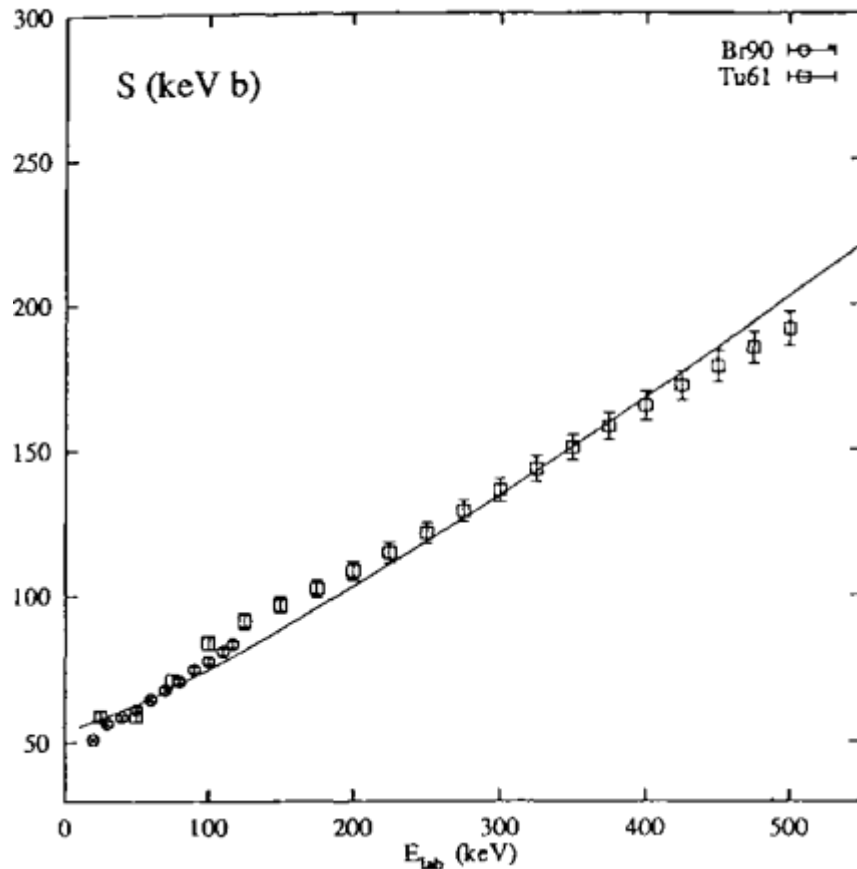


It should be noted that during irradiation of solid state body with a beam of charged particles, incident particle captures an electron from the solid body and moves like an atom, if its velocity does not exceed the so-called Bohr velocity.

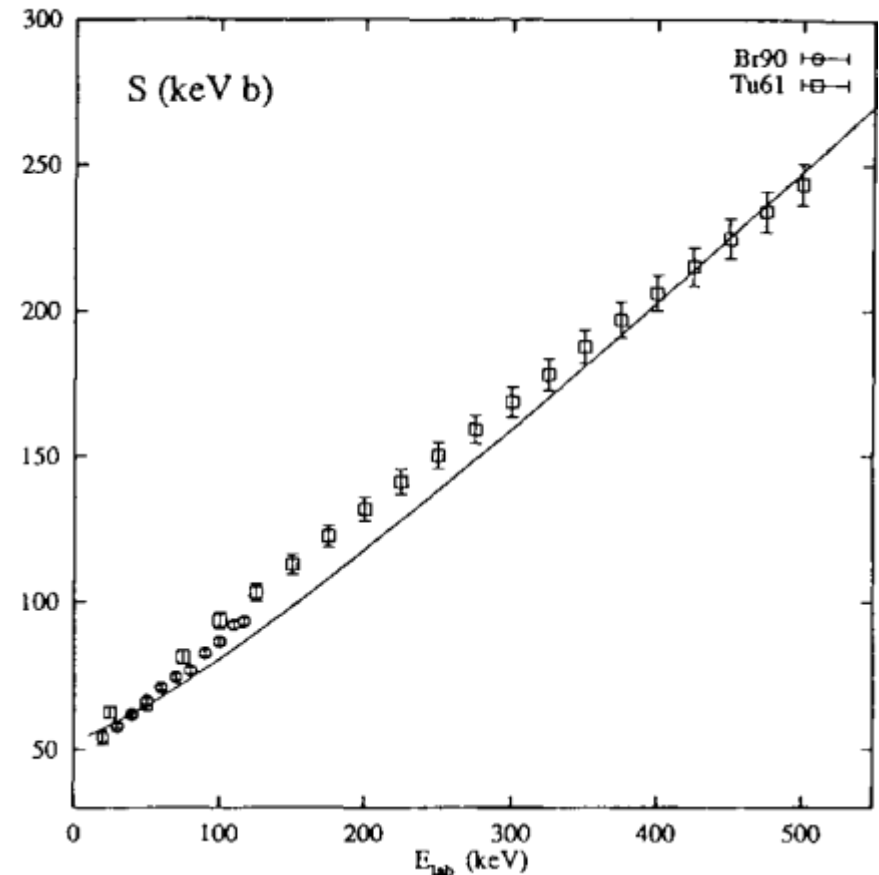
For deuterons this threshold energy is ~ 50 keV. This interesting observation was made in the paper: *Y.A. Baranov, Yu. Martynenko, S.O. Tsepelevich, Yu.N. Yavlinsky, "Inelastic sputtering of solids by ions", Physics-Uspekhi, November 1988, Volume 156, no. 3, p. 477.*

$S(E)$ – astrophysical factor for reactions $D(d,p)^3H$ and $D(d,n)^3He$,
Lemaitre, S. and Paetz gen. Schieck, H., *Ann. Physik* **2** (1993), 503.

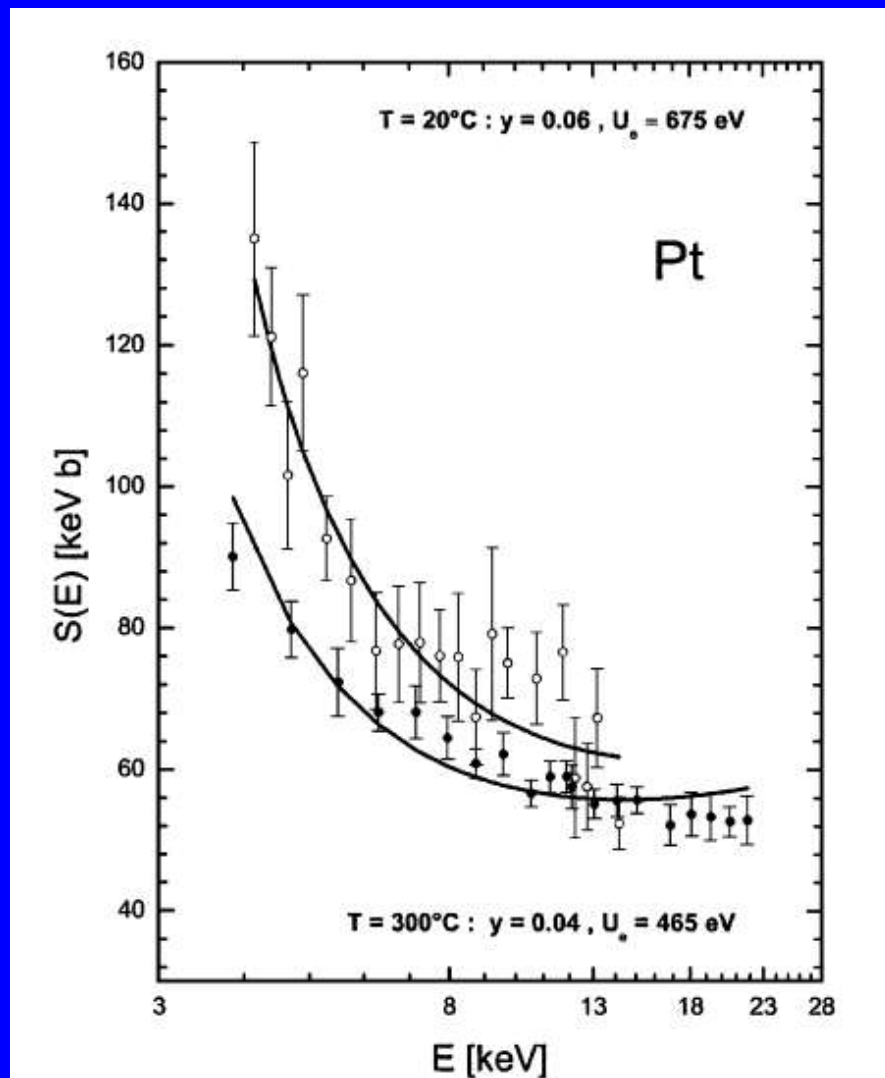
$D(d,p)^3H$



$D(d,n)^3He$



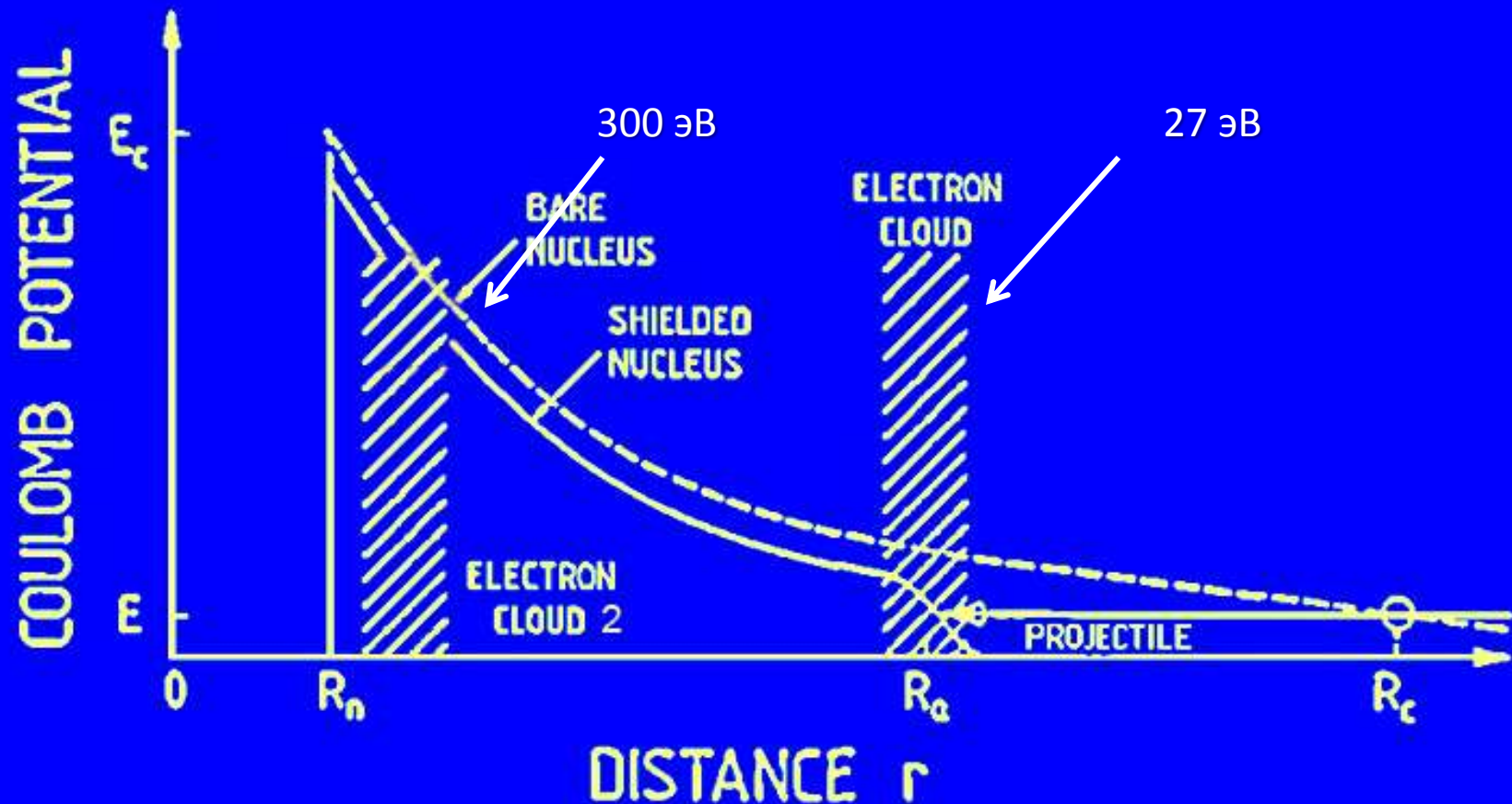
C. Rolfs et al., J. Phys. G: Nucl. Part. Phys. 31, 2005, pp 1141–1149. (Gran Sasso).
 $S(E)$ for DD-fusion, the target is implanted in Platinum, $U_e = 675$ eV.



The accelerator experiments have shown that the magnitude of the screening potential of the impurity atoms in metallic crystals can reach ***300 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 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 Prof. Bressani in 1998 at ICCF-7 conference on the basis of a series of Japanese accelerator experiments being performed since 1995.

Unfortunately, the cold fusion community at that time did not follow the call of Prof. Bressani.

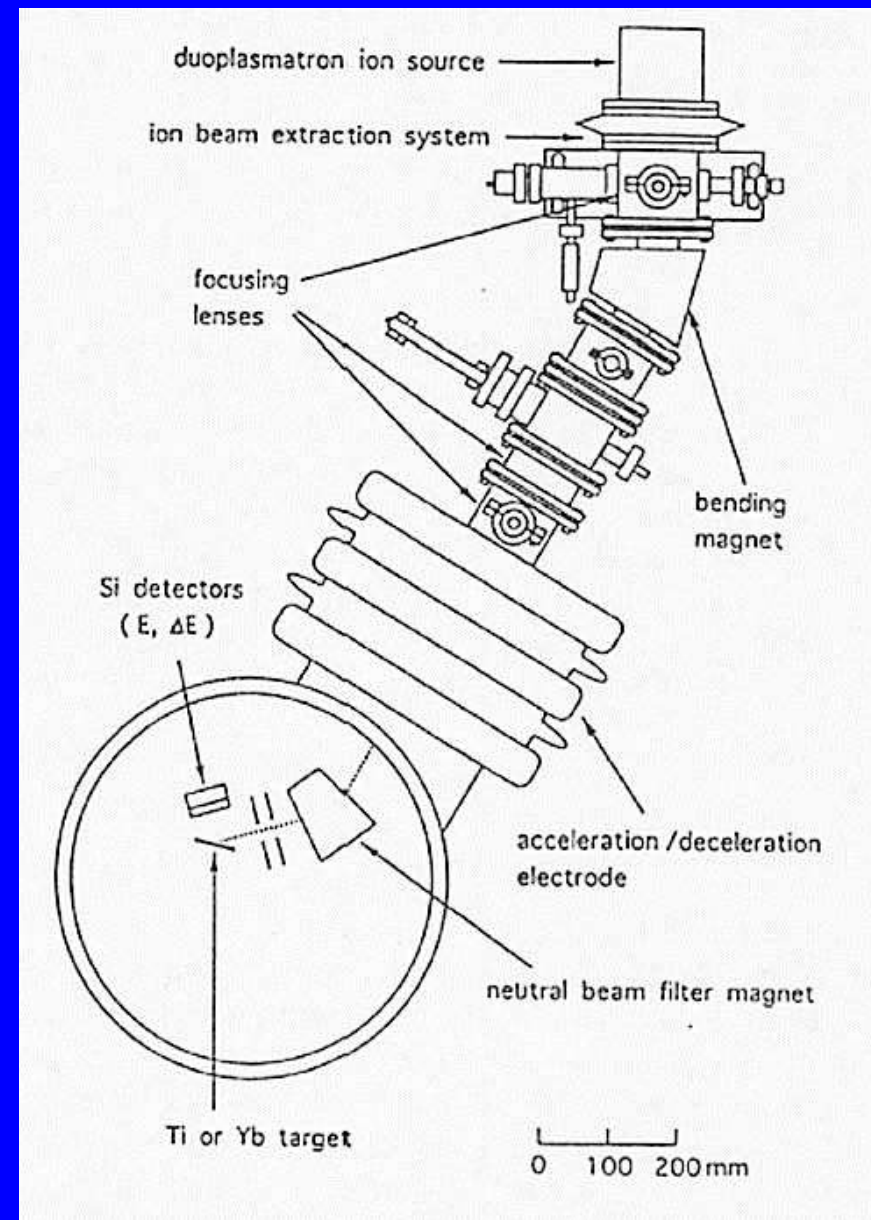
Target deuterium atoms implanted into metals *are no longer in 1s-state*. The free electron cloud in a metal causes the electron of an implanted atom to occupy the excited *p-state*. The magnitude of the screening potential of 300 eV and above in experiments on DD-fusion accelerator experiments indicates that the incident deuterium atoms in the conducting 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.

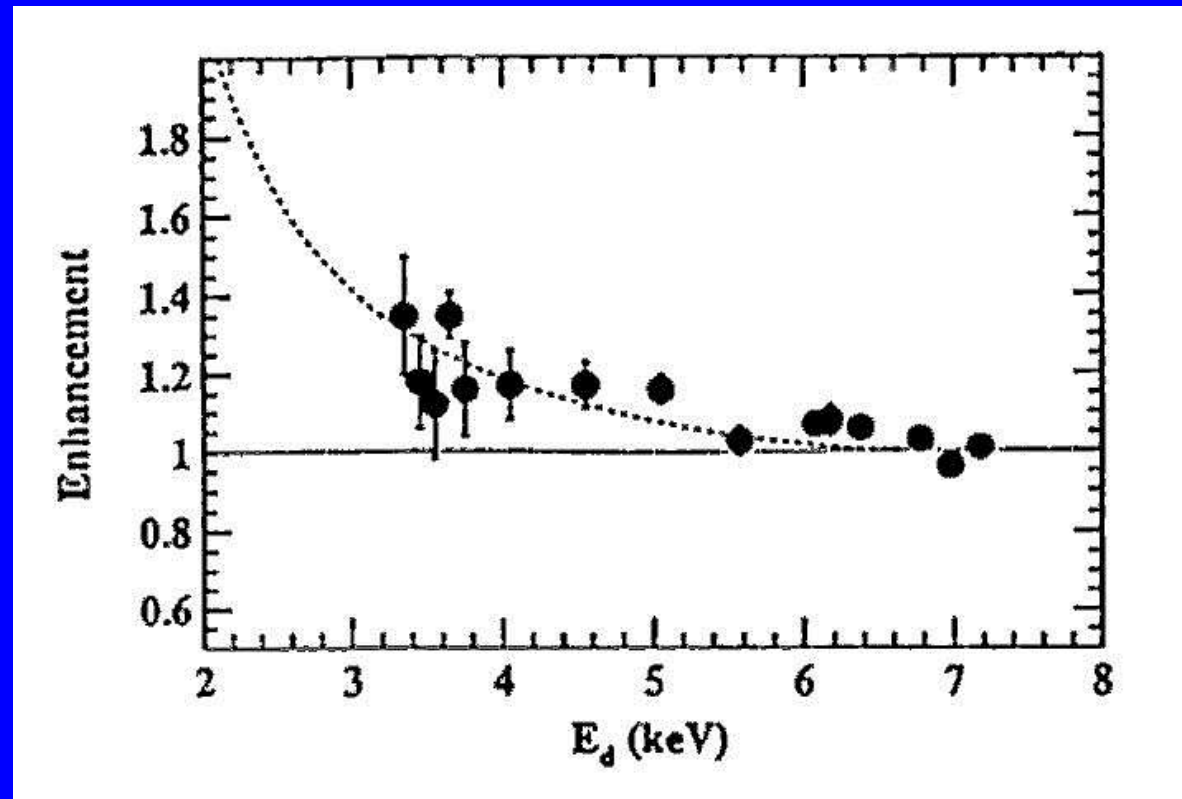
Yuki, H., Satoh, T., Ohtsuki, T., Yorita, T., Aoki, Y., Yamazaki, H., Kasagi, J. (1996).

