Featured Paper

Preparata Medal Lecture - A Tribute to Giuliano Preparata, a TRUE Pioneer in Cold Fusion Theory

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ABSTRACT

Anyone who attended an ICCF meeting before 2000 has a vivid memory of the brilliant and fiery theoretical physicist, Giuliano Preparata. He provided new insight into the deep mysteries of cold fusion, and greatly enlivened the meetings with his pointed comments and heated debates. My own discussions with him usually concerned my concepts for thin-film electrolysis. I recall encountering him after one of his ICCF talks and questioning one of his conclusions. Giuliano snapped back – “George, you haven’t read Chapter 8 of my book!! Read it before you talk to me again!” I responded that I had read it but still didn’t understand!! Giuliano took pity on me and just laughed (As others knowing him will recognize, this was a “mild” response). His book, QED Coherence in Matter, is a gem; it provides a view into Giuliano’s unique approach to the coherence of matter and to cold fusion (the “famous” Chapter 8). It is not easy reading; so, I subsequently put his book in the front of my bookcase to read whenever I had time. When I sadly learned of his untimely passing, I pulled his book out and stared at the cover, then moved to the dedication page where Giuliano credits his father for teaching him the meaning of “honour and honesty”. His father must have been proud since Giuliano learned the lesson well. The community lost a leading light that day. This lecture includes some recollections of Giuliano’s participation and interactions in ICCF meetings. In addition, the historical steps in the development of his QED coherence theory are briefly outlined.

Introduction

Giuliano was born in Padova, Italy in 1942. After receiving his Ph.D. in 1964, he became immersed in strong interaction physics theory. In 1967, he joined Princeton University and after several positions, ended up in 1970 as Associate Professor at NYU. From 1980 until his death, he was the Chair Person of High Energy Nuclear Physics at Milan University.

In the early days of cold fusion, Giuliano joined the activities of the National Cold Fusion Institute in Salt Lake City. This experience initiated his interest in the physics of this exciting new field. His later cold fusion research was done at Milan University in
collaboration with the ENEA Fascati Laboratory where he played a key role in both theory and interpretation of cold fusion experiments. This work has a continuing impact on directions in cold fusion research worldwide.

In preparation for this lecture, I contacted a number of Giuliano’s close associates and colleagues and asked for any materials or thoughts they might be willing to provide to portray his life and accomplishments. A list of contributors is given in the acknowledgements section. For the most part I agreed not to associate names with the quotations or cite names of persons actually involved in specific episodes. With this understanding, quotes extracted from the contributed materials are incorporated freely throughout the lecture.

Giuliano did forefront research in theoretical physics, covering a wide range of topics from high energy to condensed matter physics. This amazing breadth of interests is evident from the following chronological listing of his activities taken from one of his own files.

Curriculum

1942  Nasce a Padova
1964  Si laurea summa cum laude in fisica teorica, relatore Raoul Gatto,
       All’Università di Roma
1964-65 Borsista CNR (I posto della graduatoria nazionale) all’Università di
       Firenze.
1965-67 Professore incaricato di Fisica dei Neutroni all’Università di Firenze.
1967-68 Research Associate alla Princeton University.
1968-69 Research fellow alla Harvard University.
1969  Libera docenza in Fisica Teorica.
1969-70 Assistant Professor alla Rockefeller University.
1970-72 Associate Professor alla New York University.
1972-74 Assistente di Fisica Superiore all’Università di Roma.
1974-80 Staff Member nella Theory Division del CERN di Ginevra.
1975  Vincitore del concorso a cattedra di Fisica Teorica.
1976-86 Straordinario-Ordinario di Fisica Teorica all’Università di Bari.
1986  Ordinario di Teoria delle Interazioni Subnucleari all’Università di Milano
His reputation rapidly spread throughout the physics community and in the nineteen eighties he has gained a reputation as a leader in the field of theoretical Quantum Electrodynamics (QED). Subsequently some viewed him as the new star of the younger generation of theoretical physics, destined to replace Richard Feynman. This aspect of his rising career is beautifully portrayed in the following poem by Tomek Ferbelski:

_Tomek Ferbelski ha dedicato questa poesia a Giuliano Preparata_

You are old, Father Feynman, Preparata declared, and you hair has turned visibly grey: and yet you keep tossing ideas around – At your age, a disgraceful display!

In my youth, said the master, as he shook his long locks, I took a great fancy to sketching: I drew many diagrams, which most thought profound while others thought just merely fetching.

Yes I know, said the youth, interrupting the sage, that you once were so awfully clever; but now is the time for quark sausage with chrome! Do you think you can last-on forever? In your words, my young fellow, the crone did retort, as his face turned perceptibly redder; in your words I detect an impatience, I’m sure, which makes me decidedly madder.

You are old, quoth the youth, in his accented speech, while eyeing the throne of the Master: Let me help you relinquish your sceptre next day. Or would you prefer that much faster?

No, thanks, Giuliano, the sage did rebuff. Enough of your own brand of sass: Do you think I can listen all day to such stuff? be off. Or I’ll kick-in your .....

Those who knew Giuliano will appreciate how well Tomek Ferbelski portrayed the spirit of the times.
Some Insights – Preparata’s “New” QED

Since QED theory was such a major part of Giuliano’s contribution to physics in general, and to cold fusion in specific, it is worthwhile to briefly review some of his thinking that lead to his “new” QED. The following brief note is abstracted from papers contributed by Emilio del Giudice, a close friend and collaborator of Giuliano’s.

- In 1916 Walter Nernst proposed that a complex body could emerge from its component atoms just when they become able to tune together their fluctuations, producing a common phase of oscillation that could be regarded as the "identity" of that complex object. Conventional forces, electrostatic or chemical, produce a further binding in the basic structure created by the tuning of quantum oscillations.

- This pioneering proposal was left unanswered for a long time, until, starting in the fifties, a sequence of theorists, from Robert Dicke to Klaus Hepp and Elliott Lieb, to Herbert Fröhlich worked on revisions. Finally in the eighties Giuliano combined and extended these contributions to work out a new vision of the dynamics of the transition from gaseous matter. This theory explains how an ensemble of basically independent particles can become coherent to form condensed matter (liquids and solids).

- The essential result of Giuliano’s theory can be stated as follows. An ensemble of a very large number N of particles can assume two different configurations and are coupled with the E.M. field (as every particle made up of charged components, for instance atoms and molecules, does). This configuration then enters a coherent state when its density exceeds a threshold while its temperature lies below a critical value. This coherent state has energy lower than the original gas-like state. In this coherent state the particles oscillate between the two configurations in unison and in tune with an E.M. field arising from the vacuum fluctuations trapped within the assembly of coresonating particles. This coherent regime of both matter and E.M. fields holds within a region of space whose size is the wavelength of the E.M. oscillations; this region is called the "coherence domain" (CD). Its size ranges from a fraction of a micron for liquids and metal electrons to some microns for solids to several tens of microns for ions in solution. The CD is then the sum of two mesoscopic components, a coherent fraction made up by a large number of CD’s and a gas-like non coherent fraction made up by particles filling the interstices among CD's. CD's are able to establish bounds among themselves through the tails (evanescent fields) of the quite intense E.M. fields that exist inside the domains. A large “cage” of the CD's develops. Inside this cage there is a definite phase and zero entropy, trapping a "gas" of non coherent particles to form the so-called “EDG” state.
Giuliano ultimately put many of his thoughts on QED together in a book, *QED Coherence in Matter*, published in 1995 by World Scientific Press. This book contains chapters on a range of applications of the new QED to leading physics problems – superconductivity, Ferromagnetism, thermodynamics of water, …, including the famous Chapter 8 on cold fusion, with the surprisingly modest title of “Towards a Theory of Cold Fusion Phenomena”.

The cover Giuliano chose for the book, shown below, again portrays his complex compassionate but fiery spirit. On the inside flap of the book’s cover (below) Giuliano focused on his view of the quantum domain causes a “network” of interactions between particles and the radiation field inherent in matter.
QED COHERENCE IN MATTER
by Giuliano Preparata
(U. Statale di Milano, Italy)

Up until now the dominant view of condensed matter physics has been that of an “electrostatic MECCANO” (elevetor set, or Americans). This book is the first systematic attempt to consider the full quantum-electrodynamical interaction (QED), thus greatly enriching the possible dynamical mechanisms that operate in the construction of the wonderful variety of condensed matter systems, including life itself.

A new paradigm is emerging, replacing the “electrostatic MECCANO” with an “electrodynamical NETWORK,” which builds condensed matter through the long range (as opposed to the “short range” nature of the usual electromagnetic (electro)electrodynamical interaction; this interaction creates “coherent configurations” of the elementary systems (atoms and molecules), which oscillate in phase with a coherent macroscopic (and classical) electromagnetic field that, through the strong interaction with matter, remains trapped inside it.
Some Recollections from Colleagues

Giuliano was a unique individual with very strong opinions which he made sure were heard. Martin Fleischmann has described him as “the smartest person I ever knew”. Martin adds however, that Giuliano “turned out to be his own worst enemy. Indeed he was viewed early on as replacing Schwinger as the leader in cold fusion theory. But his personality slowed development of a wide discipleship (such as envisioned in the earlier poem comparing him to Feynman). Giuliano’s talents extended well beyond physics. He read widely and could delve deeply into an amazing range of topics in and out of physics.”

Some of my own personal memories of him include:

- During a discussion of x-ray diffraction-like patterns observed in experiments in his lab in Milan that he described in a presentation at an ICCF meeting, I questioned how such a pattern was possible. What could the mechanism be? Giuliano immediately snapped: “George, you still haven’t read Chapter 8 of my book!! Read it before we continue this discussion!!” (This is the second time he had told me to read Chapter 8 - see the abstract for this lecture). And he quickly walked away before I could respond...

- In the middle of a talk by a well known cold fusion theorist at another ICCF meeting, Giuliano jumped up and announced “The Italian delegation is leaving – we will not listen to this nonsense any longer.” He then proceeded to walk out of the conference room (but without the Italian delegation who sat still in amazement along with the rest of the audience.)

- My last meeting with Giuliano shortly before his death was when we served together on a paper review committee for an ICCF meeting coming up in Italy. At the time I did not realize how sick he was. His high level of energy while talking about science disguised his weaken physical condition. We were assigned to review the contributed theory papers. After a few minutes Giuliano pronounced. “Reject all of these papers – they are nonsense!!” It took several hours of diplomacy on my part, helped by others on the committee, to get him to admit a series of papers, “pending serious modifications.” At one point in the discussions he turned to me and said: “You and your Americans are all arrogant, trying to control all physics publications.” This outburst came from a lingering bitterness that one of his recent submissions to an American physics journal had been rejected, probably by a reviewer out of step with the new QED theory. I finally
convincing him that while I was an editor for *Fusion Technology*, a US journal, I had nothing to do with the rejection of his paper.

- In retrospect, I suspect that we would have normally required a day or so more to get Giuliano to concede these points had he not been in a weakened condition due to his battle with cancer!