ICCF-6, 13–18 October, Japan.



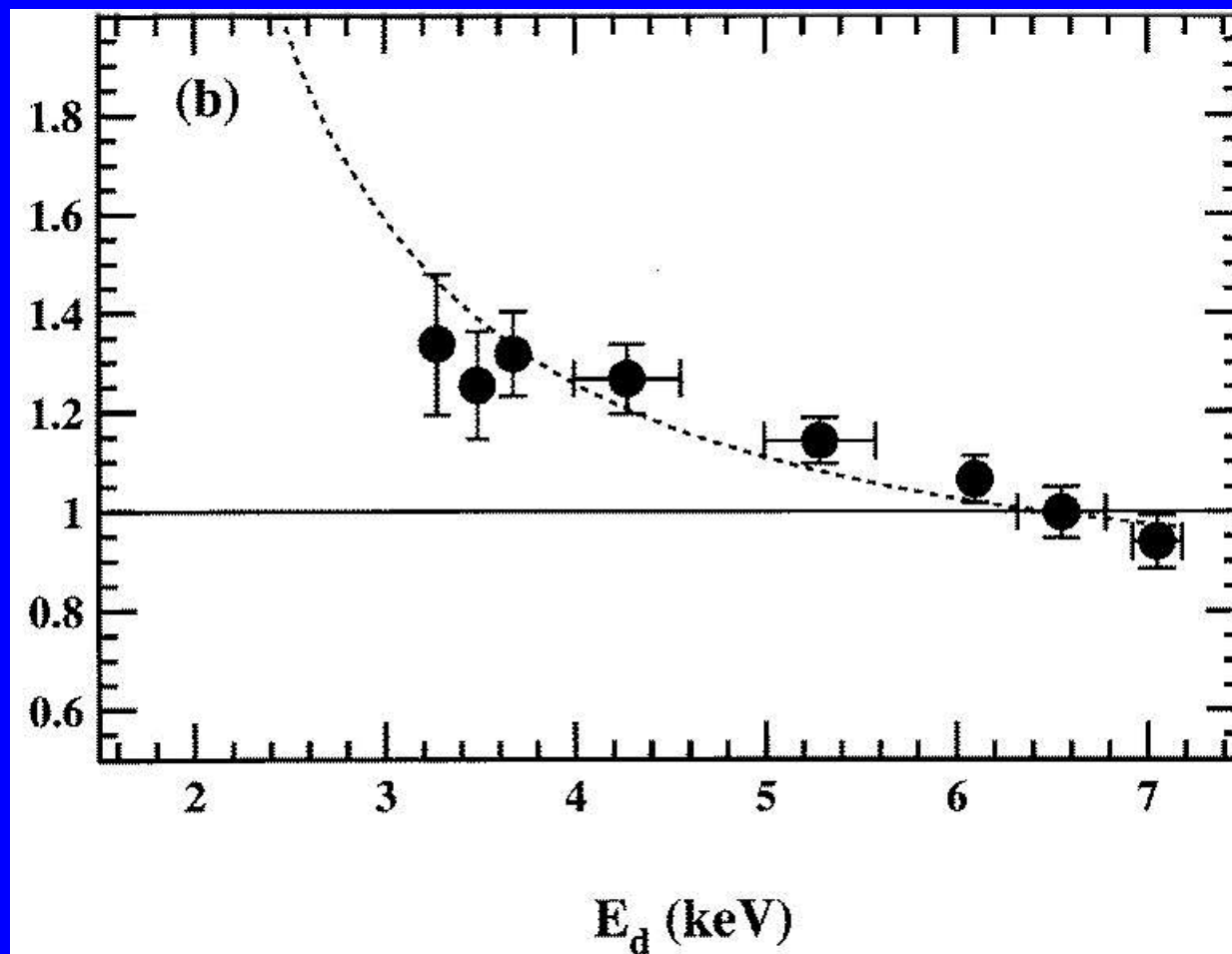
Yuki, H., Satoh, T., Ohtsuki, T., Yorita, T., Aoki, Y., Yamazaki, H.,
Kasagi, J. (1996). ICCF-6, 13–18 October, Japan.

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.

Yuki, H., Satoh, T., Ohtsuki, T., Yorita, T., Aoki, Y., Yamazaki, H., Kasagi, J. (1997). Phys. G: Nucl. Part. Phys., 23, 1,459–1,464. Increasing cross-section in ytterbium (rare earth element with a metallic conductivity)—electron screening potential reaches 81 ± 10 eV.



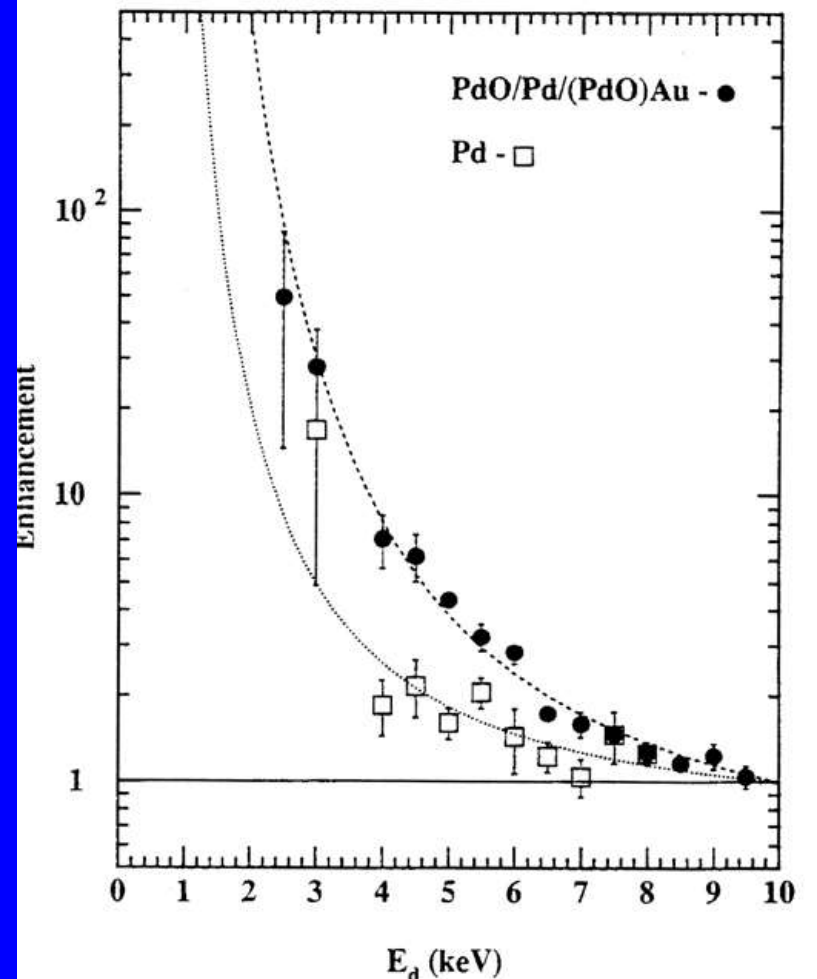
The Seventh International Conference on Cold Fusion. 1998. Vancouver, Canada:; ENECO, Inc., Salt Lake City, UT. p. 180.

“Anomalously enhanced $d(d,p)t$ reaction in Pd and PdO observed at very low bombarding energies”

J. Kasagi, H. Yuki, T. Itoh, N. Kasajima, T. Ohtsuki and A. G. Lipson *

Laboratory of Nuclear Science, Tohoku University, Japan

* Institute of Physical Chemistry, The Russian Academy of Sciences, Moscow, Russia



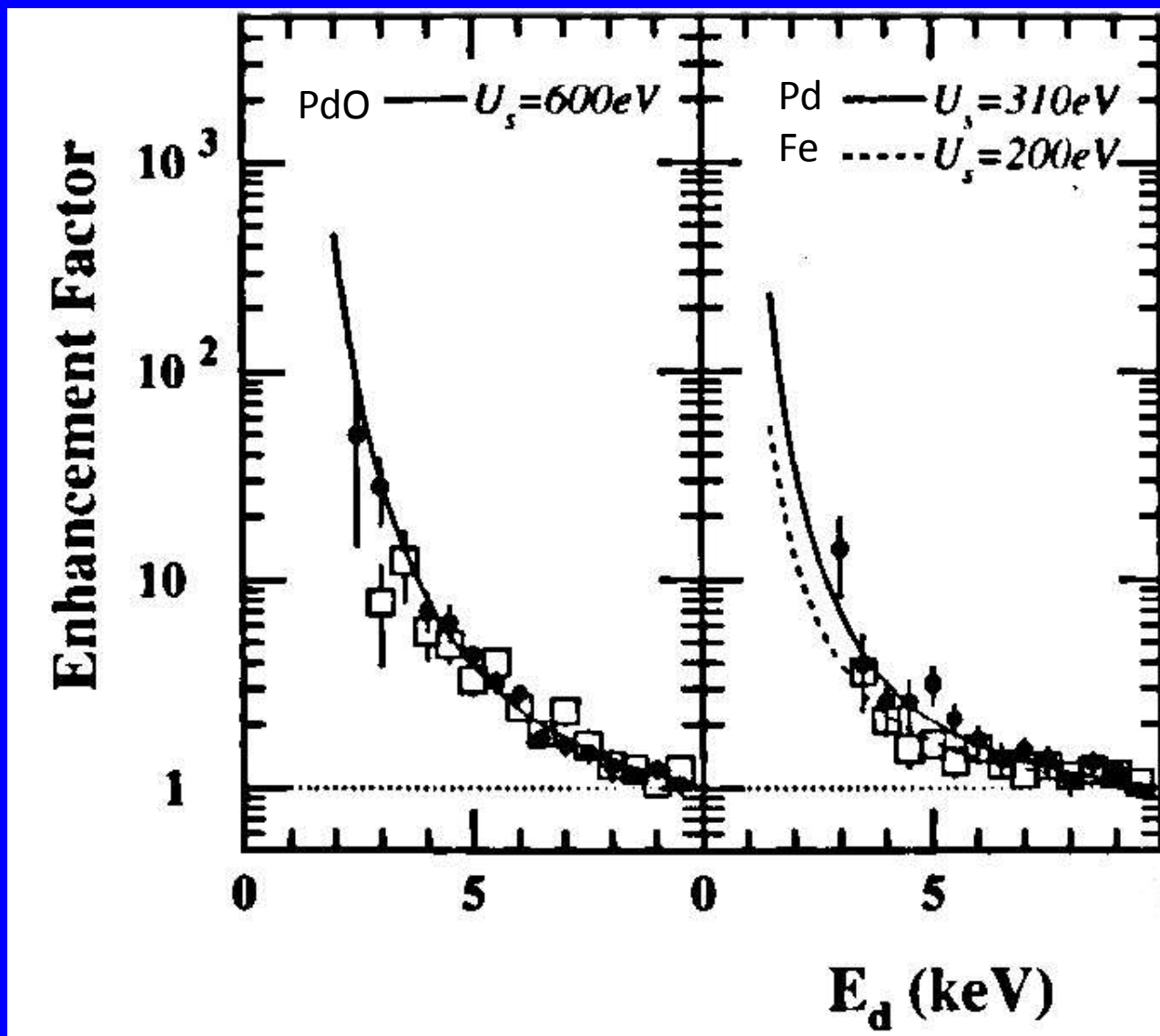
The dotted and dashed curves are those with the screening potential $U_e = 250$ and 600 eV, respectively.

One of the latest (2002) Japanese DD accelerator experiments.

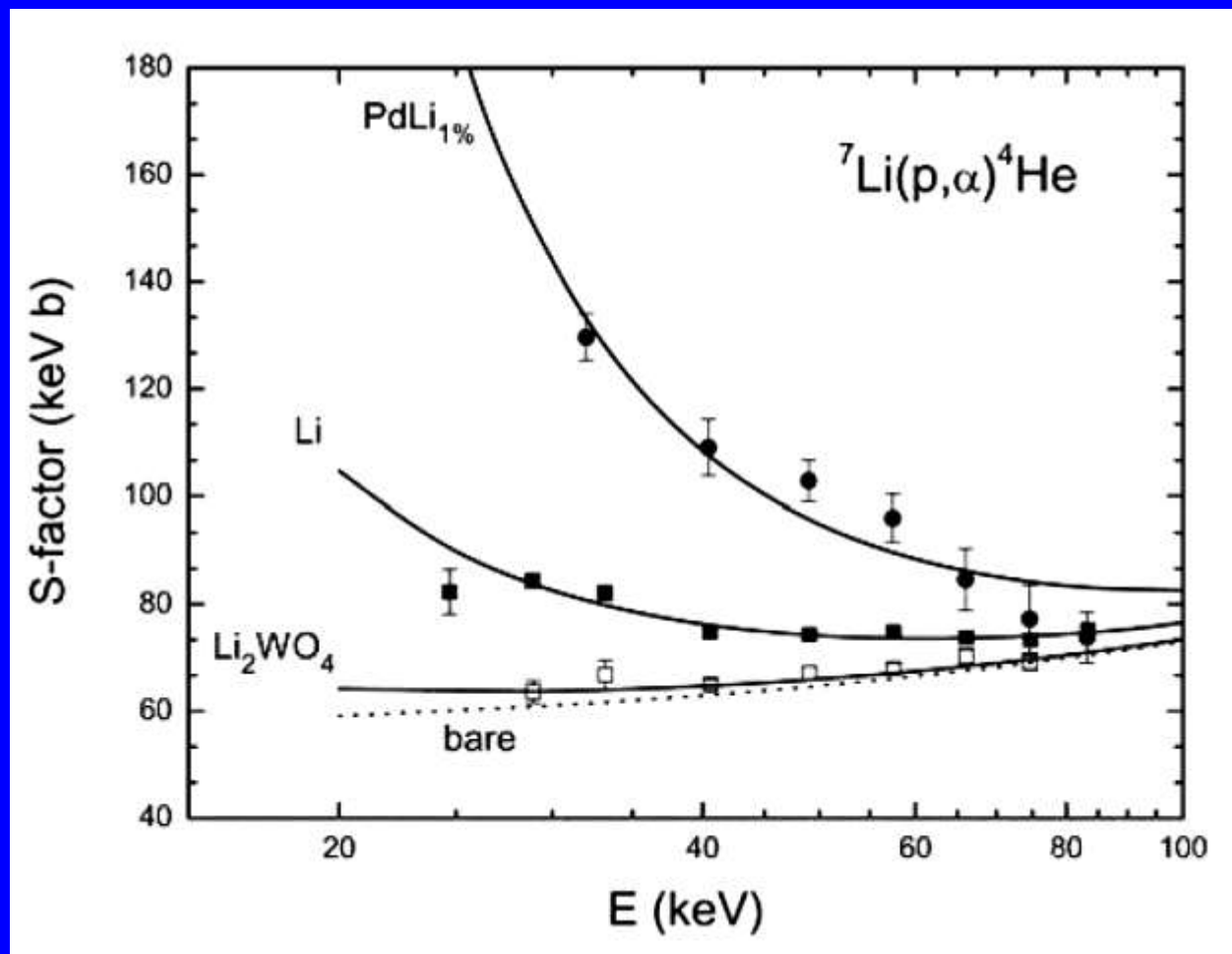
Jirohta Kasagi, Hideyuki Yuki, Taiji Baba, Takashi Noda, Tsutomu Ohtsuki and Andrey G. Lipson

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

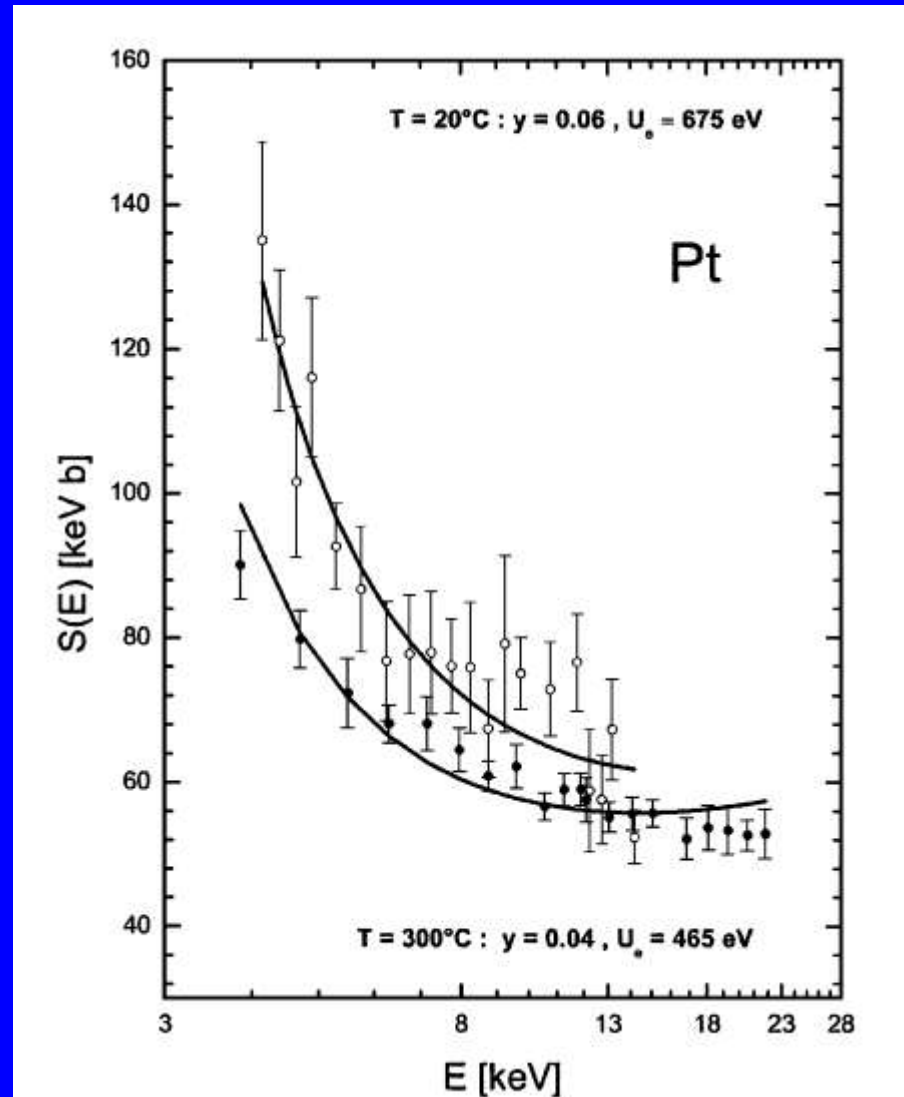
Journal of the Physical Society of Japan, Vol. 71, No. 12, December, 2002, pp. 2881-2885.



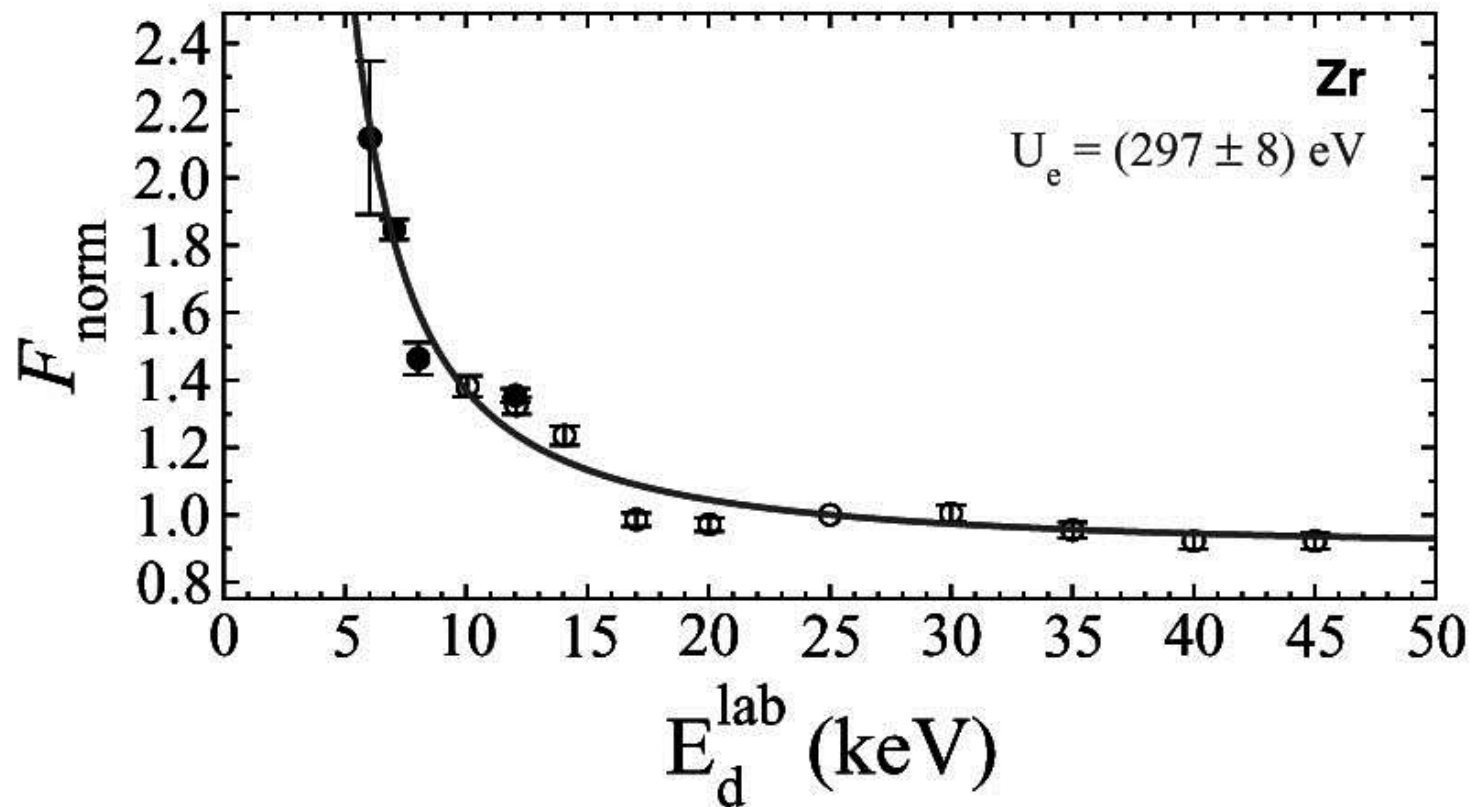
Rolfs, C. (2006). Nuclear Physics News, 16(2), 9. Normalized astrophysical factor $S(E)$ for the synthesis of $p+{}^7\text{Li}$ when a target ${}^7\text{Li}$ implanted into Palladium.



Rolfs, C. et al. (2005). J. Phys. G: Nucl. Part. Phys., 31, 1,141–1,149. (Gran Sasso). $S(E)$ for DD-fusion, targets are implanted in Platinum, $U_e = 675$ eV.

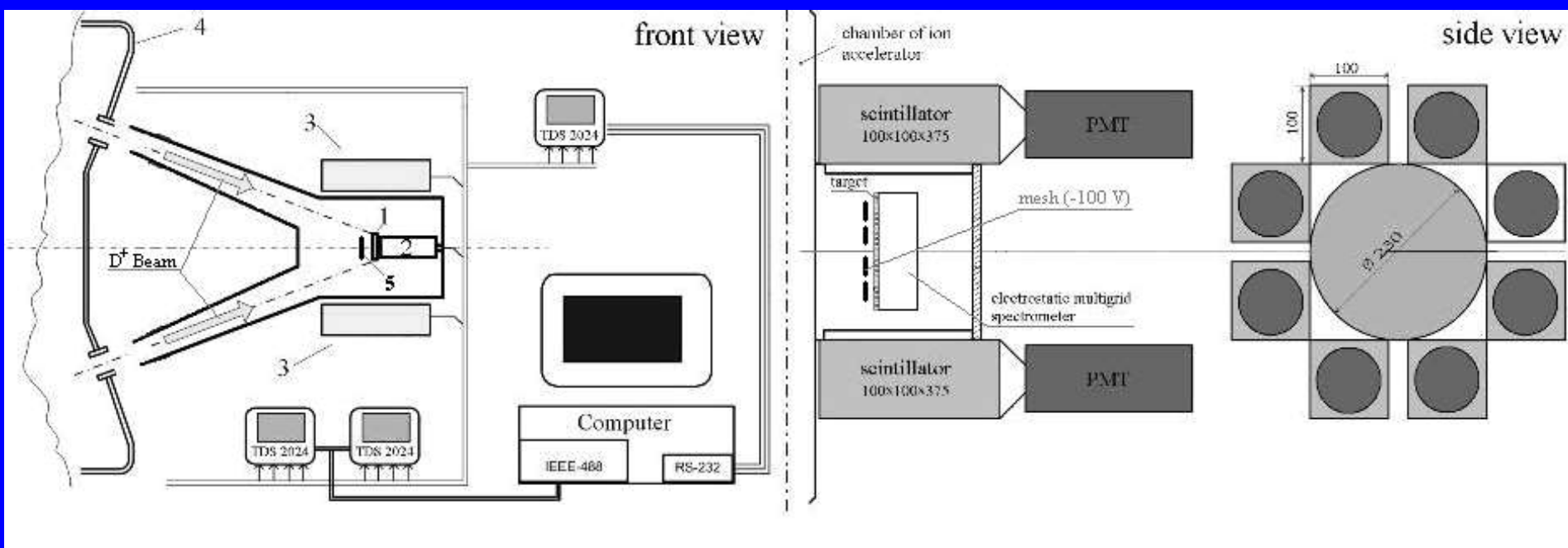


Czerski, K. et al., (2008). Physical Review C., 78, 015803, (Berlin).
Normalized astrophysical factor $S(E)$ for DD-fusion, when the target is implanted in zirconium. Screening potential is about 10 times greater than for the free atoms of deuterium.



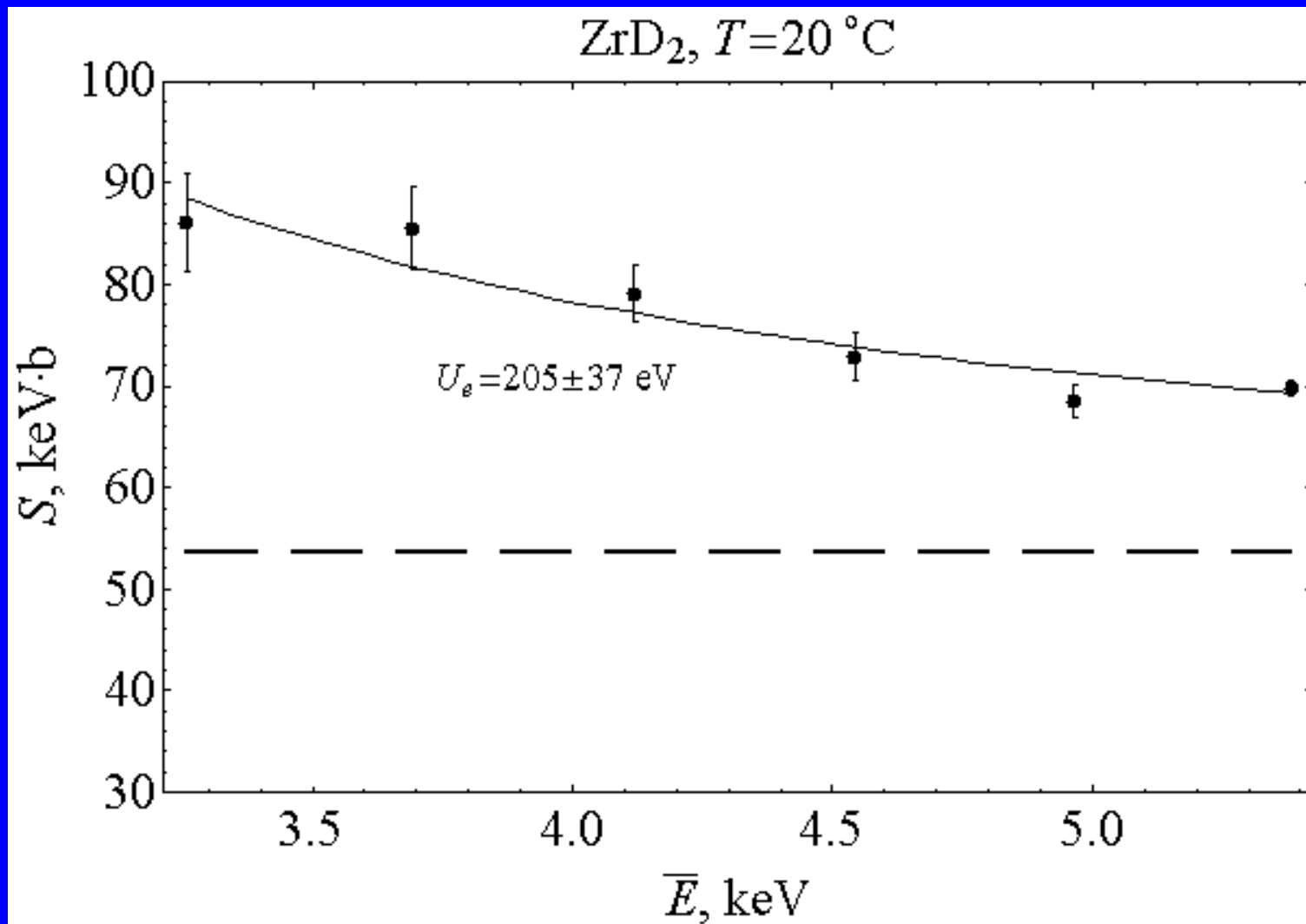
V. M. Bystritsky, Vit. M. Bystritskii, G. N. Dudkin, M. Filipowicz, S. Gazi, J. Huran, A. P. Kobzev, G. A. Mesyats, B. A. Nechaev, V. N. Padalko, S. S. Parzhitskii, F. M. Pen'kov, A. V. Philippov, V. L. Kaminskii, Yu. Zh. Tuleushev, J. Wozniak et al. (2012).

National Scientific Research—Tomsk Polytechnical University, Russia, Nuclear Physics, A 889, 93–104.



Bystritsky, V. M.
et al., National
Scientific
Research—
Tomsk
Polytechnical
University,
Russia.

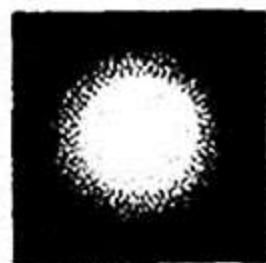
Nuclear Physics,
A 889 (2012)
93–104.



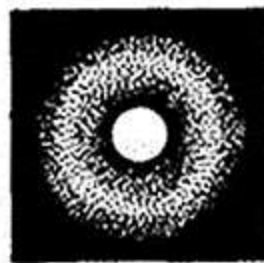
Thus, the convergence distance of two deuterium nuclei of impurity caught in the same crystalline niche of metal is an order of magnitude smaller than the size of the free atom of deuterium.

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 increased*** as compared to the permeability of the barrier in the case of the free molecule of deuterium.

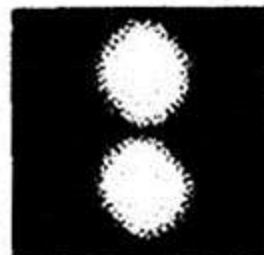
Rydberg mechanism for the hydrogen atom. Electron orbital in $2p$ -state is no longer circular.