Extracts from memories of interactions and observations provided by other colleagues include:

- I remember especially one sentence he was used to explain his “strong” interactions with other physicists: “I love physics like a woman, like a lover. While I know that I am not the only one entitled to love her, and I am not jealous in a conventional way, —still, to see her abused drives me crazy!”
- A comment I vividly remember Giuliano making on several occasions is: “There is nothing more wrongful than setting things on the same level that are very different instead”. In all of his activities, despite heated arguments with other scientists, he consistently maintained a very strong sense of honor and of honesty.
- He was not an easy man, but the opportunity to know him and work closely with him really changed my way of thinking about science and the duties of a “true” scientist. He was really a wonderful teacher for me.
- I first met him at NCFI (National Cold Fusion Institute) in Utah in 1990. He was thinking beyond light speed – much more than c!! I simply could not keep up with his reasoning.
- He was an excellent and very serious physicist, and above all, one very nice guy.
- One event that comes to mind is a discussion between (…) and Preparata during ICCF4 in Hawaii. As I recall, (……) had just published a review article on cold fusion theories in which Preparata's model did not fare well. (……) had a microphone and Preparata had a microphone. Only Preparata didn't need one since he usually spoke with so much energy. As the exchange progressed, the volume increased. At some point, Preparata yelled a response into the microphone that sounded to all like the voice of an angry God from above.
- Many of my interactions with him involved Giuliano forcefully explaining to me that his theory was right, that mine was wrong!
- I have only now acquired considerably admiration for the theory Giuliano suggested.
- I only wish that I could talk to Giuliano now and extend my heart-felt apologies for not recognizing the significance of what he suggested and for not expressing my admiration for his intuitive genius. One episode that captures this took place after ICCF in Nagoya, Japan. I decided to walk to Nagoya harbor. When I got there, by chance, I ran into Giuliano. We were very cordial, at first, but soon, all civility ended as we argued about what was relevant in cold fusion theory. What
an impression this gave me, and continues to be for me. If I could meet Giuliano again I would tell him how nicely what I am now proposing fits with the model he suggested back then.

- I would sum up Giuliano Preparata’s “enigma” as follows: He was difficult to get along with, he was loud and demanding, but this grew from his deep, deep, love of physics.
- Above all else, Giuliano was a penultimate idealist. I miss him. I really do.

**Photo Memories**

Some photographs of Giuliano contributed by colleagues follow below. I am sure they will bring back fond memories to all who know him.

[Photo of Giuliano Preparata making a point]
In the lab with Emilio del Giudice
Conclusion

Hopefully this lecture has provided some insights into Giuliano’s life and work in his most loved field of physics. In closing, I am sure all will agree that the cold fusion community and the broader physics community lost a leading light that day. Yes, we all miss him. However, his brilliance and his energy and his insight live on!!

Acknowledgements

It has been an honor and joy for me to prepare this tribute to Giuliano. I would like to recognize and thank the following for their contributions to this tribute: Emilia Preparata, Francesco Celani, Antonella de Nino, Emilio del Giudice, Vittorio Violante, Scott Chubb, Peter Hagelstein, Mike McKubre, Akito Takahashi, John Bockris, Heinz Hora and Martin Fleishmann.
Erzion Model Features In Cold Nuclear Transmutation Experiments

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I describe the history of Erzion Model from its appearance in Cosmic Rays in 1982 and its development to explain the main features of Cold Fusion Experiments.

Erzion Model can explain in principle many problems in Astrophysics and Geophysics, such as: 1) Dark matter in Universe; 2) Solar neutrino problem; 3) Jupiter energetic unbalance; 4) Tritium & He³ abundance in volcano products; 5) Ball-lightning & forest fire nature amongst others.

Some applied problems can be decided within the framework of the Erzion Model, such as: 1) new ecology-pure energy with rather simple nuclear technology; 2) elimination of certain radioactive wastes; 3) cheap production of some chemical elements & isotopes (gold for example).

The Erzion Model can explain many experiments in Cold Fusion and can predict many new experiments for its testing.

Erzion Model History in Cosmic Rays & Cold Fusion

The hypothesis of the new stable massive hadrons existence in Cosmic Rays has been appeared in 1981 to explain abnormal energy spectrum of vertical component of Cosmic Rays Muons [1]. Many characteristics of this hadron (named later as Erzion) such as: mass, charge, lifetime, intensity & spectrum, nuclear interaction modes & paths, were predicted phenomenologically. From this year the direct Erzions search had started [2-4].

Moreover Erzion existence could explain also some other abnormal experimental results in Cosmic Rays such as:
1. Long length hadron cascades;
2. Delayed particles in Air Showers;
3. High energy neutral particles flux from local space sources;
4. Large across momentums in high energy cascades and etc.

But it was a great present for the author that Erzion existence in nature could explain on principle the new Fleishmann & Pons Phenomena of Cold Fusion [5,6] by Erzion Catalysis Mechanism [7].
For strong theoretical interpretation of such exotic particles existence in nature in 1990 the Mirror model $U(1) \times SU_l(2) \times SU_r(2) \times SU(3)$ had been proposed by Vereshkov G.M. [8-10]. This model without any contradiction with all world totality of experimental results in high energy & cosmic ray physics could explain main part of abnormal experimental results in orthodox physics & main unusual features in Cold Fusion such as:

1. Suppression of the neutron to tritium yield ($10^3 - 10^{11}$ times);
2. Reducing of tritium to energy yield ($\sim 10^3$ times);
3. Unstationary condition of CF reactions running;
4. Great yield fluctuation (up to $10^5$ times);
5. New isotopes & element production & etc.

The main features of Erzion model

In the framework of this Mirror model the new massive & stable Mirror antiquark ($U^*$) must exist with very small concentration as a relict component relatively to usual quarks ($C_{U^*}/C_{u,d} \sim 10^{-15}$). This antiquark can be hadronized together with our usual (u) or (d) quarks into new meson pair: neutral Erzion $- \mathcal{E}^0 = \{U^*,u\}$, or negative charged Erzion $\mathcal{E}^- = \{U^*,d\}$. The features of quark numbers of this antiquark $U^*$ are going to the unusual feature of repulsion forces of strong interaction of Erzions. Such way this mesons couldn’t be captured by all nuclear besides only nucleons forming 5-quark bag, stable singlet state, named as Enion ($\mathcal{E}_N=\{U^*,u,u,d,d\}$). As you can see from fig.1, this particle can dissociate or to charged pair ($\mathcal{E}_N=\mathcal{E}^- + p - \Delta E_1$), or to neutral pair ($\mathcal{E}^0 + n - \Delta E_2$).
Such way in nuclear exchange reactions these Erzions & Enions can be inter-converted into each other. On the every isotope up to 6 nuclear exchange reactions can occur by this Erzion catalysis mechanism:

1. \((A,Z) + \mathcal{E}_N = \mathcal{E}^0 + (A+1, Z) + \Delta E_1\);
2. \((A,Z) + \mathcal{E}_N = \mathcal{E}^- + (A+1, Z+1) + \Delta E_2\);
3. \((A,Z) + \mathcal{E}^0 = \mathcal{E}_N + (A-1, Z) + \Delta E_3\);
4. \((A,Z) + \mathcal{E}^0 = \mathcal{E}^- + (A, Z+1) + \Delta E_4\);
5. \((A,Z) + \mathcal{E}^- = \mathcal{E}_N + (A-1, Z-1) + \Delta E_5\);
6. \((A,Z) + \mathcal{E}^- = \mathcal{E}^0 + (A, Z-1) + \Delta E_6\);

In this Erzion Catalysis model we have only 2 free energy parameters (\(\Delta E_1 & \Delta E_2\)), which we can choose for proper Cold Fusion reactions. So in framework of Erzion Catalysis model we can know all energy reactions for all nuclear Erzion reactions & can predict what (exothermic) reactions can be running.
Enion due to its special peculiarity, caused by its special quantum numbers, has strong repulsive forces. But due to its dipole electric moment thermonuclearized Enion can attract nuclei & create connected state with rather small bounded energy from $E_b \approx 1.5\text{eV}$ for proton up to $E_b \approx 60\text{eV}$ for Pb$^{208}$. The main condition for creation of such stable long-lived state is absence of exothermic exchange reactions with such nuclear. Such nuclei were named as Donor nuclei ($H^1$, $He^4$, $C^{12}$, $O^{16}$, $Ni^{64}$,...). In nuclear exchange reactions Erzions ($\Theta^+, \Theta^0$) must convert into Enions ($\Theta_N$) or Erzions with another charge ($\Theta^0, \Theta^-$) and inversely. In this way there exist only 6 different Erzion nuclear exchange reactions on any nuclear (see above - 1., 2., 3., 4., 5., 6.) with 6 their reaction energies ($\Delta E_1, \Delta E_2, \Delta E_3, \Delta E_4, \Delta E_5, \Delta E_6$ - negative for endothermic reaction & positive for exothermic reaction) on each nuclear. Such way in almost any matter we have very small concentration ($C(\Theta_N) \approx 10^{-15}$ per nuclear) of captured Enions. When this Enions became free they can react with nuclei by means of exchange exothermic Erzion nuclear reactions with very large cross sections ($\sigma$~Mbn). Such way the frequency of such reactions chain is equal to GHz at best conditions.

At usual temperatures only exothermic reactions can run. There are few such reactions among stable isotopes. In the usual matter consisted from stable isotopes of light chemical elements only following Erzion nuclear catalytic reactions can run [11]:

\begin{align*}
1^H (\Theta^+, \Theta^0) & 0^0 n + 1.65 \text{MeV} & (100\ %) & (1) \\
2^H (\Theta^+, \Theta_N) & 0^0 n + 5.6 \text{MeV} & (0.016\ %) & (2) \\
2^H (\Theta_N, \Theta^0) & 3^H + 0.1 \text{MeV} & (0.016\ %) & (3) \\
3^H (\Theta^0, \Theta_N) & 1^H + 3.9 \text{MeV} & (0.016\ %) & (4) \\
Li^6 (\Theta_N, \Theta^0) & 7^Li + 1.1 \text{MeV} & (7.5\ %) & (5) \\
Li^6 (\Theta^0, \Theta_N) & 3^Li + 0.5 \text{MeV} & (7.5\ %) & (6) \\
5^Li - & \to 4^He + 1^H + 1.7 \text{MeV} & & \\
Li^6 (\Theta^-, \Theta_N) & 5^He + 3.2 \text{MeV} & (7.5\ %) & (7) \\
5^He - & \to 4^He + 0^0 n + 1.36 \text{MeV} & & \\
7^Li (\Theta_N, \Theta^-) & 8^Be + 9.5 \text{MeV} & (92.5\ %) & (8) \\
8^Be - & \to 2.4^He + 4.8 \text{MeV} & & \\
13^C (\Theta_N, \Theta^0) & 14^C + 2.0 \text{MeV} & (1.1\ %) & (9) \\
13^C (\Theta^0, \Theta_N) & 12^C + 1.2 \text{MeV} & (1.1\ %) & (10) \\
14^C (\Theta_N, \Theta^-) & 15^N + 2.4 \text{MeV} & (---) & (11) \\
14^N (\Theta^-, \Theta_N) & 14^C + 2.3 \text{MeV} & (99.6\ %) & (12) \\
14^N (\Theta_N, \Theta^0) & 13^C + 0.25 \text{MeV} & (99.6\ %) & (13) \\
15^N (\Theta_N, \Theta^0) & 15^N + 4.7 \text{MeV} & (99.6\ %) & (14) \\
16^N (\Theta_N, \Theta^-) & 16^O + 4.3 \text{MeV} & (0.37\ %) & (15) \\
17^O (\Theta_N, \Theta^0) & 18^O + 1.9 \text{MeV} & (0.038\ %) & (16) \\
17^O (\Theta^0, \Theta_N) & 16^O + 2.0 \text{MeV} & (0.038\ %) & (17) \\
18^O (\Theta_N, \Theta^-) & 19^F + 0.2 \text{MeV} & (0.2\ %) & (18)
\end{align*}
As you can see, the rarest reactions are with neutral Erzion - \( \mathcal{E}^0 \). There are only 11 stable isotopes reacting with this Erzion, named as Converters. So if you want have the reserved Erzion nuclear reaction chains you must have in your reactor system besides Donor isotopes such Converter isotopes. The best among them is Deuterium [12]. For generating neutrons you must have Hydrogen or Lithium elements in your CF reactor.