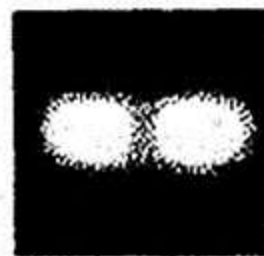
$1s \quad m=0$



$2s \quad m=0$



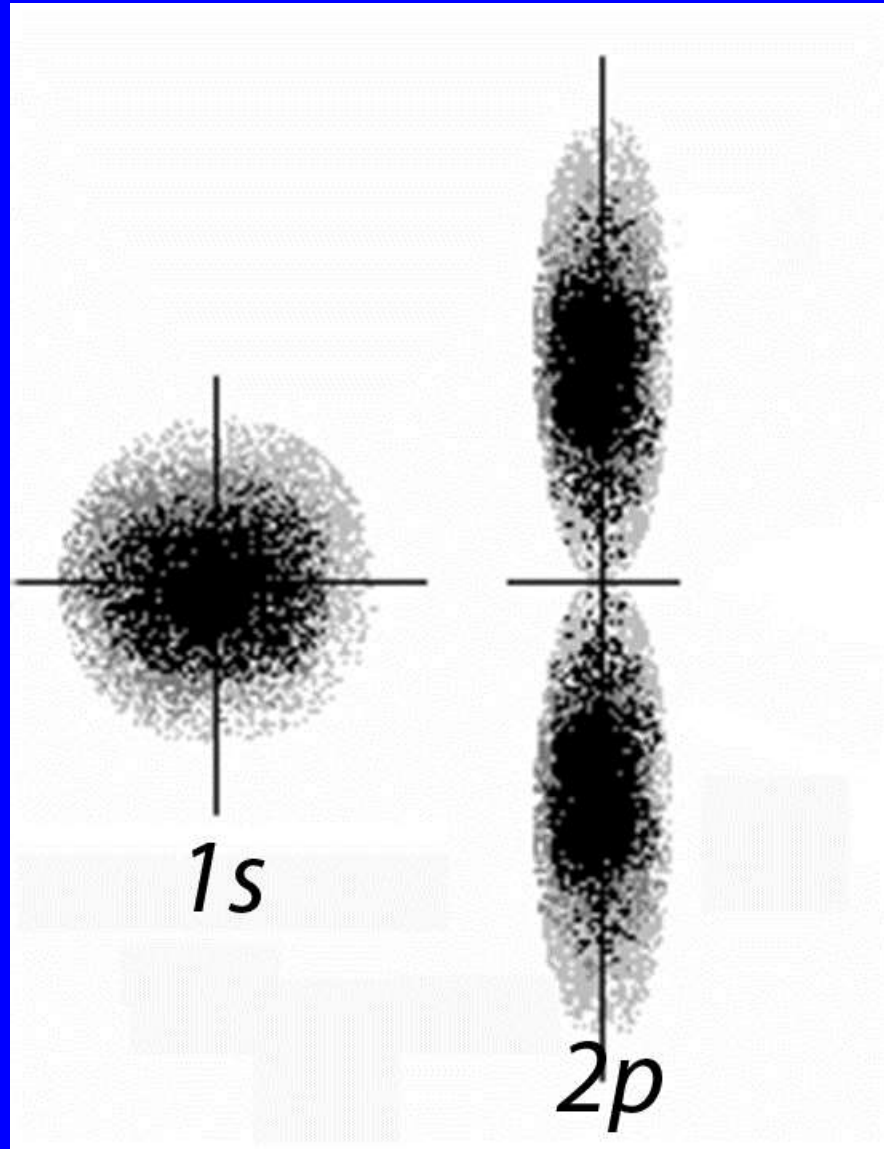
$2p \quad m=0$



$2p \quad m=1$



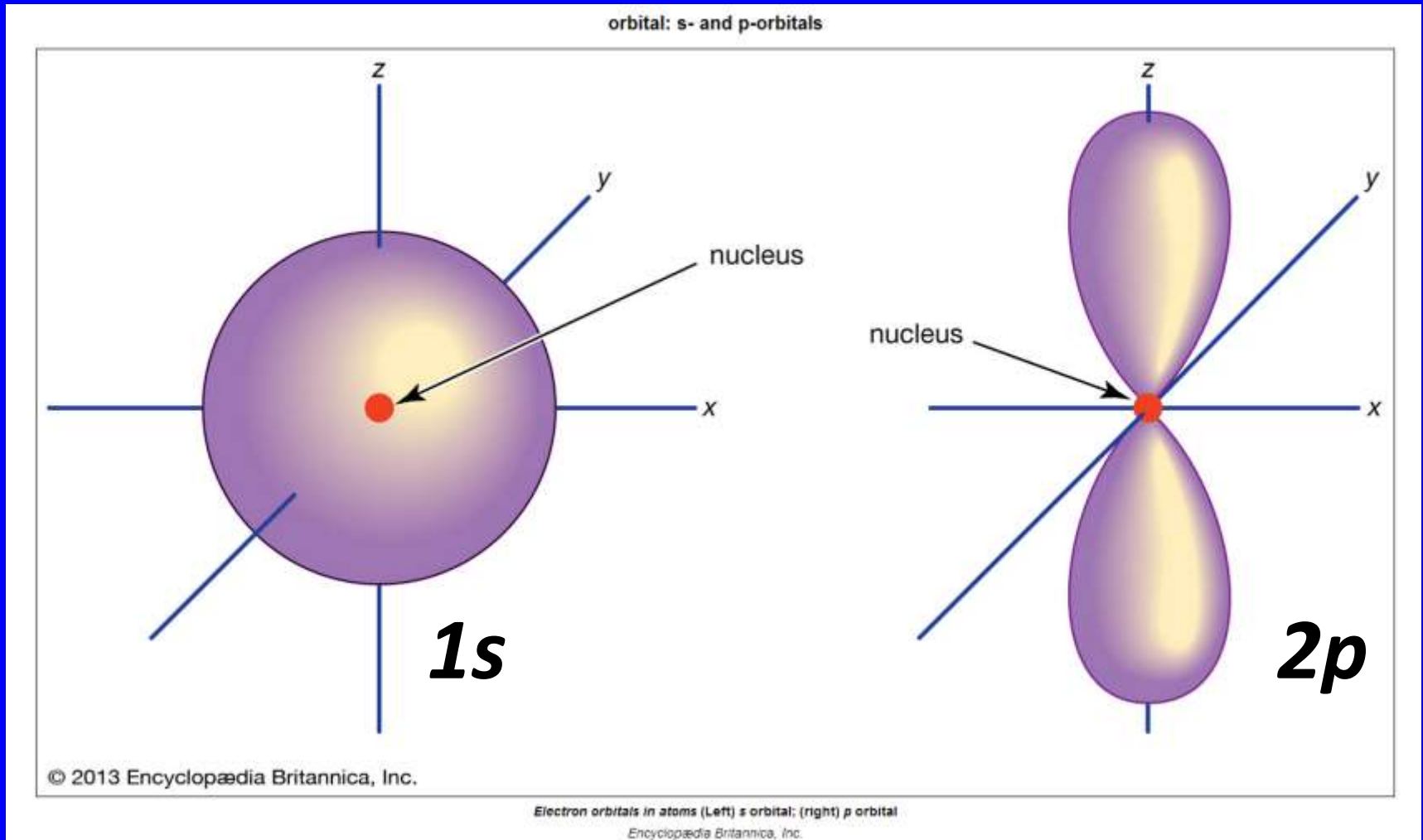
Orbitals of the hydrogen atom



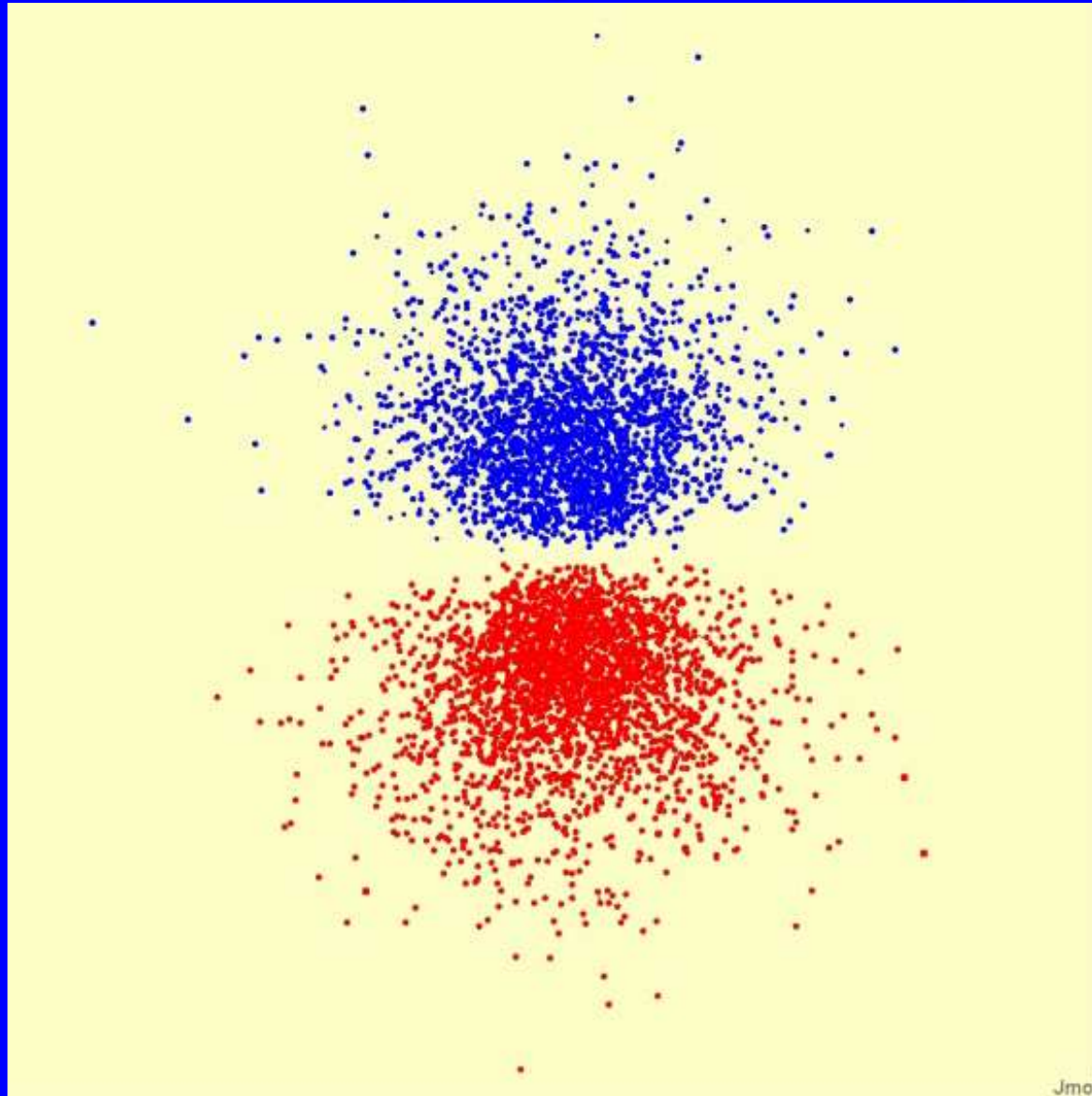
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Orbitals of the hydrogen atom.

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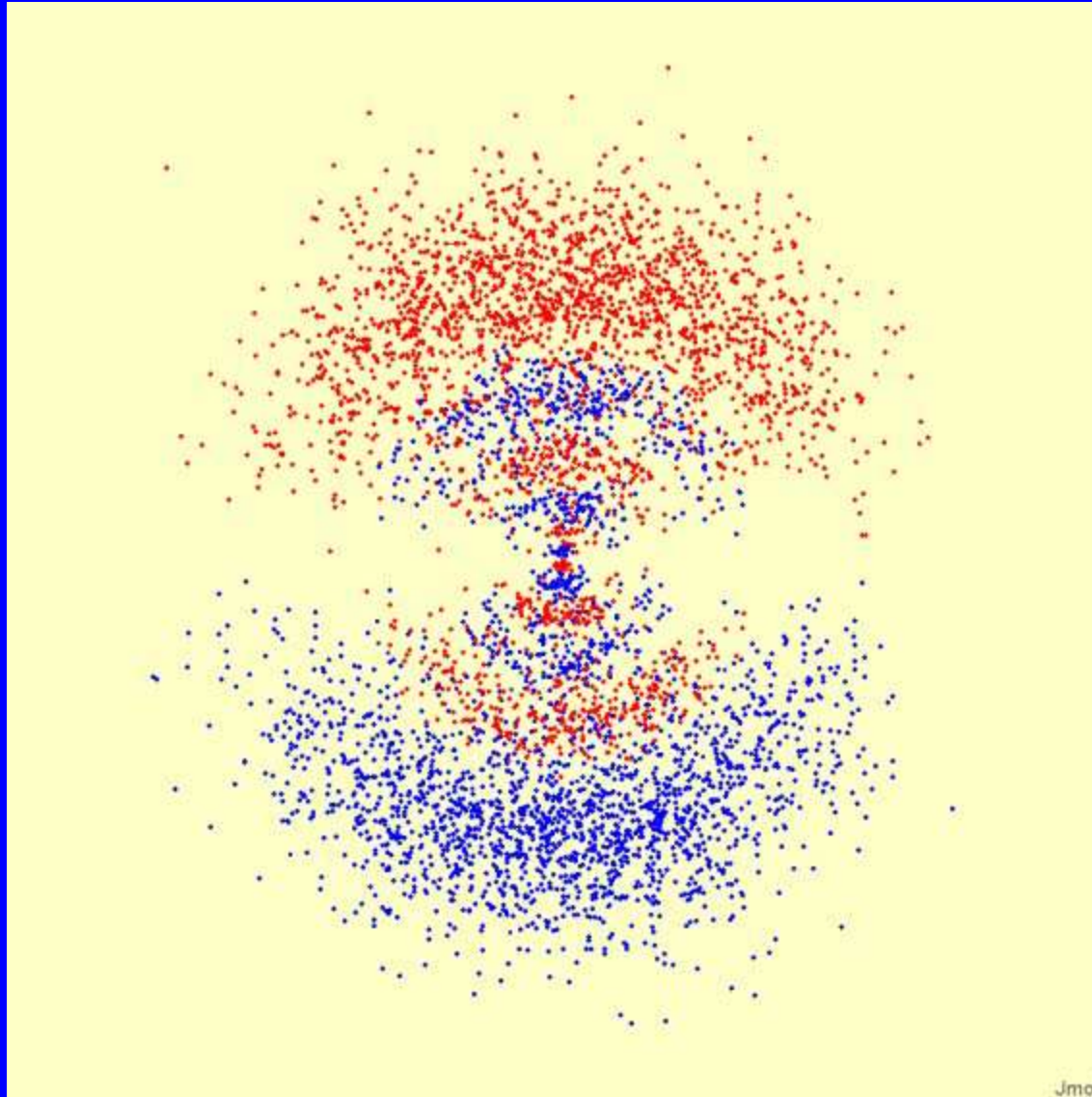


$2p$ orbital of the hydrogen atom by Dr. Winter



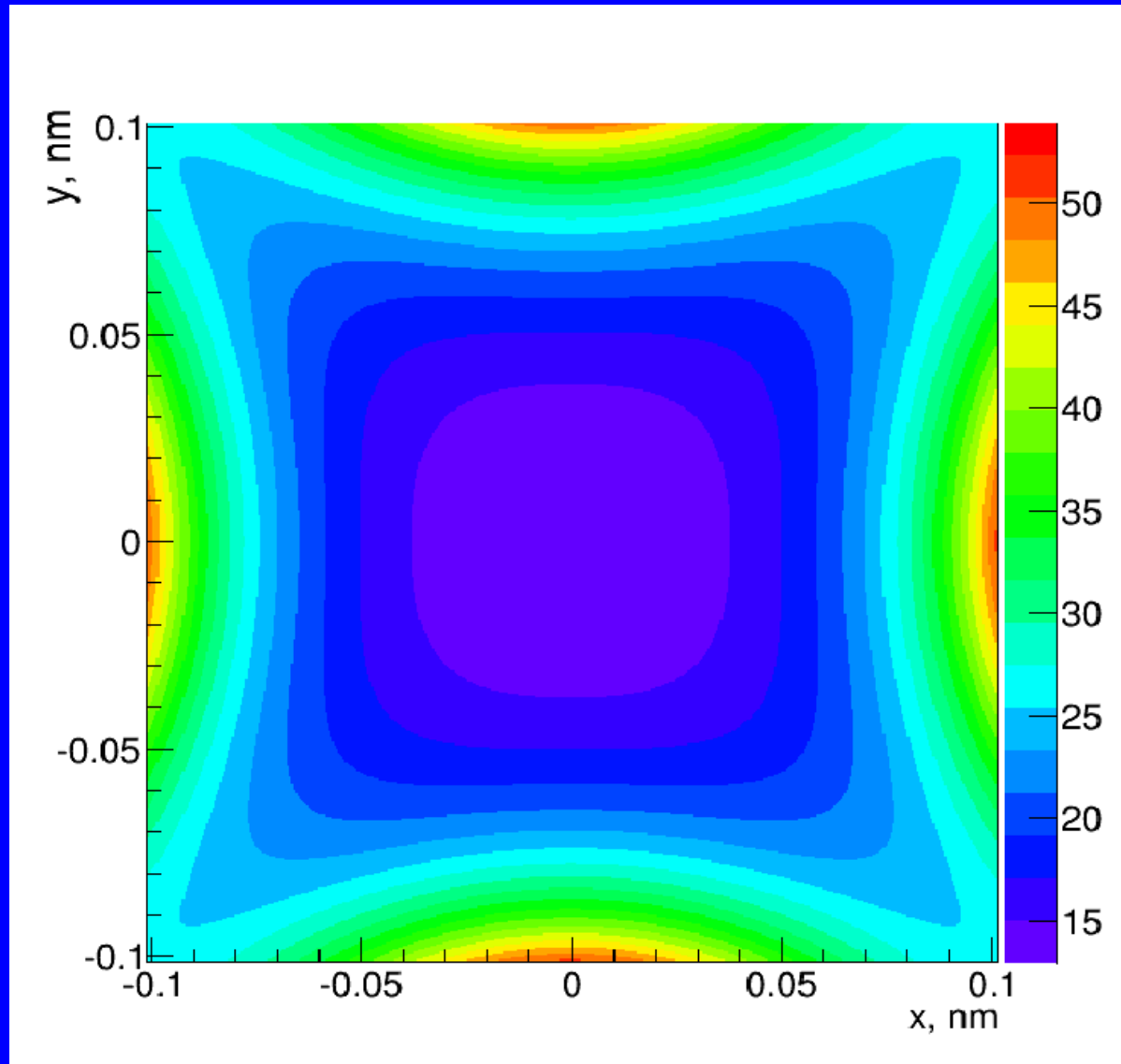
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7p orbital of the hydrogen atom by Dr. Winter



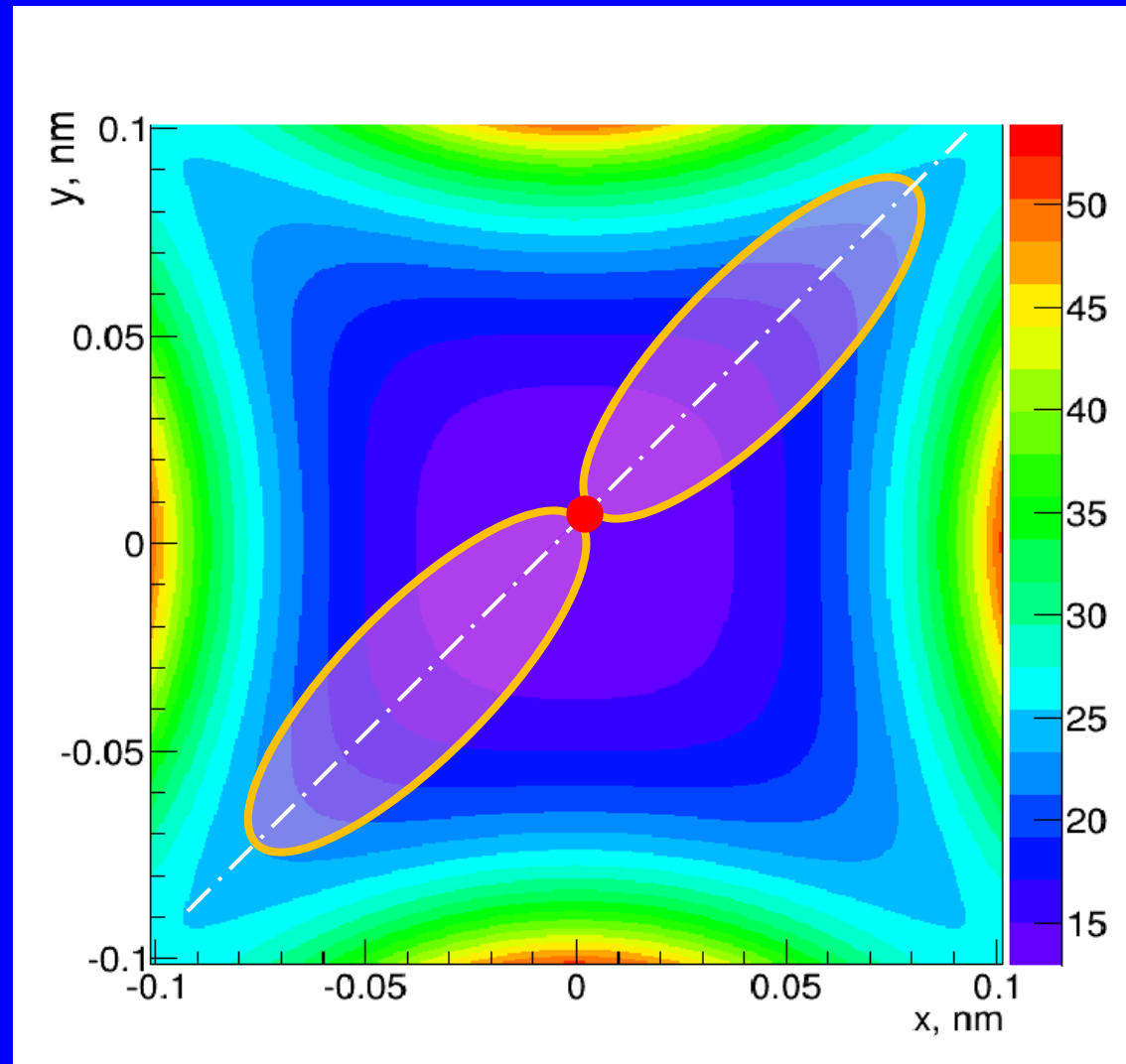
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Structure of octahedral niche in platinum crystal.