All our CF experiments [13-17] (only some last from them) fulfilled in accordance with Erzion model predictions & every time they confirmed it and had success.

**Erzion Model in Astrophysics, Geophysics & Practice**

Erzion Model can give principle explanation for many problems in Astrophysics and Geophysics [10,18,19], such as:

1) Dark matter in Universe;
2) Solar neutrino problem;
3) Jupiter energetic disbalance;
4) Tritium & \( \text{He}^3 \) abundance in Volcano products;
5) Ball-lightning & Forest Fire nature and some else.

Some applied problems can be decided in framework of Erzion Model [10,19], such as:

1) Creating the new energy-capacious, ecology-pure with rather simple technology nuclear energetics;
2) Principle & radical utilization of radioactive wastes;
3) Cheap production of some chemical elements & isotopes (gold for example).

**Conclusion**

I want thank everybody who helped me last 20 years in work on developing of such very interest & fruitful problem of Erzion Catalytic Model & hope that it will reach success.
References


Excess Heat Production During Diffusion Of Deuterium Through Palladium Tubes

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ABSTRACT

Following the work by several researchers we have undertaken experiments with deuterium gas flowing through the walls of a palladium tube. Tubes were heated at various temperatures and either filled with palladium powder or palladium compounds or empty. Our mass flow calorimeter enables us to accurately measure excess heat production. We usually used palladium tubes 10 cm long, 2 mm outer diameter with 200 µm thick walls, and closed at one end. Deuterium gas is introduced in the tube at various pressures, and temperatures and diffuses out through the walls of the tube. Thermal energy is determined by measuring inlet and outlet temperatures of cooling water and its mass flow. The energy yield of this calorimeter is 95-98% depending on input power. Our best result so far is an excess heat of 3 W with an input power of 47 W using an oxidized palladium tube filled with palladium powder. In addition to these results we describe an experiment where temperature oscillations have been measured, indicating the importance of temperature in excess heat production.

1. Introduction

Arata and Zhang (1) used a DS-cathode (that is, a “double-structured” cathode; i.e. a hollow palladium cathode filled with palladium nano powder). They show large excess heat production when using heavy water and no excess heat with ordinary water. They also measured production of helium-4 during these runs (2). Recently the same authors have developed an alternative technique to obtain similar results applying high pressure deuterium gas on the outside of a palladium tube filled with palladium nano powder.

Li et al. (3) have also observed excess heat when deuterium gas flows through a palladium foil. In 1989, Fralick et al. (4) reported a similar experiment. They loaded a hydrogen gas purifier with deuterium, and then pumped it out. They observed a temperature rise with deuterium versus no temperature change with hydrogen. However
the experiments performed by Arata (2), Li (3) and Fralick (4) are based on temperature measurements, and do not provide accurate calorimetric data.

In a previous paper (5) we described in detail our experiments with deuterium diffusion through the walls of palladium tubes. This paper gives additional results, especially temperature oscillations that indicate the role of temperature on excess heat.

2. Experimental setup

The calorimeter used in this work is described in Fig. 1. In future experiments we have improved the design in order to avoid heat transfer by conduction and convection between the palladium tube and the walls of the calorimeter (5). The vacuum chamber is a stainless steel cylinder 7 cm in diameter and 50 cm long. It is surrounded by a second stainless steel envelope where 30°C de-ionized water circulates at a constant flow rate of 180 ml/min. Inlet and outlet water temperatures are measured with two calibrated thermistors. A palladium tube closed at one end usually 10 cm long and 2 mm in outer diameter is welded on a 6 mm diameter stainless steel rod which is attached to a 6 mm diameter stainless steel tube with a Swagelok® fitting (Fig. 2). A thermocouple is inserted inside the stainless steel rod up to the center of the palladium tube. In the case of powder filling, the thermocouple is at the edge of the tube. Due to heat losses by conduction (through metal parts) and non-uniform heating, the temperature of the palladium tube is not uniform along the tube.

The palladium tube is heated by radiation with a Thermocoax® direct-current resistor wrapped around it. Four stainless steel concentric reflectors are positioned around the resistor in order to minimize heat losses by radiation. Input heat applied to the resistor is dissipated mainly by radiation and is collected by the water cooled envelope. However part of the heat is lost by conduction through the 6 mm stainless steel tube attached to the palladium tube and also through the metal flange which holds the electric feedthroughs and the various pumping tubes.
Figure 1. Design of the mass flow calorimeter.
3. Calibration

Input power is measured accurately since the heater is driven by a DC power supply. Output power is measured via the temperature difference given by two thermistors, one at the inlet, and the other one at the outlet. Temperature is measured with precision of +/- 0.01 K. The mass flow rate of the de-ionized cooling water is measured with accuracy better than 1%. As mentioned above, most heat is recovered by the flowing water, and therefore taken into account in determining the output power. However some heat is lost through the large flange of the vacuum chamber which is not cooled by the flowing water. In order to have an accurate value of the losses, we performed a blank run without the palladium tube. We replaced it with an open stainless steel tube. Our calibration shows that a correction of 2 to 5% of the input power must be added to the output power to take into account the heat loss. This value varies with input power: the larger the input power the less correction is needed percentage wise.

However, to avoid having to perform this correction, it is even better to compare the output power with deuterium to the one with the tube under vacuum. No correction is therefore needed; we simply compare the two situations.
4. Experimental results

4.1 Excess heat

Most experiments we have performed so far have been described previously (5). Figure 3 shows excess heat of 1.8 W without any correction, and probably 3 W when corrected for heat loss. The palladium tube was oxidized in air at 500°C for two hours and filled with palladium powder from Goodfellow (80–180 nm). The deuterium pressure was 9 atmospheres; and the temperature measured at the base of the tube was 85°C. More details about this work are described in Ref. 5.

![Figure 3](image_url)

*Figure 3. Input and output power during the final phase of the experiment, showing an uncorrected excess heat of 1.7 W.*

4.2 Temperature oscillations

In a previous work, we measured the temperature of the palladium tube, while lowering the input power. We observed an anomalous effect of temperature oscillations with a magnitude of 9°C, as shown in Fig. 4. These oscillations do not seem to exist at all temperatures. This is an indication of a role of temperature in the reaction. Unfortunately when these temperature anomalies were recorded, the excess heat could not be measured due to a problem with the water mass flow which was unstable.

Later experiments were performed with palladium powder inside the tube, so that the temperature measured corresponded to the temperature at the Swagelok fitting, and
therefore small variations in temperature of the tube were damped by the heat capacity of the stainless steel. So that these temperature oscillations have not been observed again.

Figure 5 shows Scanning Electron Microscopy images of the surface of the tube after the experiment showing the formation of melted area and volcano type.

Figure 4. Temperature oscillations of the palladium tube as the input power is decreased by steps.
5. Conclusion

We have shown that anomalous heat effects are produced when deuterium gas under a pressure of 9 atmospheres flows through the walls of a palladium tube. We have measured excess heat up to 3 W when the tube is oxidized in air at 500°C and filled with palladium micro powder. Also we have shown temperature oscillation anomalies when the power input is reduced. These oscillations have an amplitude up to 9°C, and need a theoretical explanation that might be helpful in understanding the actual mechanism of the Fleischmann-Pons effect.

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References

Excitation of Hydrogen Subsystem in Metals by External Influence

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ABSTRACT

Experimental results which point to the existence of a hydrogen subsystem in solids and the possibility of its excitation by external influence are described. Occupying the equivalent positions inside host metal, hydrogen forms its own subsystem inside a crystal lattice and has vibration frequencies lying outside the phonon spectrum of a crystal. Under external energy input (for instance by means of radiation) an excitation of vibrations occurs in the hydrogen subsystem. The following facts point to this: intensive migration, diffusion and release of hydrogen isotopes from metals at low temperature; superlinear dependence of H, D release from metals on the electron current density and H, D concentration; H and D release from the whole volume of samples during the irradiation process by focused electron beam; H and D release in both molecular and atomic forms.

Introduction

Hydrogen in metals is a very important technical and scientific problem. The technical problem is related to the negative influence of hydrogen on the mechanical properties of metals. Hydrogen produces various types of defects, cracks, and embrittlement. Hydrogen is the lightest element and possesses high mobility in solids; hence metal-hydrogen systems present special scientific interest. Pons and Fleischmann initiated great interest in the problem of hydrogen in metals in connection with so-called “cold nuclear fusion.” Numerous investigations have demonstrated that saturation of metals by hydrogen under electrolysis or in a glow discharge can lead to excess heat, X-ray emission, and change of isotopic and mass composition of metals. However all these processes, as a rule, are uncontrolled, realized spontaneously, and their mechanism is unknown. One of the reasons for this is insufficient knowledge about the influence of an electrolytic medium and glow discharge on the behavior of hydrogen dissolved in solids.

In the present report we discuss a new phenomenon: “excitation of hydrogen subsystems in metals by external influence,” which aids in the understanding of the processes enumerated above.
Experimental results

Systematic investigations of the influence of hydrogen and radiation (accelerated ions and electrons, X-rays, gamma-quantum) on metal properties have shown [1-4] the following: hydrogen atoms occupy regular positions in the crystal lattice, forming their own hydrogen subsystem; the hydrogen subsystem is able to accumulate the external energy; the absorbed energy is distributed inside the hydrogen subsystem and, as a result, the hydrogen atoms' kinetic energy is much higher than that of the matrix atoms.

The following experimental findings point out the existence of the hydrogen subsystem in solids, and the possibility of its excitation by external radiation.

1. Intensive migration, diffusion and release of hydrogen isotopes from metals at low temperatures.

The hydrogen migration and release from metals caused by the accelerated ions was explored by the elastic recoil detection method. This method allows us to study the hydrogen migration in the sample irradiated by accelerated ions. Fig. 1 shows the change of hydrogen concentration in 12Cr18Ni10Ti stainless steel versus the radiation flux of the 12 MeV N\textsuperscript{14} ions for three depths x=50, 100, and 200 nm. In all layers the hydrogen concentration decreases in the process of irradiation. Similar results were obtained on other metals. A large yield of H atoms cannot be explained by the nuclear collision of H with nitrogen nuclei since the number of collisions calculated from the Rutherford cross-section is $10^8$ times less than the corresponding experimental value.