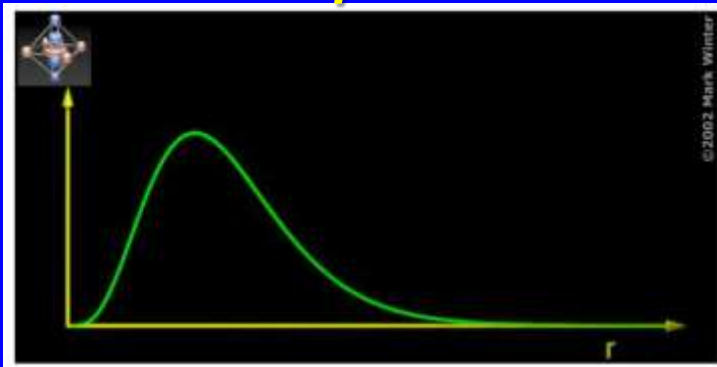
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Octahedral platinum crystal niche filled with a deuterium atom in $2p$ -state

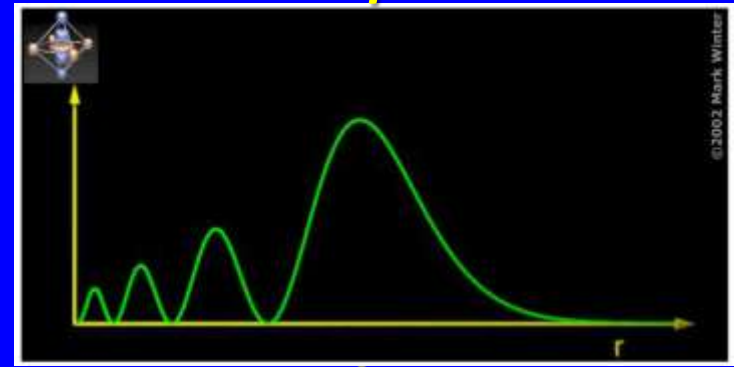


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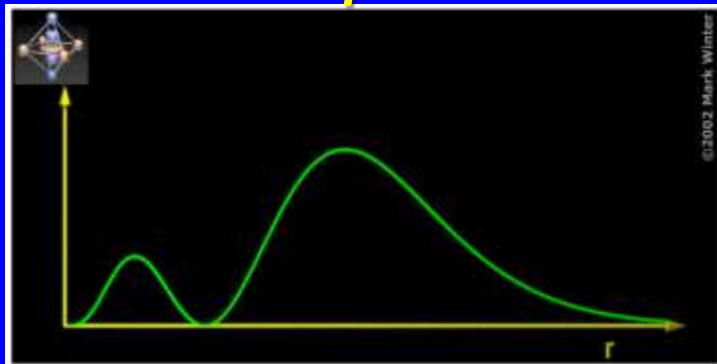
2p



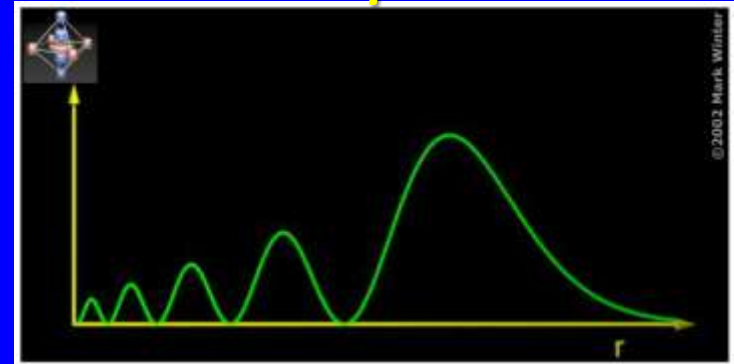
5p



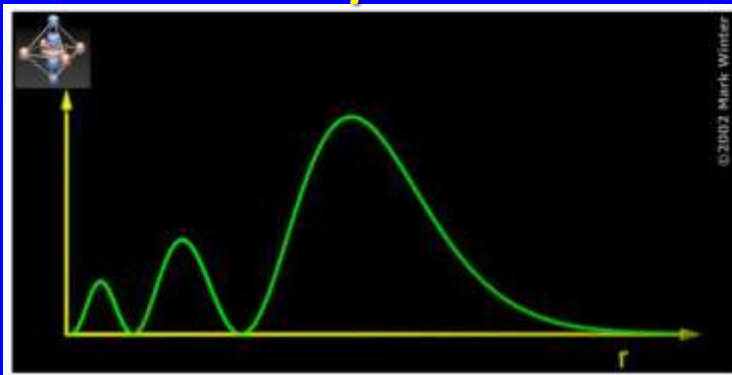
3p



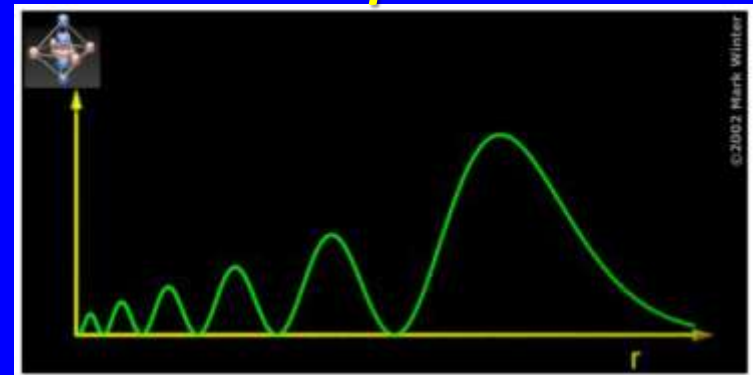
6p



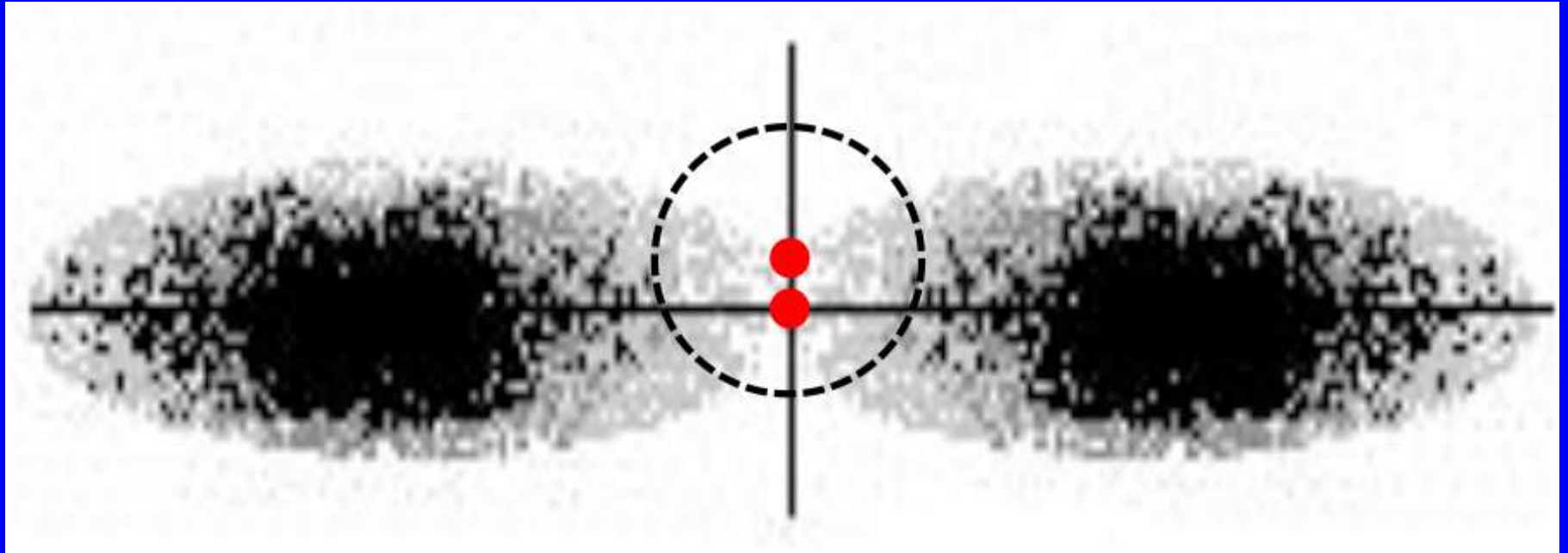
4p



7p

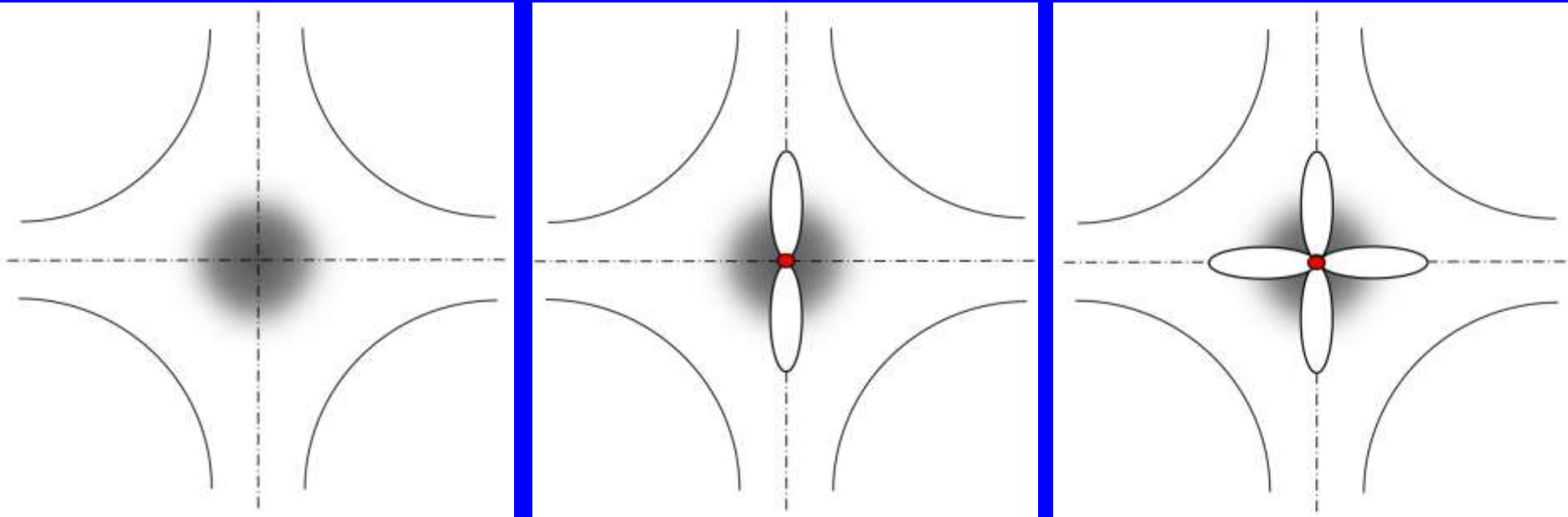


The case when two atoms of deuterium in $2p$ -state are located in the same octahedral niche of conducting crystal.

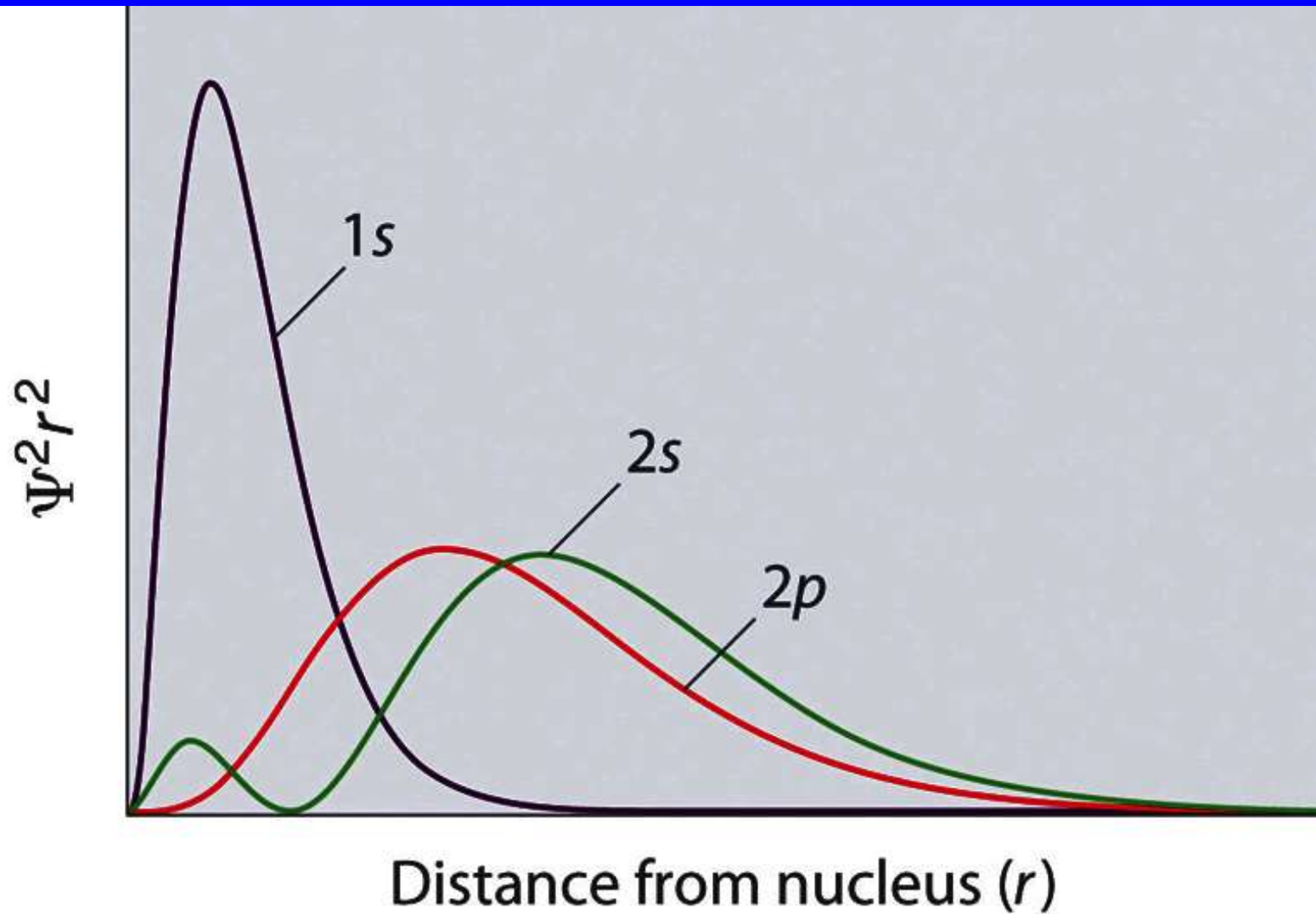


The situation is quite similar to the process of μ -catalysis

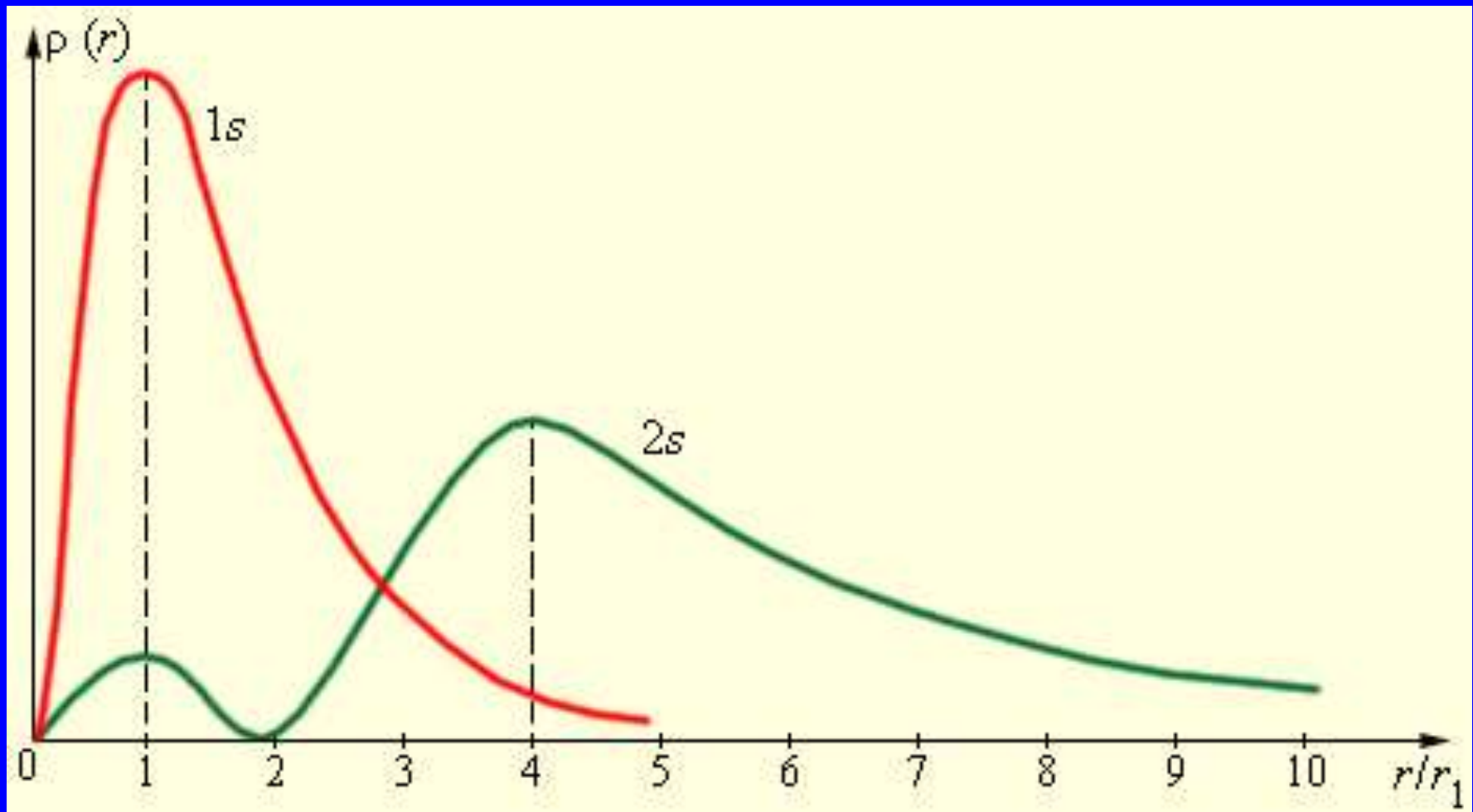
Crystal cells of conductor. The simple cubic structure is used as a didactic example. The shaded area shows the location of free electrons. Free electrons of conducting crystal are unwilling to vacate their positions completely, and the deuterium atom is transferred from $1s$ -state to $2p$ -state or higher.



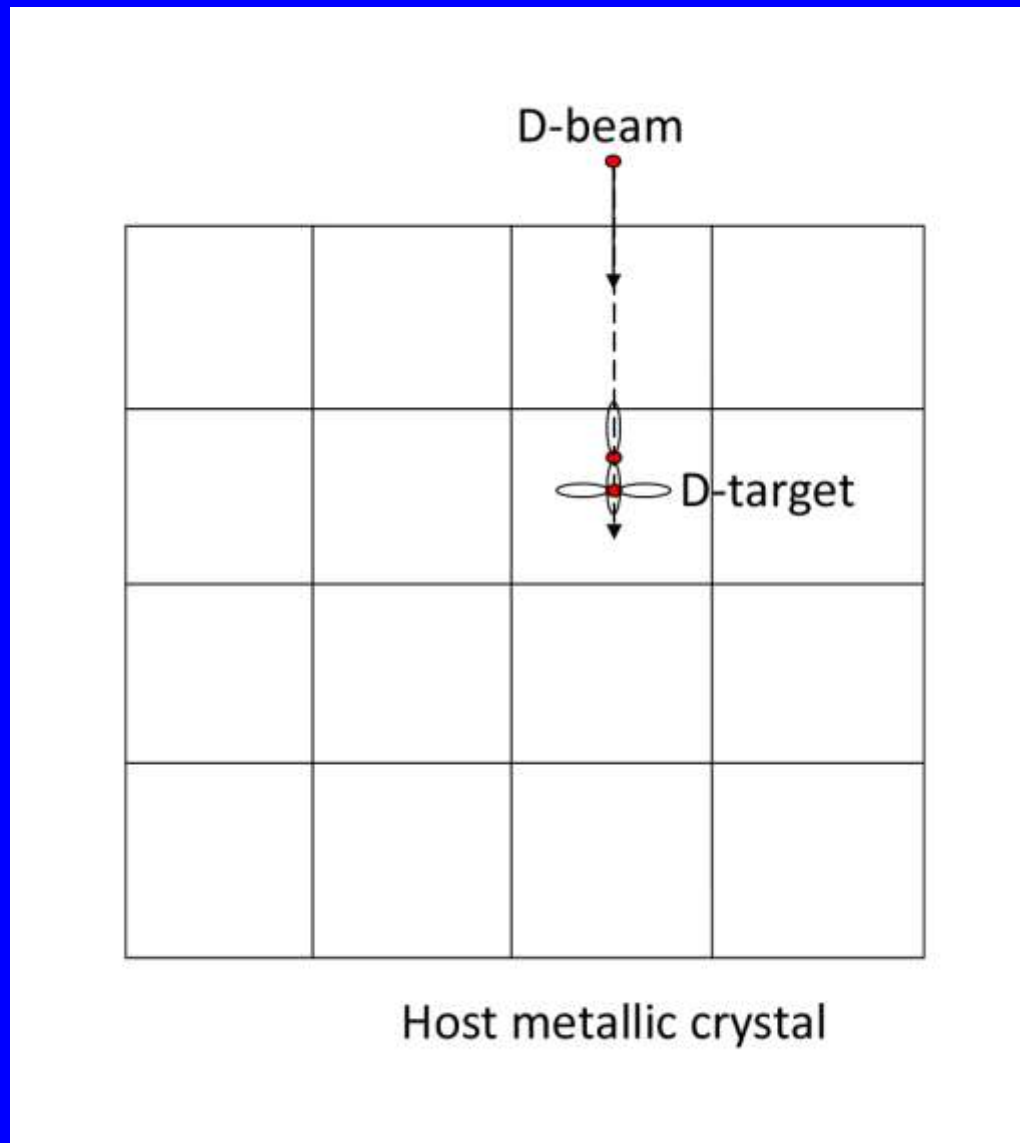
1s, 2s and 2p orbitals of hydrogen atoms



1s and 2s orbitals of hydrogen atom

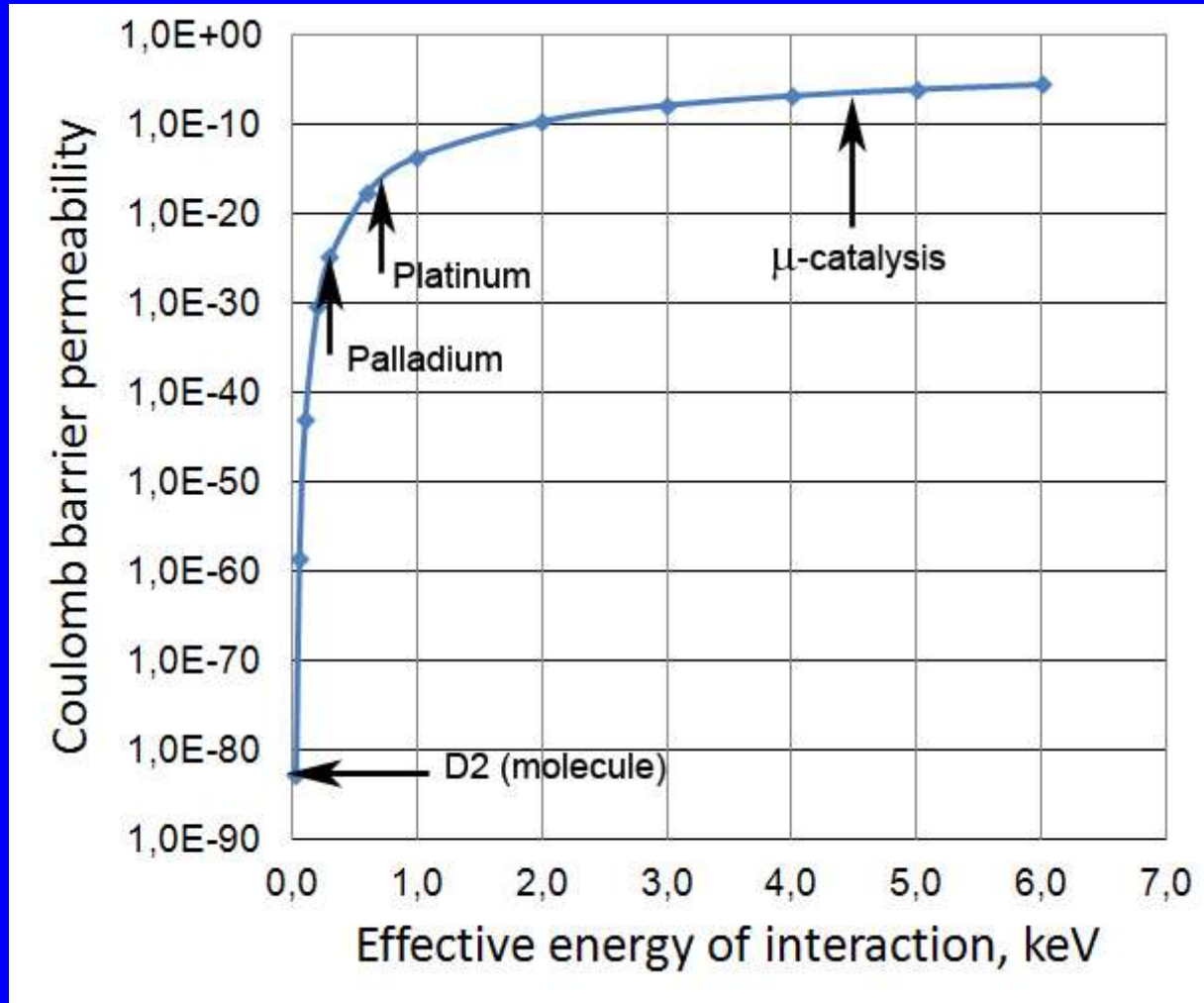


Accelerator experiments



Coulomb barrier permeability for DD fusion:

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



For cold fusion,
 $E \cong 0.040 \text{ eV}$

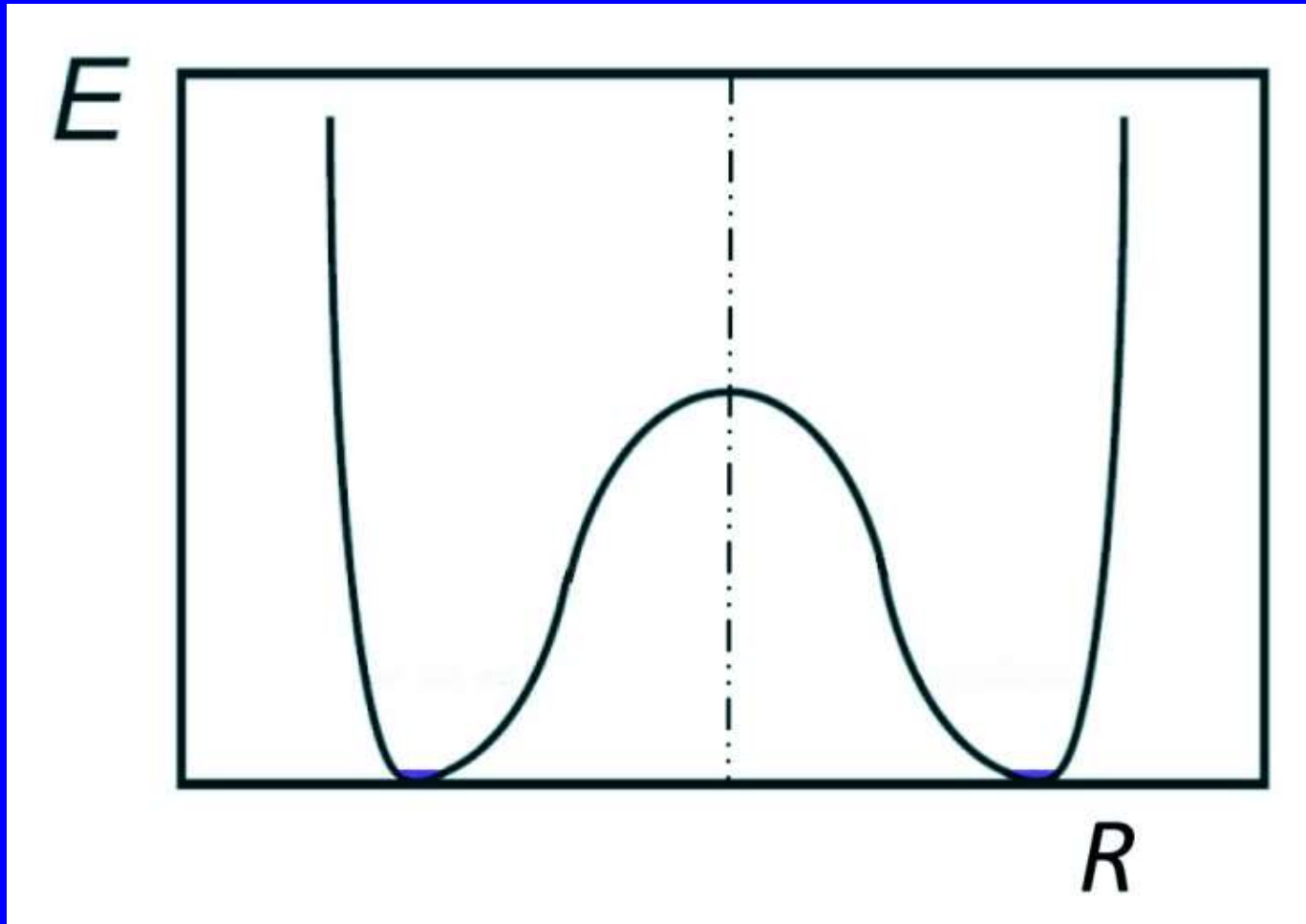
$\text{Pt}/\text{D}_2 \cong 10^{65}$ ★

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 $^4\text{He}^*$.

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.



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*.

However, “*Statistical principle of correlation weakening with distance*” (N. N. Bogolubov, Selected works on statistical physics, M., 1979) may be working for neutrons.

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.

First publication

ISSN 1063-7788, *Physics of Atomic Nuclei*, 2012, Vol. 75, No. 2, pp. 153–159. © Pleiades Publishing, Ltd., 2012.
Original Russian Text © E.N. Tsyganov, 2012, published in *Yadernaya Fizika*, 2012, Vol. 75, No. 2, pp. 174–180.

NUCLEI Experiment

Cold Nuclear Fusion*

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University of Texas Southwestern Medical Center at Dallas, Texas, USA

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.

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Rate of DD-fusion in the crystalline cell

Crystal type	Screening potential, eV	Oscillation frequency ν , s ⁻¹	Barrier permeability $e^{-2\pi\eta}$	Rate of DD fusion 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

E.N. Tsyganov, *Physics of Atomic Nuclei*, 2012, Vol. 75, No. 2, pp. 153–159.


Э.Н. Цыганов, *ЯДЕРНАЯ ФИЗИКА*, 2012, том 75, № 2, с. 174–180.

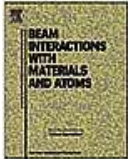
In our recent articles, we discuss the possibility of experimental detection of the “cold” DD-fusion process using low-energy electrons, which are the result of the fusion reaction of two deuterons in palladium crystals at very low (thermal) excitation energies of the compound nucleus $^4\text{He}^*$.


Author's personal copy

Nuclear Instruments and Methods in Physics Research B 309 (2013) 95–104

Contents lists available at SciVerse ScienceDirect

 Nuclear Instruments and Methods in Physics Research B
journal homepage: www.elsevier.com/locate/nimb



Registration of energy discharge in $\text{D} + \text{D} \rightarrow ^4\text{He}^*$ reaction in conducting crystals (simulation of experiment) 

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ARTICLE INFO

Article history:
Received 30 November 2012
Received in revised form 29 December 2012
Accepted 12 January 2013
Available online 3 April 2013

ABSTRACT

The experiment on registration of low-energy electrons which occur after the fusion reaction of two deuterons in the palladium crystal at very low excitation energies was modeled using Monte Carlo simulations.

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Engineering Physics 2013

**УЧРЕДИТЕЛЬ
И ИЗДАТЕЛЬ ЖУРНАЛА:**

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Журнал зарегистрирован в Федеральной службе по надзору в сфере связи, информационных технологий и массовых коммуникаций (Роскомнадзор). Свидетельство о регистрации средства массовой информации ПИ № ФС77-37278.

Подписной индекс в каталоге

ОАО «Роспечать» 79217

«Пресса России» 34117

Сайт издательства: www.tgizd.ru

Главный редактор:

Рухадзе А.А.

д-р физ.-мат. наук, проф., заслуженный
деятель науки Российской Федерации

Зам. гл. редактора:

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Редакция:

Боброва Е.А., Гончарова В.Б.,

Морозова Т.Ю., Чистякова М.А.

Инженерная физика

№ 9

2013

ISSN: 2072-9995

НАУЧНО-ТЕХНИЧЕСКИЙ ЖУРНАЛ

СОДЕРЖАНИЕ

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Цыганов Э.Н., Бавижев М.Д., Головатюк В.М.,
Дабагов С.Б., Лобастов С.П.

Механизм выделения энергии в реакции $D+D \rightarrow {}^4\text{He}^*$

в проводящих кристаллах (моделирование эксперимента) 3

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Гаврилов Н.М., д-р физ.-мат. наук, проф.;
Галченко Ю.П., д-р техн. наук;
Шербаков Н.С., д-р техн. наук, проф.,
заслуженный деятель науки РФ

Редакция:

Боброва Е.А., Гончарова В.Б.,
Чистякова М.А.

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№ 6
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E. N. TSYGANOV

Doctor of Phys.-Math. Sciences, Professor, President

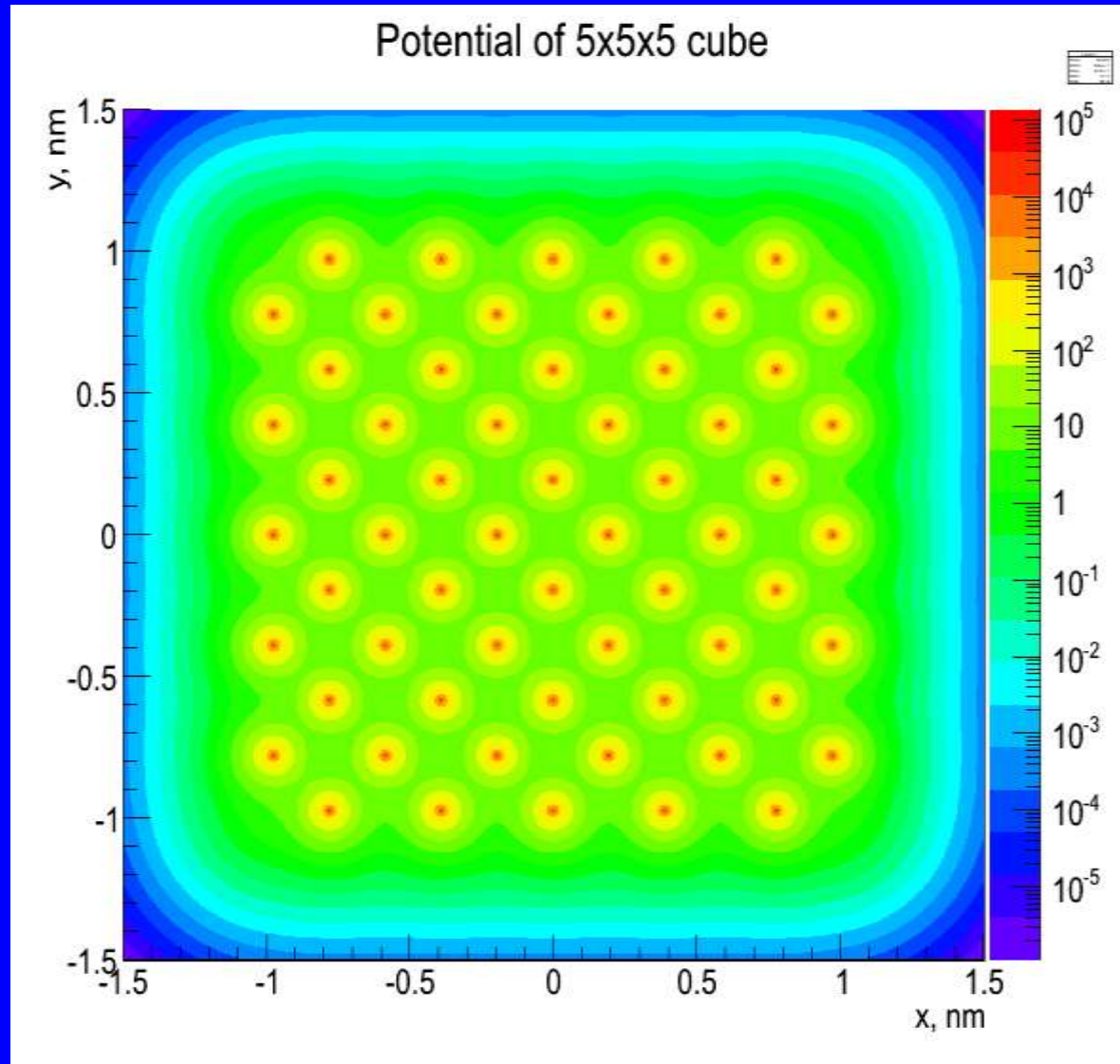
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*Cold Fusion Power, International
USA*