![Figure 1](image.png)

Figure 1. Hydrogen concentration dependence at different depths x on the N\textsuperscript{14} dose.
Hydrogen migration and release under irradiation by accelerated electrons and X-rays were studied in a high vacuum installation. This installation includes a programmed heating unit, a vacuum cell connected to a mass-spectrometer and an electron gun with energy of 10-100 keV. Metal samples were saturated with deuterium electrolytically. Loading with deuterium made it possible to study the gas release alone, separating it from uncontrollable hydrogen presence in the vacuum system. During radiation exposure the sample temperature was measured by a thermocouple. Under the electron beam influence U of 20 keV energy and the current I=50 μA, 100 μA, and 150 μA, the intensive release of deuterium from the stainless steel takes place (Fig. 2). The maximum deuterium release rates under accelerated electrons irradiation are observed at the times of 150s, 60s, and 45s for I=50 μA, I=100 μA, I=150 μA, respectively. During these measurements, the temperature of the external side of samples in the electron beam area did not rise more than 60°C, and on the rear side, it did not rise more than 40°C. In the absence of an electron beam the equilibrium release of hydrogen was not observed at these temperatures.
2. **Superlinear dependence of H, D release from metals on the electron current density and H, D concentration.**

The dependence of H, D release from stainless steel and niobium on electron current density is shown on Figs. 3a and 3b. This dependence reveals that a collective interaction between the radiation and the hydrogen subsystem exists.

![Graph a)

Figure 3. Dependence of D release from a) stainless steel and b) niobium on the electron current density, I.

3. **Hydrogen isotopes release from the whole volume of samples during the irradiation process by focused electron beam.**

Hydrogen isotope release from the metals was studied under the simultaneous application of an electron beam and linear heating. The area of the sample irradiated by the electron beam is 0.20 cm\(^2\), which is much smaller than the total sample area (2-4 cm\(^2\)).

The linear heating along with the electron beam effect was accompanied by the maximum hydrogen release shift into the low temperature region (Fig. 4). This shift is 80°C in stainless steel; 125°C in niobium, and 65°C in palladium.
Deuterium release from stainless steel (a), Nb (b) and Pd (c) versus the linear heating at the rate of 0.4°C/s: 1 – without electron beam; 2 – with electron beam; $E = 20$ keV. The current I is a) 100 μA, b) 50 μA, and c) 20 μA.
4. Hydrogen isotopes released in both atomic and molecular forms.

The presence of released atomic hydrogen was measured by a special dye, which is sensitive to hydrogen in atomic form. The measuring method is based on the bleach effect of organic pigments placed on a catalytic substrate. Atomic hydrogen bleaches the dye, changing its color from red to white, while molecular hydrogen does not affect the dye color. The bleach of the dye is more effective the longer it is exposed to hydrogen and the greater the hydrogen concentration is. The bleach of the pigment by D and H atoms allows us to estimate the intensity distribution of atom release along the surface. The experimental scheme is presented in Fig. 5.

![Figure 5](image_url)

Figure 5. The arrangement of the diagram and pigments at the Pd film irradiated by an electron beam: (a) the scheme of the experiment; (b) initial pigment; (c) a state of the upper pigment after irradiation; (d) a state of the lower pigment after irradiation.

In this experimental setup the copper and iron diaphragms form an e-beam. A second copper plate with holes was placed between Pd and the dye. The whole "sandwich" was tightly pressed together in order to avoid a lateral clearance between the Pd film and the plates.

Measurements have shown that atomic hydrogen is released most intensively under the direct effect of the electron beam (Fig. 5c). In addition, a weak release of D and H atoms was observed from the opposite side which was not exposed to the electron beam. This resulted in the appearance of the bleach region in the dye in the shape of the Pd sample (Fig. 5d). The bleach area in the dye on the rear side of the Pd sample was uniform throughout the whole surface in its contact with Pd and had no peculiarities at the point.
opposite to the electron beam entrance. The uniform bleach of the dye on the rear (not irradiated) side showed that D and H atom release is not correlated with the thermal heating of Pd at the point of electron beam effect. The temperature on both the lower and upper sides of the irradiated thin Pd sample (d ~0.15mm) was practically the same. It was measured by thermocouples placed on the upper and lower sides of the sample. In our experiments it did not exceed 60-100°C.

The most important finding is that the hydrogen releases from metal not only in a molecular but also in an atomic form. Moreover, the electron beam directly affects the sample only locally, while it excites the entire internal hydrogen subsystem.

**Electron structure of the palladium hydrogen system**

An unexpected observation here is that hydrogen diffusion is stimulated by ionizing radiation (accelerated electrons and ions, and X-rays). It is known that ionizing radiation loses its energy in the process of collision with sample electrons producing an excited electron subsystem. The lifetime of these processes in metal is very small \((10^{-15} - 10^{-16} \text{ s})\) and it is not clear how the energy from the electron subsystem is transferred to the hydrogen subsystem.

To answer these questions it is necessary to study the modification of the host electronic structure of metals by the presence of hydrogen. With this purpose the electronic structure of a pure Pd crystal in the FCC lattice and the Pd-H system in which the hydrogen atoms occupy octahedral sites have been calculated using the self-consistent linearized augmented-plane wave method. The \textit{ab initio} calculations were performed within the local-density-functional approximation, using the Hedin-Lundqvist exchange-correlation potential. The valence states were treated in a scalar-relativistic approximation, while the core states were treated fully relativisticly. Using thus obtained band structure the imaginary part of the dielectric function \(\varepsilon_2\) in the energy range \(\hbar\omega < 18\) eV has been calculated within the constant matrix element approximation.

Figure 6 shows the calculated electronic densities of states for pure Pd and PdH. From a comparison of the band structures of the pure Pd and Pd-H systems one can note the following characteristic modification of the pure Pd electronic structure upon hydrogen absorption:

- the filling of the \(s\) - band of palladium by the electrons of dissolved hydrogen;
- the lowering of the bottom of the conduction band due to hybridization of \(s\) states of hydrogen with \(s, p\), and \(d\) states of Pd atoms;
- an upward shift of the Fermi level relative to the top of the \(d\) Pd band which results in a decrease of the electronic density of states of the system at the Fermi level.
It can be also seen from Fig. 6 that the presence of hydrogen in a Pd lattice results in a pseudogap in the electronic spectrum of the Pd-H system having energy of around ~4 eV. The presence of this pseudogap in the electronic spectra of the Pd-H systems indicates the appearance of a covalent component of the bond between palladium and hydrogen atoms in addition to the metallic bond characteristic of the pure palladium. It is known that in crystals with a covalent bonding the lifetime of electronic excitations is longer than in pure metals. Hence, during this longer time, hydrogen is capable of starting to migrate.

Figure 6. Calculated partial and total electron densities of state for Pd and PdH.

Figure 7. Imaginary part of dielectric function $\varepsilon$. 
Figure 7 shows the calculated imaginary part of the dielectric function, $\varepsilon_2(\hbar\omega)$. From this figure it is seen that the presence of hydrogen in the palladium significantly enhances the value of the dielectric function $\varepsilon_2(\hbar\omega)$ in the energy range from ~1.5 eV up to ~7 eV. This fact leads to the increase in absorption by the metal-hydrogen system under the influence of external energy. Thus, one can conclude that the features of the electronic structure of the metal-hydrogen system can lead under the influence of irradiation to the following effects:

- increase of lifetimes of the one-electron excitations due to the local character of the metal-hydrogen bonds;
- increase in absorption of the irradiation energy by the crystal due to the appearance of an additional electronic density localized in the vicinity of the hydrogen atoms.

In the next stage of our research, we studied the characteristics of collective electronic excitations in metal-hydrides, taking as an example the Pd–H system. Our calculations show that in both pure Pd and PdH a large number of peaks are observed in the excitation spectra in agreement with existing energy-loss experiments. Fig. 8 shows the dominant plasmon peak dispersions in the pure Pd and Pd–H systems. One can see that dominant plasmon energy in the Pd–H system is lower than in the pure Pd case.

![Figure 8](image_url)

Figure 8. Dispersions of the low energy dominant collective electronic excitations in Pd and PdH.

This fact indicates that the probability of excitation of plasmons in Pd–H system increases in comparison with the pure Pd case. Hence one can suggest that in the process of ionizing irradiation large-scale oscillations of the electronic density are possible in the Pd–H system at lower energy. As a result, strong local electric fields can appear inside the crystals (Fig. 9) in which hydrogen atoms could be accelerated.
The hydrogen subsystem can be excited under a glow discharge. Hydrogen atoms in plasma have energy sufficient to excite plasmons in metal. The excitation of the hydrogen subsystem during electrolysis process takes place as the result of impact of hydrogen babbles. The impact of babbles is accompanied by the emission of the low energy photons. The excitation probability can be increased by drawing the hydrogen bubbles to the cathode. This can be done, for instance, by using of porous films (such as nuclear filters).

Conclusion

During occupation of the regular positions inside a metal, hydrogen forms its own subsystem inside a crystallographic lattice of a host metal. This subsystem has vibration frequencies lying above the phonon spectrum of a crystal. Under the input of energy, for instance, by means of radiation, electrolysis process, and glow discharge, the hydrogen subsystem can be excited. Non-equilibrium vibrations of the hydrogen subsystem are long-lived on the time scale of electronic relaxations in metals. Therefore, the diffusion of hydrogen can be stimulated by absorption not only of the energy of thermal vibrations kT, but also by the energy of non-equilibrium vibrations of hydrogen \( \hbar \omega \) which exceeds kT. In the process of ionizing irradiation, large-scale oscillations of the electronic density are possible in the Pd–H system at lower energy. As a result, strong local electric fields can appear inside the crystals in which hydrogen atoms could be accelerated. Excited hydrogen subsystem in metals is a specific medium, a high density and low temperature plasma, in which some exothermal chemical and nuclear processes can occur.

References

Roles of Approximate Symmetry and Finite Size in the Quantum Electrodynamics of d+d→⁴He in Condensed Matter Nuclear Science

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Abstract

Resonant electromagnetic interaction (EMI) in finite solids not only can be used to explain conventional, electron energy band theory (which explains charge and heat transport in solids), but also how, through finite size effects, it is possible to create many of the kinds of effects envisioned by Giuliano Preparata. Through a generalization of conventional energy band theory, it is also possible to explain how resonant EMI, as a function of time, can cause coherent effects, in which momentum can be transferred from external regions of a lattice to its center-of-mass. As a consequence, virtual processes can cause large changes in momentum between two, indistinguishable particles, without either particle acquiring large momentum or velocity. With increasing time, these changes can occur over shorter and shorter length scales, through (“Bloch”) oscillations of the charged particles within the lattice, leading not only to possible deuteron (d)-d nuclear dimension overlap, but, as a result of resonant EMI, to forms of overlap that are consistent with those that occur through quantum electro-dynamic (QED) effects in the conventional d+d→⁴He+γ reaction. The resulting theory predicts that the orientation of the external fields in the SPAWAR protocol has direct bearing on the emission of high-energy particles. Resonant EMI also implies that nano-scale solids, of a particular size, provide an optimal environment for initiating Low Energy Nuclear Reactions (LENR) in the PdD system.