DD FUSION IN CONDUCTING CRYSTALS

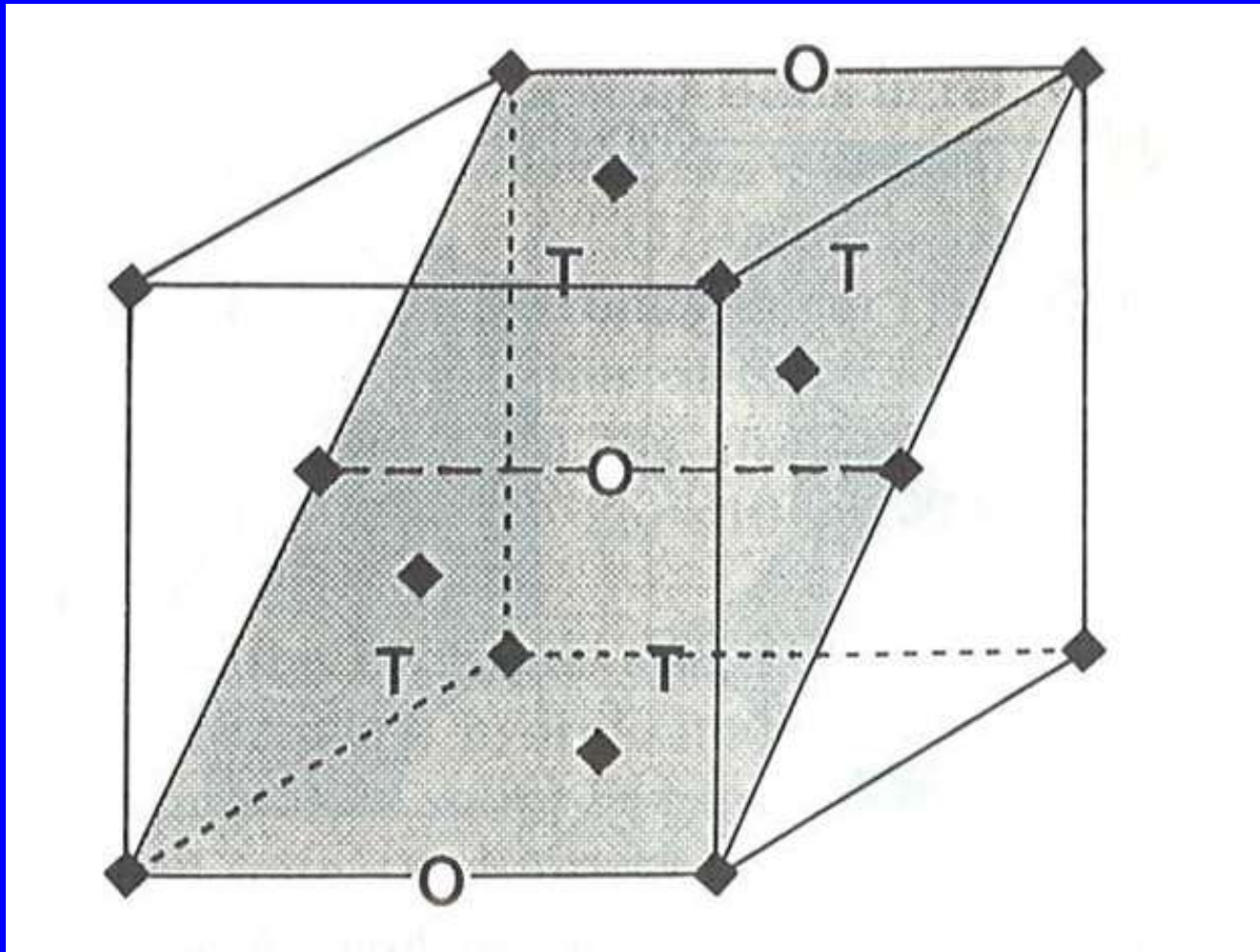
The paper presents a brief background on cold fusion leading to a discussion on some aspects of atomic physics. We are explaining the selection of the only permitted orbitals of deuterium atoms in conducting crystals when saturated with deuterium. Conduction electrons in metallic crystal are grouped 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 $DD \rightarrow {}^4\text{He}^$. 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 $5 \times 5 \times 5$ cells in the platinum crystal

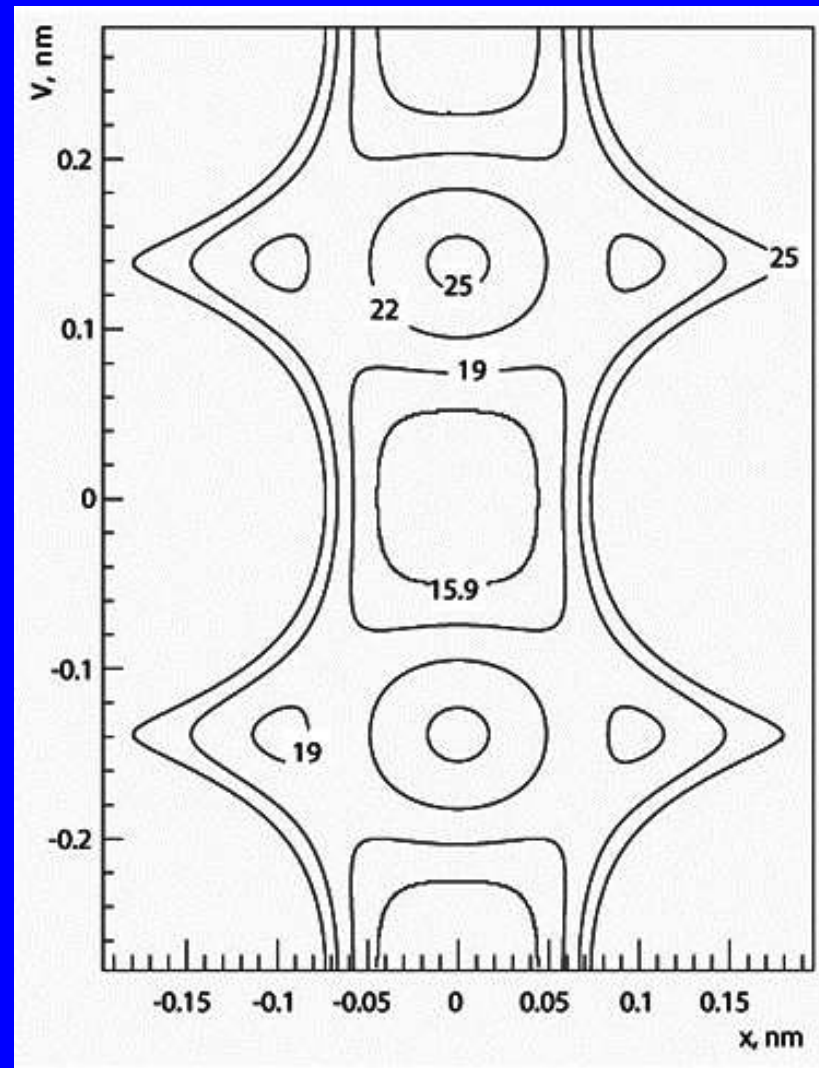


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Diagonal X-V plane of fcc crystals. Signs O marks octahedral vacancies; signs T - tetrahedral ones.



Potential contours in the diagonal X - V plane for platinum.



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Potential in the vicinity of the center of octahedral niche of platinum crystal cell along the V -direction.

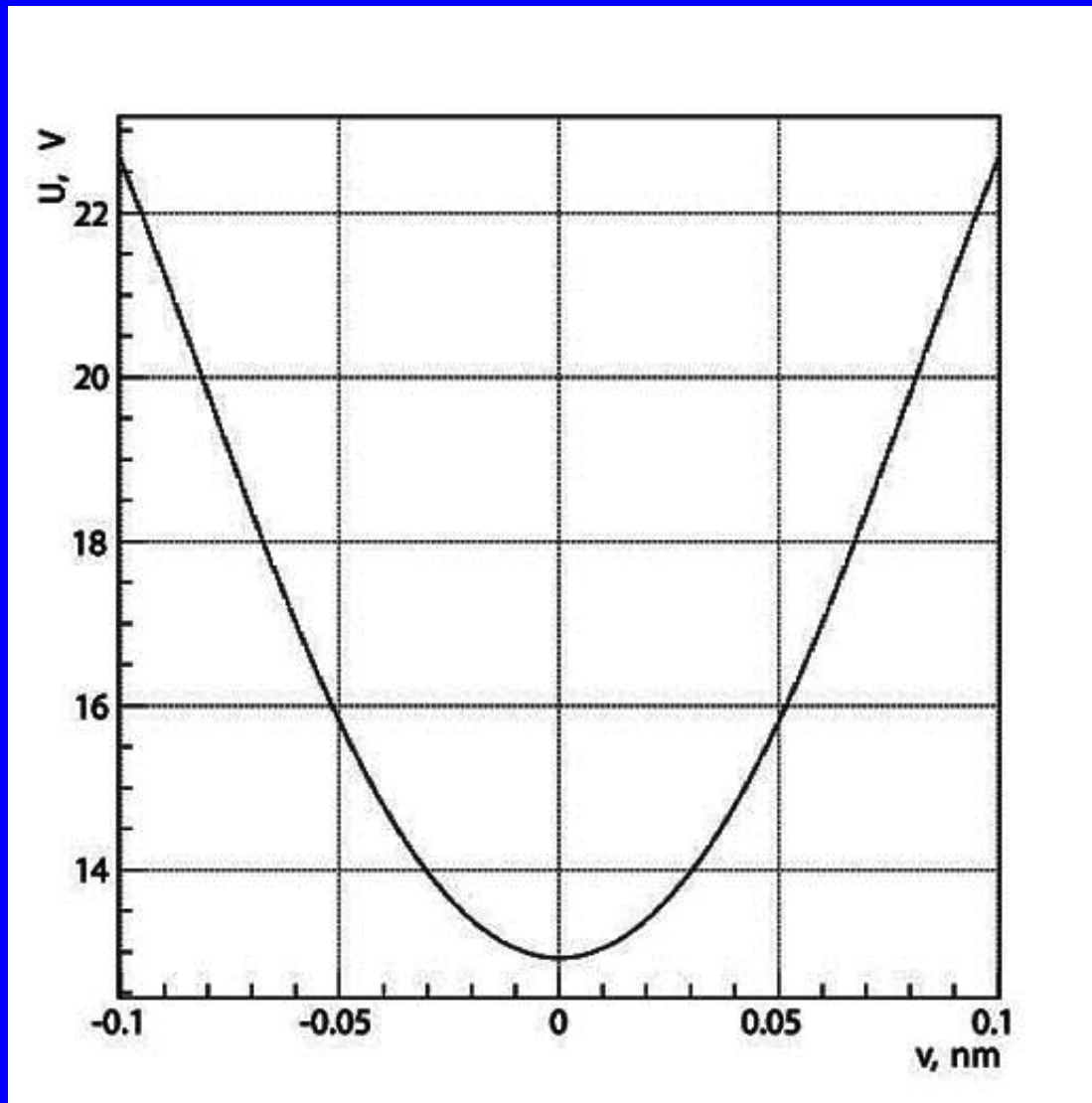
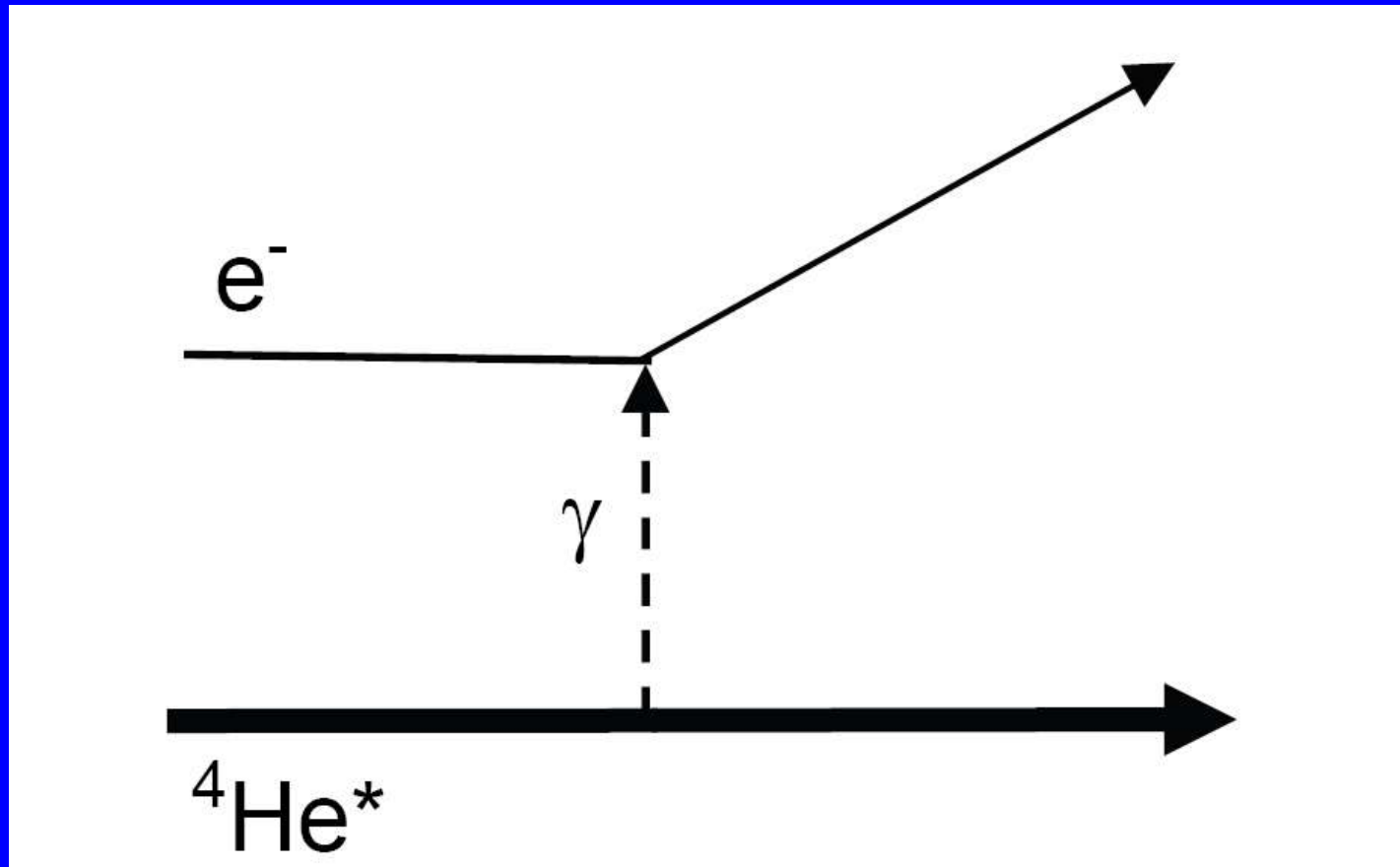
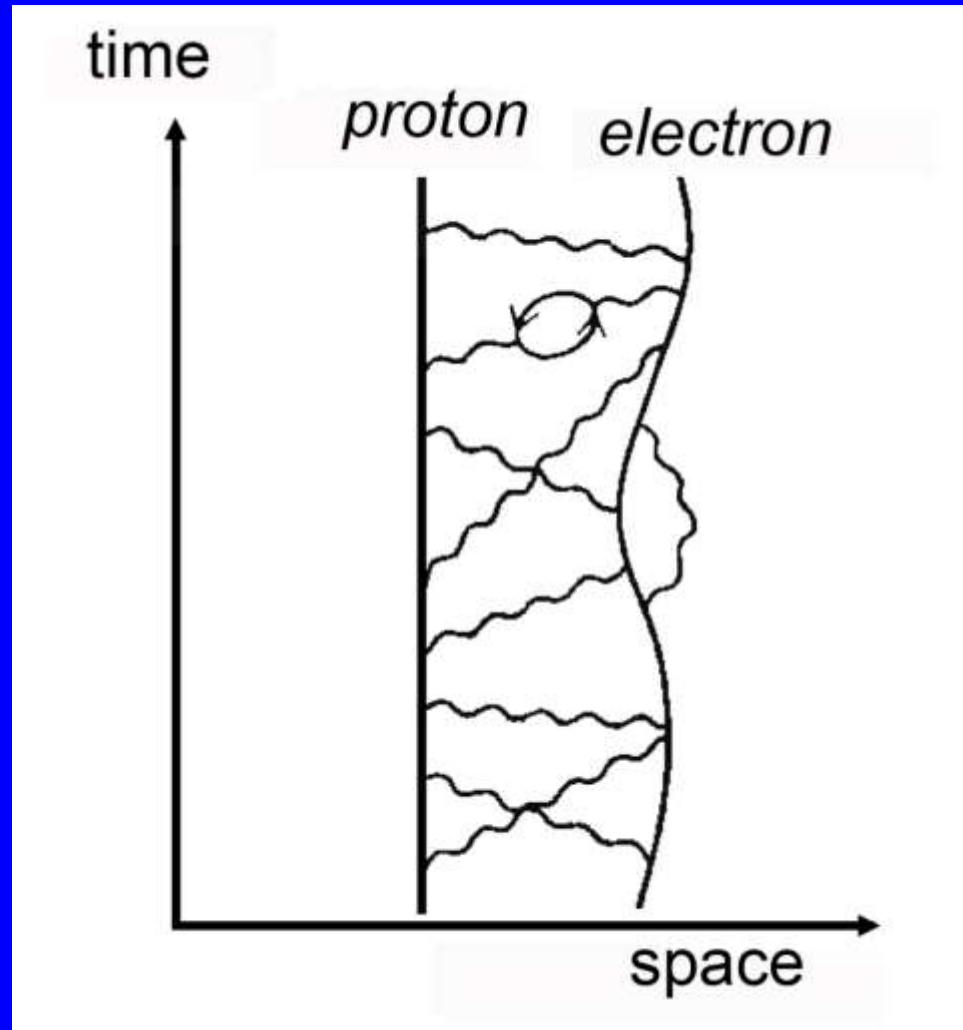


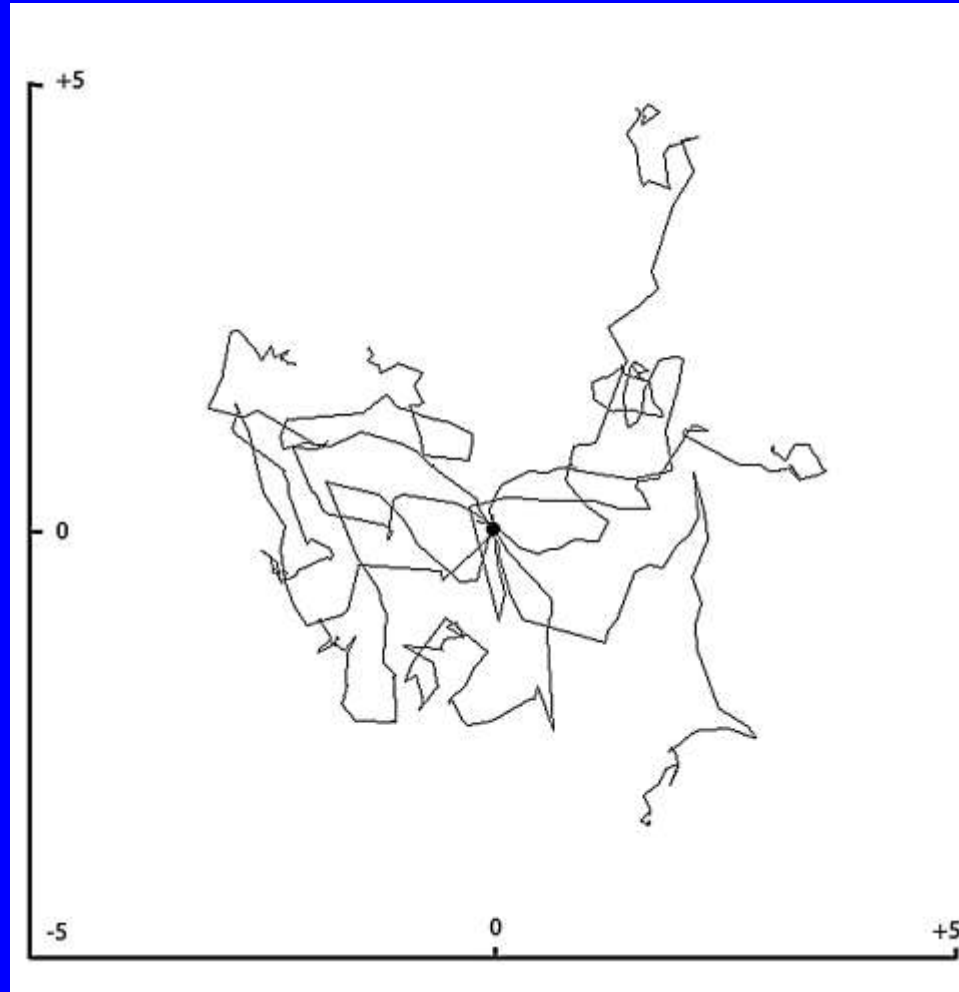
Diagram of the process, providing “thermalization” of DD fusion with the formation of $^4\text{He}^*$ in conducting crystals. In order for this process to work, the existence of a metastable state of $^4\text{He}^*$ is necessary.



Virtual photons in the hydrogen atom (Richard Feynman)

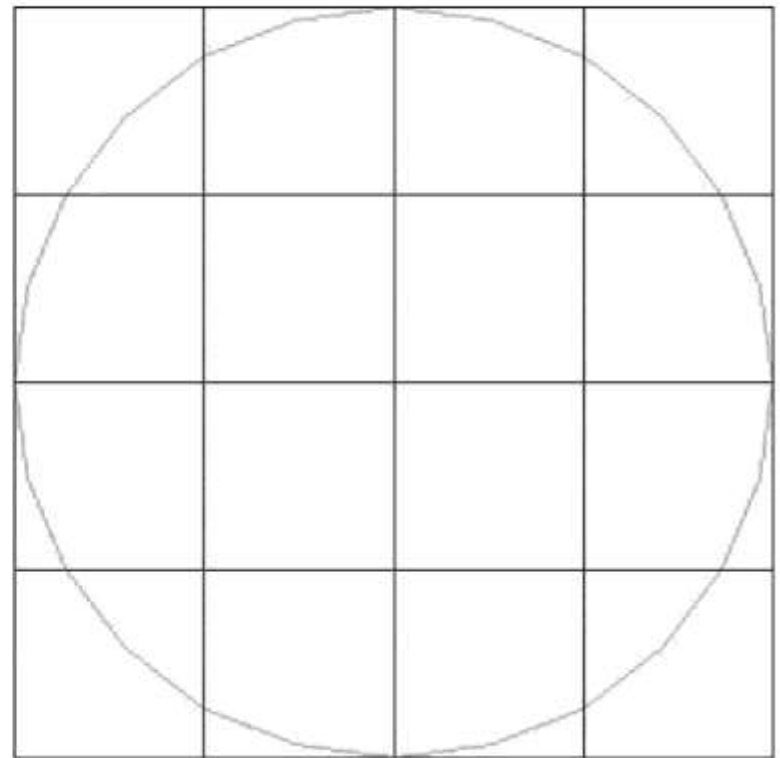
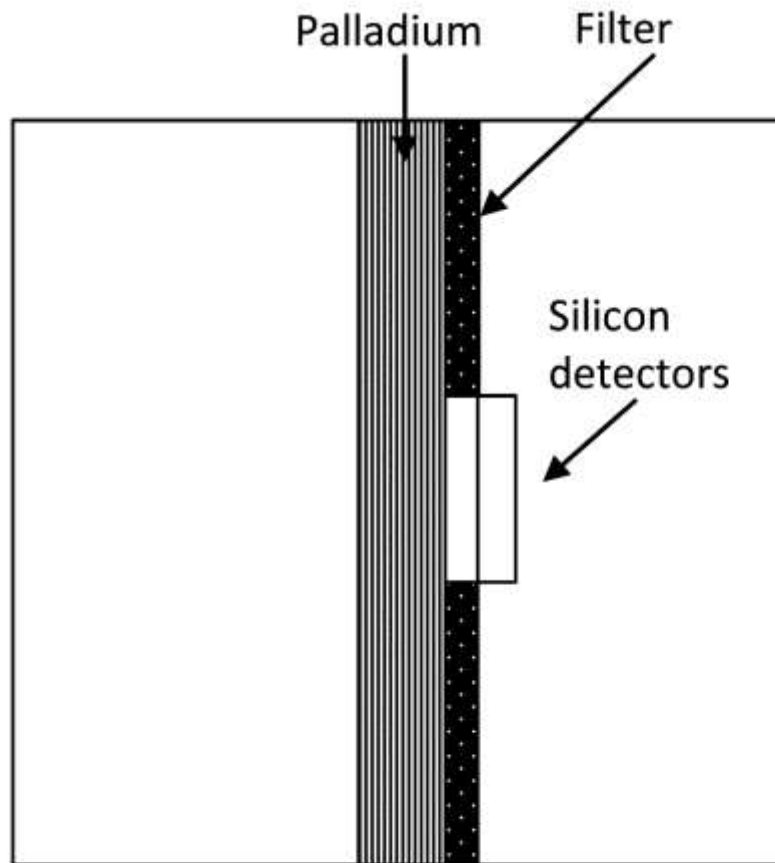


**The trajectories of electrons (Monte Carlo) generated
in the process of DD cold fusion in palladium.
Dimensions are in micrometers.**

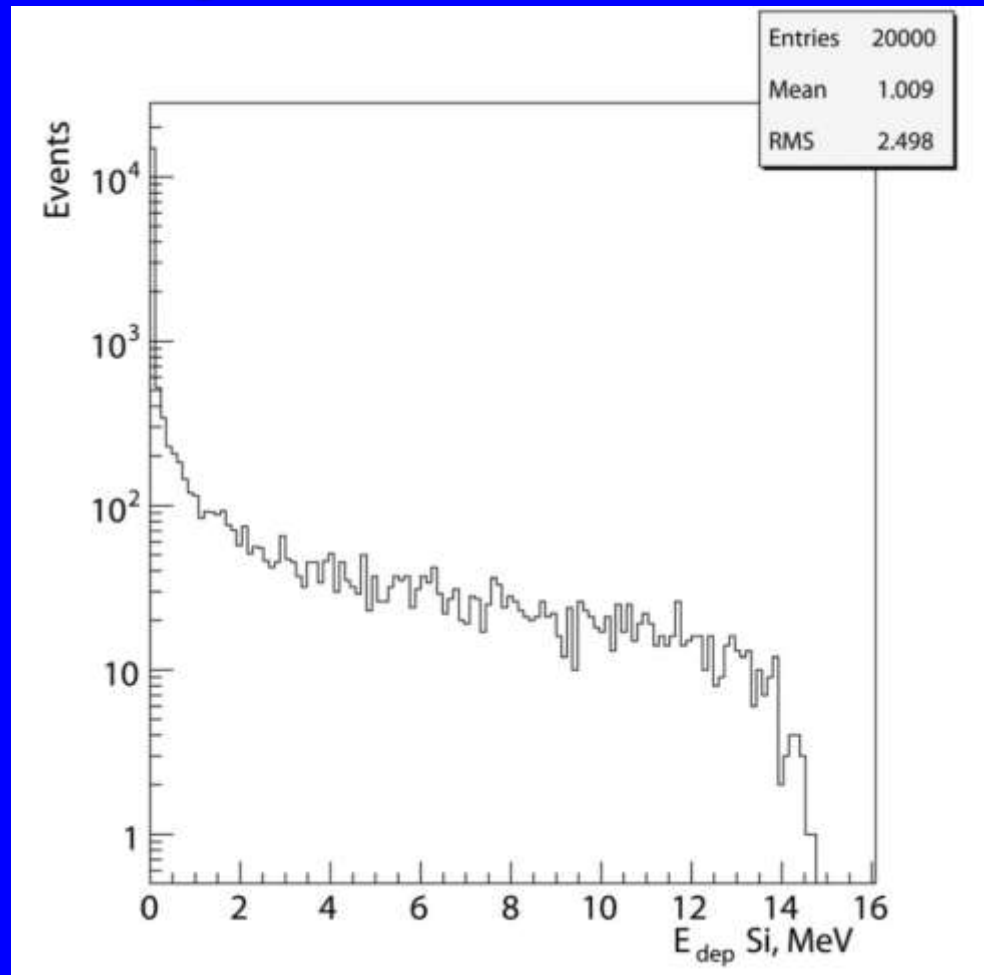


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One-side scheme of the experiment. Several silicon detectors are placed on the same side of the palladium foil and included in coincidence. Left — side view, right — the relative positions of the aperture and detectors.



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.



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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.

Conclusion - 2

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.

LPHE, November 15, 2012




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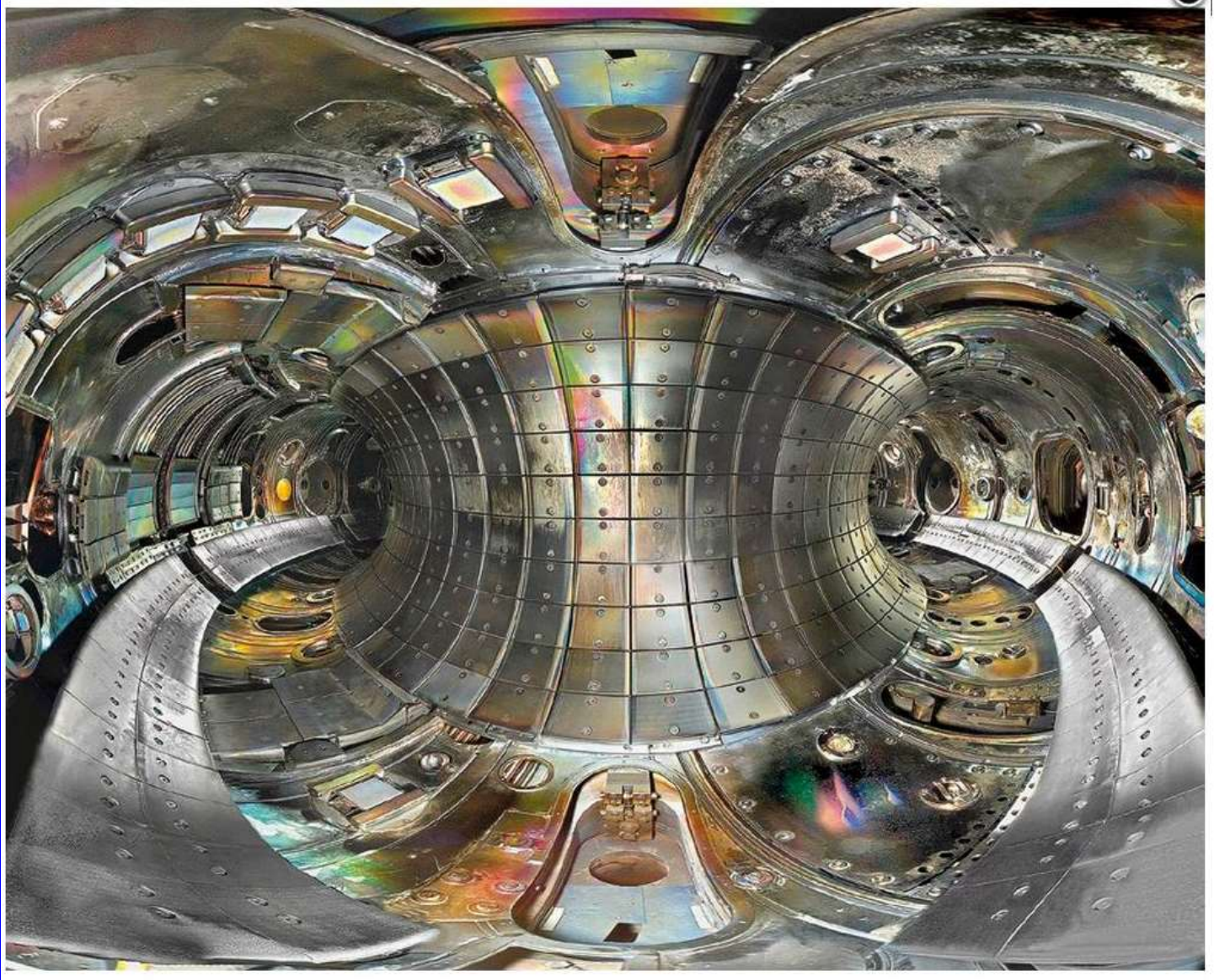
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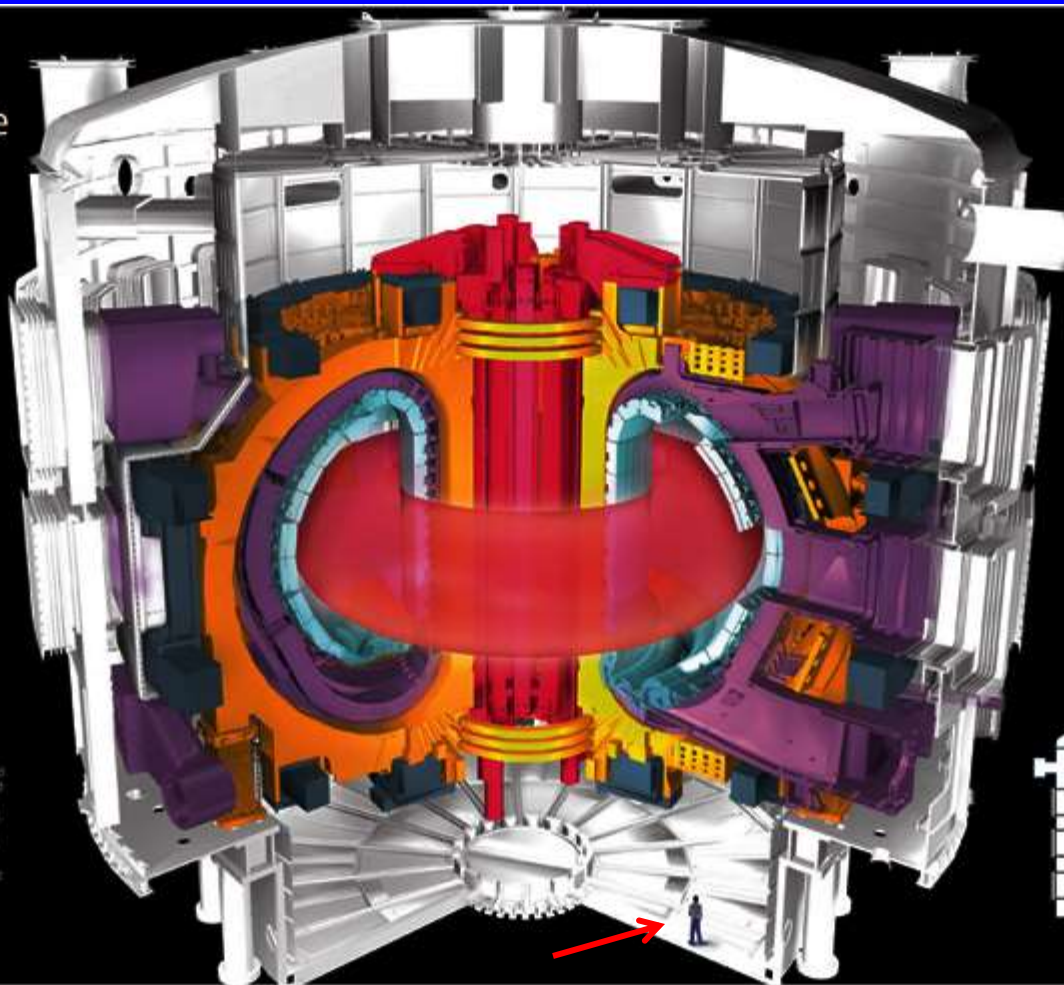


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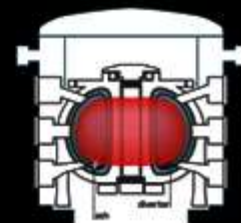
ITER project

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.



1 Puffs of deuterium and tritium gas are injected into the doughnut-shaped vacuum vessel, called a tokamak. The gas weighs less than a postage stamp and fills a volume one-third that of an Olympic swimming pool.



6 Fusion produces high-energy neutrons and helium particles that deposit their energy into the plasma and keep it hot, before becoming "ash". The "ash" is eventually forced out through the divertor.

of the total transported by the local vendor.

Fusion reactors are predicted to be 100 times lower in the regulatory level.

Fusion reactors produce a low long-lived waste; low-level radioactive waste will result from the activation of some of the machine's components. All waste materials will be treated, packaged and stored on site.

In all, "protection of rare species will benefit from research on the 180-400 km ITF zone," two areas have been fenced off to protect the birds. The ITF zone is a 100 km long butterfly woodland habitat strip and rare species.

Of the 2.5 million cubic meters of earth and rock moved to level the ITF platform, over two-thirds were reused on the

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This journal was produced with the support of ITER Domestic Agencies (CNET, ITER-Russia, ITER-India, the European Joint Undertaking Fusion for Energy (FusionEU) and the Fusion Research and Development Directorate, Japan Atomic Energy Agency).

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Joint Institute For Nuclear Research
Bogoliubov Laboratory of Theoretical Physics
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