Introduction

In this paper, important facts about the importance of electromagnetic interaction (EMI) in the conventional deuteron (d)+d→⁴He+γ reaction are reviewed that are not widely appreciated. These facts reveal that as opposed to a static Coulomb barrier, the “barrier,” in this reaction, involves important time- and spatially- dependent effects that require that for the reaction to take place, the incident d’s that are involved must be prepared, far from the reaction, in a particular way, through EMI, that occurs infrequently in thermonuclear fusion. As a consequence, the reaction occurs infrequently, relative to the dominant reactions, in hot fusion, not because of the large energy release (which is commonly believed by most nuclear physicists to be the reason the reaction does not occur frequently) but because it involves important EMI effects that are conventionally ignored that occur infrequently at high temperatures.
In the next section, the associated facts about EMI in this reaction are discussed. In this section, a rationale is also presented that justifies the idea that a generalization of this kind of “QED” barrier can be applied in solids, involving resonant forms of interaction, associated with approximate translation symmetry. Elsewhere[1], it is argued that these forms of reaction can convert the γ-ray that occurs in the conventional situation, through generalized forms of parametric down conversion processes, into many, lower frequency photons in smaller, finite solids, and can cause electromagnetic emission to completely disappear, and the associated energy and momentum to be dispersed through radiationless processes, in larger solids. The motivation for both arguments is: 1. Because time-dependent EMI effects can cause particles separated by macroscopic distances to interact with each other, the presence of this alternative “barrier” suggests that coupling can occur between many different “particles,” located at positions that are separated by considerably larger distances than in the dominant (d+d→$^3$He+n and d+d→t+p; p=proton, n=neutron, t=triton=$^3$H) hot fusion reactions, where a static, Coulomb barrier, at close separation, can be used; and 2. In situations that are consistent with the palladium-deuteride experiments, many particles are allowed to “move” rigidly (i.e., when the particles are capable of moving without the relative position of any of them relative to the others being altered, while the location of their center-of-mass is allowed to change); and 3. As a consequence of approximate periodic order, the associated forms of overlap can result in highly non-linear coupling through EMI that can lead to new (potentially massive) forms of parametric down conversion processes (as discussed elsewhere[1]).

In this section of the present paper, I argue that resonant EMI effects not only can explain how Low Energy Nuclear Reactions (LENR), involving d+d→$^4$He+23.8 MeV, can take place, but these effects are based on an assumption that changes in the time-dependent interaction potential, associated with EMI, as opposed to the changes in the time-dependent strong force, are responsible for the effect. This assumption, in turn, is consistent with the situation in the d+d→$^4$He+γ reaction, and the observation that the associated “QED” barrier, associated with this reaction, is different from the Coulomb barrier that applies in conventional fusion. Because of an approximate symmetry associated with rigid translations, it is possible to explain the commonly observed d+d→$^4$He+23.8 MeV reaction, through a form of resonant EMI, and the fact that it occurs without high energy particle emission.

In the following section, some new results associated with applying a generalization of conventional energy band theory are summarized. The generalization, which is explained in detail elsewhere[1, 2], involves including finite size effects in a more precise way than they are included in the conventional theory, in which a model has been used that involves infinitely repeating, periodically ordered unit cells. The generalization is based on an approximate form of resonant EMI that applies to the ground state (GS) and the lowest energy excitations of the GS, which are associated with the kinds of rigid forms of translation, alluded to above.
Here, a situation involving approximate forms of palladium (Pd)-deuterium (D) compounds is discussed and generalized, associated with a “hypothetical” limit (approaching stochiometric palladium-deuteride, PdD), defined by PdD, x→1, that we suggested earlier in the ion band state theory of cold fusion could initiate excess heat effects[3]. In particular, in the present paper, a more realistic model is introduced, based on the assumption that in finite lattices, involving real boundaries, dynamical effects can evolve that can explain a number of the known effects and be used to make new predictions. As opposed to the “quasi-particle” formulation (which was presented previously), inferred from an argument based on energy minimization, leading to the possible occupation of a potentially unstable, initial state, from which cold fusion could be initiated[3,4,5], a new, dynamical picture is identified, in which a nuclear transition can take place, in which all of the particles in a particular region, possessing approximate periodic (translational) symmetry, can accelerate, rigidly, (i.e., without altering any of the inter-particle separations), relative to regions that do not possess this approximate symmetry. The resulting picture, in general terms, involves, long wave-length, rigid oscillations, of charged deuterons, and applies in sufficiently large crystals, in a semi-classical limit, through effects that are strikingly similar to the oscillations suggested by Giuliano Preparata[6]. An important distinction is the resonant coupling picture, presented here, includes effects, involving deuteron-deuteron exchange, and electron-electron exchange, that are not included in Preparata’s model. The present, resonant EMI model also includes finite size effects that he does not include, except in very general terms. A common point in both theories involves the importance of boundaries. In his model, these enter through the idea of fixed fluctuations in what he refers to as the vacuum zero. He also estimates these fluctuations. In the finite-size QED model, presented here, this concept is generalized, based on the idea that the associated fluctuations, in principle, can be arbitrary, and their magnitude and their coupling to potential reactions are determined by the allowable forms of overlap that are consistent with externally applied fields and the sizes of the potential crystal lattices where the potential reactions are initiated.

**Importance of the QED (as Opposed to the Coulomb) Barrier in d+d→α+γ**

By assumption, within the conventional picture of nuclear fusion, a static Coulomb barrier is used to explain how same-charged, heavy hydrogen nuclei (deuterons-d’s) can have appreciable overlap. In this conventional picture, d’s initially approach each other with such a high velocity that their momenta do not change appreciably, except when their separation approaches nuclear scale, where they are allowed to interact dynamically entirely through the strong force, and the EMI can be treated, entirely statically (through the semi-classical, Coulomb barrier model), based on the standard (WKB), Gamow-Teller tunneling formula. Fig. 1 shows a schematic diagram of how the most frequently observed reactions occur. In the figure, two proton-neutron pairs collide at a point, where
the two pairs can be viewed as forming an “excited state” of a helium-4 nucleus, in which the dynamical changes are dominated by the strong force. In this limit, the distinction between protons (p’s) and neutrons (n’s), at the point of nuclear contact, effectively (except through differences in kinetic energy, associated with changes in mass that do not relate to time-dependent EMI effects), is inconsequential, and the normal, intuitive picture that nuclear physicists have applies: The most frequent reactions occur when the amount of nuclear energy that is released is minimized.

Based on this intuitively appealing idea, most nuclear physicists assume that the least common reaction (d+d→α+γ) occurs infrequently because the energy release (23.8 MeV) is considerably (7 to 8 times) larger than it is in the remaining reactions. In fact, this picture is not right. Important details about time-dependent, EMI effects, which are responsible for the fact that the d+d→α +γ reaction occurs rarely (a fact that was not appreciated even by Schwinger and Preparata[6]), have been ignored. In Fig. 2, a second schematic diagram is used to illustrate this fact.

In particular, the fact that EMI plays a central role is this reaction is known because although d+d→α+γ rarely occurs, the reverse reaction (the photo-dissociation process: γ+α→d+d) has been studied in detail. As discussed elsewhere [1], it is known, implicitly, as a consequence, as opposed to the conventional picture, involving a static Coulomb barrier, and the common, intuitive idea that the large energy release that is involved is responsible for the reaction occurring infrequently, an alternative model applies: Selection rules exist and a well-defined electromagnetic transition is involved in the photo-dissociation process. The analysis shows quite conclusively that the reaction can be explained as resulting from a well-characterized (quadrupolar) transition, in which the total spin of the final state d’s vanishes and that it is necessary to include the effects of EMI (and the requirement that the d’s obey Bose Einstein statistics) on length and time-scales that are far from the location of the photo-dissociation process. Because in QED, the rate of any transition is proportional to the absolute square of the associated transition matrix element, by construction, the theory requires that a transition rate forward in time be equal to the comparable rate for a transition backward in time. As a consequence, the common intuition, that this reaction does not occur frequently because of the large energy release, is wrong.

An important point has and continues to be the role of time-dependent effects in QED phenomena. The potential relationship of these EMI effects in potential nuclear fusion reactions, and in LENR, involving d+d→⁴He is not widely appreciated because it is widely believed that the charge-neutral, strong force potential provides the time dependent dynamics associated with the reaction.

An important reason for this is that, as outlined above, the importance of the effect of QED in d+d→α+γ is not widely appreciated because this reaction, superficially, appears to be dominated by strong force effects since it conserves isospin and also because it is
believed, as a consequence, it occurs infrequently because the energy from the reaction is so much larger than the comparable reaction energies associated with the other reactions. The possible importance of QED in the LENR situation, and the possibility that approximate symmetry in this situation might be important, in solids, has not been widely considered probably because the conventional theory, of periodically ordered solids, that is commonly used, involves a semi-classical limit that does not include the possibility that, effectively, many channels for de-excitation can become possible through resonant phenomena in which an approximately ordered lattice is allowed to move and accelerate, rigidly. In this situation, in principle, all of the charged particles in a particular region can “move” together at once, in such a way that the separation between any two particles does not change.

**Facts About Conventional Fusion**

![Diagram of dominant Hot Fusion Reactions](image)

**Figure 1.** Schematic diagram of dominant Hot Fusion Reactions; on the left-side two deuterons, pictured as two proton-neutron pairs (each pair has a single proton—shown as a red sphere—and a single neutron—shown as a blue sphere) come together with high velocity, where conventionally, they are viewed as forming an excited state of a helium-4 nucleus, which is pictured as four nucleons (two red spheres and two blue spheres), near the center of the figure. As shown in the figure and explained in the text, in these reactions, the time dependence in the electromagnetic interaction (EMI) can be ignored. Static, Coulomb Barrier applies.

In fact, collisions between charged particles at the “boundaries” of such a region with “particles” outside the region introduce forms of coupling that limit the extent and lifetime of these forms of “rigid-body” motion. In fact, because it is never possible to identify where the “boundary” of such a region occurs, implicitly, the lowest energy excitations that result from these forms of approximate symmetry occur through resonant
EMI processes, in which momentum and energy are conserved globally, and the perturbations (resulting from collisions) that result involve situations in which the net flux of each kind of particle into and away from the “ordered” region vanishes. Possible coupling between different configurations involving different center-of-mass velocities (and momenta) necessarily can result in forms of approximate degeneracy, and (as a consequence) many alternative forms of partial excitation and de-excitation can take place.

In free space, comparable forms of coupling are not present. As summarized elsewhere[1], in a finite solid, not only through these kinds of effects, can the “single γ ray” be converted into many (lower frequency) photons, but through the Zener/ionic breakdown model summarized here (and elsewhere [7,8, 1]), the phenomenon can occur through a time-dependent process, involving a form of coherent tunneling, in which the necessary changes in momentum for triggering the reaction can increase in magnitude with time.

“Secret Reaction” (d+d→\(^4\)He+\(\gamma\)) Has QED (as opposed to Coulomb) Barrier

FIGURE 2. Schematic Diagram of d+d→\(^4\)He+\(\gamma\); the common assumption, that the reaction occurs infrequently because the energy release is too large and involves a static “Coulomb Barrier,” is wrong. The relevant dynamical interaction potential \(V\) does not involve the strong force. \(V\) is proportional to \(J(r,t)\bullet A(r,t)\) \((J(r,t)=current\ at\ location\ r\ and\ time\ t;\ A(r,t)="vector\ potential,"\ which\ creates\ and/or\ destroys\ photons),\ has\ both\ a\ time-\ and\ spatial-\ dependence\ everywhere,\ not\ just\ in\ the\ neighborhood\ of\ the\ reaction.\ This\ reaction\ is\ rare\ because\ far\ from\ the\ reaction,\ proton\ (red\ sphere)\ neutron\ (blue\ sphere)\ pairs\ are\ prepared\ with\ vanishing,\ total\ spin,\ and\ with\ relative,\ orbital\ angular\ momentum\ l=2\hbar.\ The\ reaction,\ which occurs through a quadrupolar transition, has a dynamical range that is considerably longer than the conventional strong force dynamical range, associated with d+d→\(^3\)He+n and d+d→\(^3\)H+p.
Roles of Approximate Symmetry and Finite Size in Resonant EMI in $d+d\rightarrow^4\text{He}+23.8\text{ MeV in PdD}$

A detailed description of resonant EMI is provided elsewhere[1]. This paper also summarizes how resonant EMI effects can be used to relate conventional energy band theory, as it applies to infinitely repeating, periodic lattices, to situations in which the lattices possess finite extent. An important point is that although it is impossible to precisely determine the boundary of an approximately ordered region of a solid, because the ground state and lowest lying excited states are required to have minimal overlap with processes that couple to the outside world through the exchange of energy and/or momentum, it is possible to identify important forms of approximate translational symmetry (associated with rigid displacements of approximately ordered regions), involving a form of Galilean invariance, that can be used to characterize and identify the lowest energy excitations. In the limit in which these excitations involve no net flux of particles and momentum, forms of “resonant” coupling can take place, in which, in the interior of the periodic regions, rigid forms of oscillatory motion (referred to as “Bloch Oscillations”) are allowed to take place, in which the separations between particles do not change. When these oscillations occur, the center-of-mass (CM) momentum of large numbers of d’s (which effectively can occupy a single state, through the formation of a Bose Einstein Condensate) can increase, and coupling (through the time evolution between states involving different CM momenta) can take place that can result in large changes in the relative momentum between d’s, over short length scales, when externally applied, static, electric fields are applied.

Through these resonant EMI’s, effectively, a finite region of a solid, that is approximately periodically ordered, can appear to behave like one of any number of “moving targets,” in sufficiently small crystals, that can absorb changes in momentum, rigidly, through many possible processes (referred to as “virtual processes”) that are entirely elastic and conserve momentum, non-locally, but provide a way, for momentum to be transferred instantly to the CM of a system or a portion of a system, involving many, charged particles. This can explain how the momentum (and energy) from a potential reaction (involving many different states) can couple to the environment that is profoundly different from a situation involving two isolated d’s colliding at a point. Ideas associated with resonant EMI can be used to explain the underlying dynamics. In particular, an analogy exists between a situation involving triggering effects associated with resonant EMI’s, resulting from finite size effects, in possible LENR, involving $d+d\rightarrow^4\text{He}+\text{energy}$, with an alternative situation, involving the acceleration effects associated with gravity, in a different (known) system (not related to LENR).

These kinds of processes, in principle, provide a way for many particles to transfer momentum coherently to many different, indistinguishable locations where particles can be present, instantly, through virtual processes that allow for the possibility that changes
in momentum between two, indistinguishable particles can become large, without either particle acquiring large momentum or velocity. With increasing time, larger and larger changes in momentum over shorter and shorter length scales are allowed to take place, through these (“Bloch”) oscillations. Provided collisions, between particles, occur sufficiently slowly, these forms of resonant EMI can induce nuclear dimension overlap and interaction, in which the dominant, dynamical portion of the interaction potential involves QED, not the strong force. Here, in particular, the initial and final states are eigenstates of a static, as opposed to dynamic, strong force potential, in a manner that is similar to the way that the initial and final states in an atom, prior to an electromagnetically induced transition, are defined to be eigenstates of a time-independent (electrostatic) potential.

The analogy that exists between the kind of situation involving triggering effects associated with resonant EMI’s, resulting from finite size effects, in possible LENR, involving $d+d \rightarrow ^4$He+energy, with identifying the acceleration effects associated with gravity, is related to the underlying dynamics. In both situations, it is possible for a periodic “lattice” (or a portion of it) to accelerate rigidly. In the alternative system, involving gravity, the “lattice” (which is referred to as an optical lattice) is created artificially, by introducing an interaction between finely tuned counter-propagating laser beams, and an Atomic Bose Einstein Condensate (ABEC). In particular, an ABEC is formed, using characteristic (nearly resonant) excitations of an alkali vapor, through non-linear optics and applied, external magnetic fields (using a magneto-optical trap—or MOT), through a process that is referred to as Laser Cooling. After the ABEC is formed, the initial fields are turned off, and counter-propagating laser beams are turned on, at a frequency (or frequencies) that is (are) finely tuned, relative to each other. When this (these) frequency (frequencies) is (are) far from the resonant frequency that is used to form the ABEC, the counter-propagating laser beams are used to form standing waves that interact with the ABEC, effectively, in an elastic fashion. Because the associated ABEC laser beam scattering (which occurs through the A.C. Stark effect) involves a periodic electromagnetic field, effectively, the atoms in the ABEC interact with a periodic potential (referred to as an optical potential), and provided the ABEC remains confined, within the region that has approximate periodic symmetry, the atoms in the ABEC can behave cooperatively in a way that is similar to how deuterons can behave, when they are in a common (Bose Einstein Condensate) ion band state, and they interact with a periodic potential.

In the situation involving an ABEC, it is possible to control the velocity of the (optical) lattice precisely and, effectively, to make it accelerate, relative to the atoms in the ABEC, by externally increasing or decreasing the frequency of one of the laser beams, in a manner that varies linearly with time. The associated “chirp” procedure can be used to induce an acceleration that closely mimics the acceleration that is induced in the center-of-mass motion of the ABEC, as a result of gravity, provided the lattice is sufficiently
small, and the external fields induce an acceleration that is sufficiently close to the gravitational acceleration. Because it is never possible to determine if the “lattice” (in these kinds of situations) is either in motion or at rest, a potentially huge time-dependent degeneracy is present (associated with alternative configurations in which the lattice “moves” with slightly different velocities), that can result in implicit forms of coupling, through “virtual” transitions, that are required to take place in the limit in which particle-particle collisions (resulting from interaction at the boundaries of the lattice) are allowed to take place.

A feed-back (servo-) mechanism, involving altering the chirp frequency, in response to changes in the occupation of atoms within the ABEC, can be constructed that, in principle, can force the gravitational and lattice acceleration to approach each other. This can be accomplished by altering the chirp frequency in response to changes in the intensity of absorption and/or fluorescence images of the atoms, that are formed by turning off the counter-propagating lasers and simultaneously tuning one of the lasers to a nearly-resonant frequency.

In the LENR situation, the boundaries “of the lattice” occur in regions where charge, locally, need not be conserved, which not only includes regions immediately at the boundaries of the lattice (near surfaces and interfaces, where periodic order disappears), but it also includes regions where deuterons potentially can have overlap at nuclear-size length-scale. When changes in momentum in these (nuclear) regions become appreciable over a sufficiently small length-scale, nuclear reactions can occur, in which the momentum of the reaction is transferred rigidly to all of the d’s that potentially can interact, and (in sufficiently small crystals) the helium-4 product is released at the boundaries of the lattice. In this situation, as opposed to “chirping” a laser, to cause the “lattice” to accelerate, provided the “lattice” is sufficiently small and/or an applied electric field is sufficiently weak, the analogous configuration, associated with confining the atoms in the ABEC within the optical lattice, occurs at the point of perfect stoichiometry: \( x=1 \) in \( \text{PdD}_x \). The associated limit, in nano-scale crystals, in which the lattice accelerates, can occur when an external, static, electric field \( \mathbf{E}=\rho \mathbf{E} \), that is sufficiently weak, is applied.

When this occurs, resonant forms of interaction can take place when the change in momentum \( \Delta p \) of the CM of any collection of indistinguishable, charged particles equals the product of a reciprocal lattice vector, \( G_n \), with \( h \) (i.e., when \( \Delta p = hG_n \)). When this occurs, momentum can be transferred coherently (and rigidly) to the center of mass of the lattice. This resonant condition was postulated by Bloch to take place at each time \( t_n \) defined when the condition,

\[
q\mathbf{E}t_n = \hbar \mathbf{G}_n,
\]  

(1)
is satisfied. Here, q is the total charge, associated with particles that are involved with the resonant condition, and the associated form of resonance (as identified above) is referred to as a Bloch Oscillation.

When the limit x=1 in PdDₓ occurs (associated in the gravity situation with the limit in which no atoms leave the lattice), the most coherent form of interaction (which I have referred to Zener/Ionic breakdown in PdD[7,8]) can take place. This corresponds, effectively, to a situation in which the d’s do not occupy ion band states (and can be viewed as being in an insulating state) but are constrained to acquire larger and larger momentum (ℏGₙ), until the momentum reaches the critical value that is necessary to create the d+d→⁴He reaction. In the semi-classical limit, the reaction will then take place provided the total energy E, defined by the integral of the power (expressed using the dot product of the force F of each “particle”— charged or neutral, and located inside or outside the lattice and/or the solid — with its possible velocity v), over time, equals 23.8 MeV. Here, when the applied electric field E is constant and uniform, within the lattice, each value of the wave-vector, for each electron and ion band state, evolves from its initial value, kₒ, through the associated change in the zero of momentum[2], defined by k(t) = kₒ + qEt.

Then, inside the lattice, the possible electron and ion band (excited) state transitions associated with the resonant effect can be constructed using the representation of the power (defined by the product of the charge of the particles in the band q(k(t)), with the dot product, \( \frac{\hbar \delta \tilde{k}(t)}{\hbar \delta \tilde{k}(t)} \cdot \tilde{E} \), between the group velocity \( \frac{\delta \tilde{\varepsilon}(\tilde{k}(t))}{\hbar \delta \tilde{k}(t)} \) and the applied field, \( \tilde{E} \).

In general, additional contributions to the power occur through forces and changes in the velocity of particles outside the lattice and/or the solid. In situations associated with gas-loading, a number of the more important, additional contributions can be constructed, using the applied pressure and density. Details about the associated construction are developed elsewhere[9]. Previously, I showed for the model to be self-consistent, the requirements that collisions be stifled, which require that when all d’s occupy a common band, the group speed be sufficiently small and that the d’s remain in an insulating state, lead to the result that the crystal be sufficiently large but not too large. Optimal crystals, in the context of this model, have characteristic dimensions of ~ 60 nm[7,8].

The possibility that overlap can take place at nuclear scale size is associated with the potential for momentum to change abruptly, over sufficiently short length scales. When this occurs, the conventional tunneling picture completely breaks down, and overlap becomes possible because the variance in momentum can become appreciable, through processes that are not forbidden by the uncertainty relationship. These forms of potential overlap become more likely with increasing time because as time increases, larger and larger changes in momentum can result from the associated forms of resonant coupling,
through the oscillations of the charged particles within this approximately periodic region. A new result, in this context, involves the idea of modeling the underlying dynamics in smaller, nano-scale structures, in which these idealized compounds are allowed to form through resonant EMI, transiently, for finite periods of time, in which small variations $\delta$, in loading $x=1\pm|\delta|$ are allowed to take place through EMI coupling that results from the possibility that $\delta$’s and electrons associated with the variations in $x$ involve the occupation of energy band states.

Provided $|\delta|$ is sufficiently small, this occurs in situations when $x=1-|\delta|$, effectively, from ion band states that have “negative” ionic charge (and each of the associated states can be viewed as forming a “hole,” in the ion energy band, similar to the positively charged “electron hole” states that can be created by doping a semi-conductor), and when $x=1+|\delta|$, the situation can be viewed as involving the occupation of conventional (positively) charged, deuteron, ion band states. In an analogy with the situation associated with electron-hole pairs and electron-hole annihilation in semi-conductors, we can infer that in suitably small crystals, slight variations in loading, potentially triggered by external fields, in principle, can induce coherent fluctuations, involving delayed forms of excitation and the emission of light. The associated forms of coupling, potentially, can be generalized and be applied in other systems, including some of the kinds of situations encountered in some of the glow discharge work. These results, as well as other results, presented elsewhere[1], which suggest that the orientation of externally applied fields, potentially, can be important for triggering high energy particles in situations involving the SPAWAR protocol[10], suggest that it could be useful to conduct a series of experiments, involving a detailed investigation of the potential role of field orientation and variation, in possible forms of electromagnetic radiation emission and the creation of high energy particles.

References

[9] Scott R. Chubb, to be published
Synthesis Of A Copper Like Compound From Nickel And Hydrogen
And Of A Chromium Like Compound From Calcium And Deuterium

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ABSTRACT

A working hypothesis is presented that aims to explain results observed in the LENR-CF field. This hypothesis is based on a novel conjecture: a very sizeable increase of the strength of gravitation at pico-meter distances. Experiments designed to confirm (or deny) this working hypothesis are described.

Introduction

Various phenomena have been observed when hydrogen isotopes are brought in contact with metals or submitted to the action of an electrical discharge. Among them, most striking are the following:

- a positive difference between the energy released by a system under experiment and the energy it receives from the outside has been observed for instance in the electrolysis of heavy water with palladium electrodes (Fleischmann and Pons). This has been called “excess energy.”
- elements with an abnormal isotopic composition have been observed to appear in some systems (electrolysis, deuterium permeation through palladium, glow discharge…) during and sometimes after the experiment. (Iwamura, Miley, Savvatimova…).
- according to various teams (Oriani, Storms and Scanlan) nuclear radiations are emitted in some systems (electrolysis, glow discharge…) during and sometimes after the experiment.

Given the very low level of “reaction products” appearing in the experiment, when compared to the level of “excess energy” observed, these phenomenon have been ascribed to a special kind of nuclear reactions (Cold Fusion: CF, Low Energy Nuclear Reactions: LENR). These reactions would emit several orders of magnitude less radiation than expected from the “excess energy” or the amount of “reaction products” observed.

A series of experiments have been run to shed some light on the field. They have been designed to confirm or deny a conjecture that was previously presented [1] and that might explain the whole features of the CF, LENR field. They imply contacting hydrogen
isotopes with various metals, under well defined experimental situations. That could result in the synthesis of unusual chemical elements, formed by a novel type of binding between the metal nucleus and the hydrogen isotope (a bond strength ranging from hundreds of electron volts to several thousand electron volts). The results will be presented and discussed in relation to this conjecture.

**Experimental strategy**

From an operational point of view, these reactions (assuming they exist) are very difficult to trigger. A macroscopic effect (sizeable excess energy) is seldom achieved. This might be the consequence of a relatively high level of energy required for those unknown reactions to occur (5 to 10 eV). Such levels of activation energies are indeed found in metal lattices or in gaseous plasmas. These reactions usually result in the appearance of reaction products in trace amounts and/or the emission of nuclear radiations, without measurable “excess energy.” It has nevertheless been thought that the microscopic features of these products could well provide guidance for better controlling the macroscopic effect (excess energy). As will be seen, the basis of the experimental approach is to characterize the trace elements produced. It is thus of paramount importance that these traces be perfectly controlled in the starting material. Various situations have thus been studied to choose the one that satisfies best this condition. In this series of experiments, 3 types of situations, in which hydrogen isotopes are in contact with metals have been studied or are under study:

- Situations where hydrogen is in contact with nickel. Various experiments have shown that in these conditions excess energy and/or “transmutation” of nickel into copper occur [2],[3]. Hydrogen in contact with nickel during the reduction of nickel chloride (**system I**) and the hydrogen in contact with Raney nickel (**system II**) have been studied. It will be seen that only hydrogen reacts in that case.
- Situations where hydrogen is in contact with calcium (in the form of calcium carbonate or calcium oxide). Palladium, present in the experiment yields atomic hydrogen (deuterium). This configuration is intended to reproduce experiments presented in [4], where strontium is transmuted into molybdenum. The approach was to contact hydrogen with a LINDLAR type of catalyst (**system III**). It will be seen that only deuterium reacts in that case.
- Situations where hydrogen, activated in a low pressure ozonizer is in contact with metals, are under study.

The following 3 systems have been studied:

- I Reducing nickel chloride by hydrogen isotopes
- II Hydrogen isotopes in contact with Raney nickel
- III Hydrogen isotopes in contact with Lindlar catalyst (Palladium on calcium Carbonate)

Experimental description

NICKEL

System I

A number of studies (particularly with regard to batteries) have been carried out with the objective of finding a process yielding finely divided nickel.

Such a process is described in [5]. Basically, nickel in nickel chloride is reduced to its metallic state by hydrogen, according to:

\[
2 \text{NiCl}_2 + H_2 \rightarrow 2 \text{Ni} + 2 \text{HCl}
\]

As such, the reaction proceeds at 450°C, yielding particles with mean diameter 2.5 µm (see [5]). The addition of 0.1% weight palladium allows a lowering of the reduction temperature to 380°C, together with a reduction to 0.4 µm of the mean diameter (see [5]).

Experiments have been carried out using NiCl₂,6H₂O (Rectapur from PROLABO), containing less than 5 ppm copper, to which 0.1% weight palladium was added according to [5]. The reduction was carried out in a vertical Pyrex reactor, heated to 380°C, the hydrogen isotope flowing through the chloride to be reduced (see Reactor I, figure 1).

System II

Raney nickel is a well known catalyst used for hydrogenation. It is prepared by dissolving (by sodium hydroxide), the aluminum contained in an aluminum/nickel alloy. This yields finely dispersed nickel particles, supported on an alumina matrix. PROLABO Raney nickel 25 820.230 was used. The catalyst was placed in an alumina boat, inside a metallic reactor (see reactor II, figure 2). It was first dried and activated by heating to 450°C under vacuum. It was then placed in contact with a hydrogen isotope (hydrogen or deuterium) at 450°C, under a pressure of 5 bars, for 2 hours.
Fig. 1. Reactor I

Fig. 2. Reactor II
CALCIUM

System III:
Lindlar catalysts were developed to selectively hydrogenate acetylene bonds. Palladium is deposited on alkaline-earth carbonates as nano-particles. Palladium loading between 5 and 10% weight are used. Both a commercial catalyst (Alfa-Aesar palladium 5% weight on calcium carbonate) and a homemade one were used. Experiments were run after de-carbonation of the catalyst, thus yielding the CaO-Pd system. Hydrogen isotopes (hydrogen and deuterium) were placed in contact with the de-carbonated catalyst under various temperature and pressure conditions, in Reactor II.

Characterization of the processed samples
As mentioned in the introduction, the synthesis of novel chemical elements is suspected in the CF LENR field. To get insight on the features of these new elements, their outermost electronic layer has been explored by ICP-AES (Varian) available at the laboratory in CNAM and their nucleus by ICP-MS available outside.

All samples have been dissolved in hot aqua-regia. Nickel from the reduction of nickel chloride and Lindlar catalyst were completely soluble, whereas a residue (alumina) was left with the Raney nickel.

Main results

NICKEL
Results are summarized in Table 1 below. It can be seen that the copper content (in mgCu/gNi) is always higher for treated samples when compared to blank ones (RATIO mgCu/gNi), when hydrogen is used. One sample submitted to the action of deuterium shows no variation of the RATIO mgCu/gNi being within the error bars.
Table 1. Ratio of mgCu/gNi processed samples compared to blanks

<table>
<thead>
<tr>
<th>Nickel Type</th>
<th>Exp. No.</th>
<th>Reactor I</th>
<th>RATIO AES</th>
<th>MS</th>
<th>AES/MS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Gas</td>
<td>AES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RANEY</td>
<td>1</td>
<td>1.976</td>
<td>Hydrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RANEY</td>
<td>2</td>
<td>2.102</td>
<td>Hydrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NiCl₂ red.</td>
<td>3</td>
<td>2.833</td>
<td>Deuterium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NiCl₂ red.</td>
<td>4</td>
<td>3.089</td>
<td>Hydrogen</td>
<td>1.777</td>
<td>1.738</td>
</tr>
<tr>
<td>NiCl₂ red.</td>
<td>5</td>
<td>1.186</td>
<td>Deuterium</td>
<td>0.944</td>
<td>1.256</td>
</tr>
<tr>
<td>NiCl₂ red.</td>
<td>6</td>
<td>2.636</td>
<td>Hydrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NiCl₂ red.</td>
<td>7</td>
<td>1.420</td>
<td>Deuterium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NiCl₂ red.</td>
<td>8</td>
<td>1.842</td>
<td>Hydrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean value</td>
<td></td>
<td>2.039</td>
<td>Hydrogen</td>
<td>2.364</td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td></td>
<td>0.089</td>
<td>Hydrogen</td>
<td>0.704</td>
<td></td>
</tr>
</tbody>
</table>

Samples from experiments 4 and 5 (and a corresponding blank), were then analyzed by ICP-MS. It can be seen that ICP-MS sees significantly less copper than ICP-AES for experiment 4 (hydrogen), the RATIO AES/MS being 1.738. In contrast, experiment 5 (deuterium) is within the errors bars: no excess copper appears in the treated sample; ICP-AES and ICP-MS sees the same amount of copper (RATIO AES/MS being 1.256). This conclusion is in line with what was expected (see below for the case of calcium and the discussion of the conjecture).

ICP-MS did not reveal any significant variation of the isotopic composition of the copper found in the hydrogen treated sample compared to that of the blank one. An important increase of the $^{63}_{29}Cu$ isotope was indeed expected (see below the case of calcium for more detailed explanations). It cannot be excluded that the model presented in [1] is too simple to correctly predict the rate of reaction of the various isotopes involved (indeed reference [3] indicates an increase of $^{65}_{29}Cu$ compared to $^{63}_{29}Cu$). More trivial reasons could also play a role to explain this result:

- Conditions of the ICP-AES and ICP-MS measurements. Matrix and nebulization effects could play a role. This could be better understood with more elaborate (and more costly) analysis: standard addition in the case of ICP-AES, isotopic dilution for ICP-MS.
- Heterogeneity of the samples of starting material. Indeed, the nickel chloride to be treated is obtained by evaporation, and one cannot exclude a selective crystallization
of the trace amounts of copper. The case of Raney nickel is even worse, because an insoluble residue of alumina remains after the attack by aqua-regia.

In view of these problems, it was decided to switch to a more favorable system, prompted by the results of [4].

CALCIUM

Results are summarized in Fig. 3 below.

The calcium and chromium contents of the samples (respectively in g/l and mg/l) were measured by ICP-AES and the RATIO mgCr/gCa calculated. 10 experiments gave a comparable RATIO, yielding an average value with which all results were normalized. The lines “average value of the blanks ± 3 sigma” are shown in Fig. 3.

Various operating conditions were used:
- De-carbonation temperature.
- Hydrogen (deuterium) contact time.
- Hydrogen (deuterium) pressure.
- Blanks were run with argon, in comparable conditions and the RATIO mgCr/gCa was also determined on the untreated catalyst.
It can be seen from Fig. 3 that three experiments are beyond the 3 sigma limits (note that 2 experiments can have the same number on the graph. They are indeed different; it is just a matter of presentation of the graph).

Experiments with hydrogen, argon, deuterium, high temperature (450°C) and untreated catalysts are within the 3 sigma limits. In contrast, experiments with deuterium at low temperature (130 to 150°C) are beyond these limits.

No attempt as yet been done to measure chromium by ICP-MS. The results expected will be discussed in the following section. For the time being, the work on the system CaO-hydrogenating metal is directed in two directions:

Synthesize Lindlar type catalysts starting from calcium compounds having the lowest possible chromium content.

Submit Lindlar type catalysts (as a very thin layer spread on one of the Pyrex electrodes of an ozonizer), to the action of an ozonizer discharge in various gases (deuterium, hydrogen, argon…). This experimental set-up is very clean: the discharge taking place between 2 Pyrex dielectric barriers only sees Pyrex and the catalyst to be treated, thus avoiding pollution of the samples to be analyzed after the experiment.

Conditions of the discharge currently under study are:

- Gas pressure of the gas 1 to 50 mb
- Temperature 50 to 150°C
- Distance between electrodes 5 mm
- Voltage 1500 to 2500 V
- Current 2 to 40 mA
- Frequency 5 to 15 kHz

Under these conditions, a sizeable amount of H+, D+ or Ar+ with energy of around 10 eV will impact the LINDLAR type catalyst.

Interpretation of the results

In order to make clear what is expected, according to the conjecture that will be discussed below, the case of calcium is summarized in Table 2.
Table 2. Isotopic composition of calcium

<table>
<thead>
<tr>
<th>Isotope Composition (‰)</th>
<th>ICP - AES Mass Addition Composition (%)</th>
<th>ICP - MS ISOTOPIC COMPOSITION (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca48 0.187 47.952533</td>
<td>39.962591 41.955818 48.1018591</td>
<td>Ca48 55.940643 52.940651 52.940651</td>
</tr>
<tr>
<td>Ca46 0.004 45.953689</td>
<td>43.95548 42.9558766 49.946046</td>
<td>Cr56 9.5 2.365 83.79 4.345</td>
</tr>
<tr>
<td>Ca44 2.086 54.000669</td>
<td>52.01148 51.014766 49.946046</td>
<td>Cr54 2.365 9.5 83.79 4.345</td>
</tr>
<tr>
<td>Ca43 0.135 43.95548</td>
<td>51.014766 51.940579 49.946046</td>
<td>Cr53 2.365 9.5 83.79 4.345</td>
</tr>
<tr>
<td>Ca42 0.647 42.9558766</td>
<td>50.944768 51.940579 49.946046</td>
<td>Cr52 2.365 9.5 83.79 4.345</td>
</tr>
<tr>
<td>Ca40 96.941 41.955818</td>
<td>49.946046 51.940579 49.946046</td>
<td>Cr48 2.365 9.5 83.79 4.345</td>
</tr>
</tbody>
</table>
In the first part of Table 2 (ICP-AES) the isotopic composition of calcium and the mass of the corresponding isotopes is given (columns composition and mass). In column “addition of 4D”, the mass of hypothetical compounds, obtained by the addition of 4 deuterons to the various calcium isotopes is given. If the conjecture is verified (see below), ICP-AES, used for determining the calcium content of a sample, will see all these hypothetical compounds, because they all have the same outermost electronic layer.

In the second part of Table 2 (ICP-MS), the masses of known chromium isotopes (both stable and unstable) are given (in the Mass column). In order to determine the chromium content of a sample by ICP-MS, the amounts of isotopes 50, 52, 53 and 54 are measured. If the conjecture is verified (see below), the amount of chromium like compounds, coming from the various calcium isotopes and seen by ICP-MS will be much lower than the amount of these compounds seen by ICP-AES (2.737 compared to 100). Moreover, an upward shift of masses will be observed.

In other words, the ratio mgCr/gCa for a treated sample will be higher when measured by ICP-AES than when measured by ICP-MS.

More generally, when measuring the amount of converted products, there will be a discrepancy between the results obtained by ICP-AES and those obtained by ICP-MS. This was observed for the conversion of nickel to “copper” (see above).

The pico-chemistry conjecture

This conjecture has been presented in [1]. The following basic hypothesis is made: at distances within atomic dimensions (say 100 pm as an order of magnitude), there is a considerable increase of the strength of gravity, up to a level where the gravity attraction between the nucleus of an atom A and a proton (or deuteron) can counter balance the electrostatic repulsion between them. An (over-simplified) calculation points to the possibility of bound states between A and the proton (or deuteron), at distances well within the electronic layers of A. The enthalpies of reaction in this new chemistry (pico-chemistry) would in the range of hundreds of electron volts up to several thousand electron volts (partly emitted as X-Rays), whereas the activation energies would be tens of electron volts, which explains why it is difficult to trigger these reactions. In the case of deuterium, this initial pico-chemistry reaction could be followed by a true nuclear reaction, the deuteron reaching the nucleus of A and reacting with it, thus yielding a transmuted nucleus and various nuclear radiations (α, β, γ). The conjecture and its consequences are summarized in Fig. 4 below.
As can be seen from Fig. 4, the pico-chemistry conjecture could explain:

The production of energy from deuterium and/or hydrogen (depending upon the treated atom A).
The emission of X-Rays.
The emission of nuclear particles ($\alpha, \beta, \gamma$), in very small amounts.
The appearance of transmuted products.
Conclusion

The working hypothesis presented in this paper, leads to clean, simple and reproducible experiments that will confirm (or deny) the pico-gravity conjecture. If the results of these experiments are positive, a novel field of chemistry will open. It is proposed to call this new field “pico-chemistry”. Pico-chemistry enthalpies of reaction (in the range of hundreds of electron volts to several thousand electron volts) could provide a new source of energy. A massive graviton, with mass between 25 to 50 keV, would be associated with pico-chemistry.

References

External Radiation Produced by Electrolysis — A Work in Progress

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Abstract

Oriani has shown that electrolysis of ordinary water generates showers of energetic charged particles that can be detected outside the electrolysis cell. Here I attempt to confirm external radiation and to explore some of its properties. Possible sources of error are investigated. Preliminary experiments have not revealed showers, but they suggest that a flux of radiation may be emitted from the cell with an intensity that declines with distance from the cell. Further work with better control of environmental factors is required before a definitive statement can be made. Nuclear reactions and decay products that may be responsible for the radiation remain to be identified.

Prompted by the initial report by Fleischmann, Pons and Hawkins [1] of nuclear reactions accompanying electrolysis, hundreds of other investigators have reported various nuclear phenomena including energy production, generation of helium and tritium, nuclear transmutations, and emission of energetic charged particles. A comprehensive bibliography of this work can be found in the review by Storms [2].

Many experiments have employed an electrolysis system consisting of a glass cell with an electrolyte of a lithium salt in water or heavy water as electrolyte, a platinum anode, and a nickel or palladium cathode. Energetic charged particles associated with electrolysis can be recorded in CR39 plastic detectors and can be revealed by chemical etching. The present work employs a system with an electrolyte of Li$_2$SO$_4$ in ordinary water (sometimes slightly enriched with D$_2$O) and a nickel cathode, and is addressed to the investigation of energetic charged particles in the air outside the electrolysis cell.

The detector chips employed contained many latent tracks as received from the manufacturer, apparently alpha particles from decay of airborne radon and from radon that had diffused into the surface layers of the chips and decayed there. $^{222}$Rn has a half life of 3.8 days which is long enough for it to diffuse a short distance into the plastic detector. Within a few hours after decay it emits three alpha particles in a series of reactions ending with $^{210}$Pb. The $^{210}$Pb has a half life of 22 years and emits a fourth alpha particle in reaching stable $^{206}$Pb. Fewer than 10% of the $^{210}$Pb atoms will have decayed during the two or three years between manufacture and use of the detector material. Hence most embedded radon atoms generate tracks for three alpha particles. With sufficient etching to reach beyond the maximum penetration depth of radon, tracks with...
favorable orientations (i.e. near enough to perpendicular to the detector surface) can be revealed by etching and many of these can be resolved.

The density of etch pits developed on a detector chip depends on the duration of the etching process. Figure 1 shows etch pit densities for as-received detector chips as a function of etching time at 80°C in 6.5 N KOH. For times of 1 and 2 hours no pits at all were observed. For 3 or more hours etch pits were observed, at first increasing in numbers and then leveling off after 6 or 7 hours. The upper curve shows total etch pits per chip and the lower curve shows the numbers of pits that occurred in multiplets for which two or three distinct tracks from decay of a single radon nucleus could be resolved. Based on this study an etching time of 7 hours was employed in subsequent research.

As-received detector chips showed wide variation in latent track density, which is largely responsible for the fluctuations in etch pit numbers in Fig. 1. This variation was examined in a series of 23 chips with the result shown in Fig. 2. The mean track density was 314 etch pits per 1.5 cm² counted area per detector chip. The large dispersion suggests that chips should be pre-etched before undertaking an experiment to reveal pre-existing tracks, then etched again after the experiment to reveal the desired incremental tracks. However, double etching was not employed in the present work.
FIGURE 1. Etch pit density as a function of etching time in 6.5N KOH at 80°C. Density is measured in etch pits per 1.5 cm² detector area. Total pits include those that occur in multiplets of 2 or 3 from decay of embedded radon. No pits are formed for etching times of 1 or 2 hours, after which the density of pits rises and levels off after about 7 hours.

Oriani [3] observed external particles utilizing an electrolysis cell whose cathode was a sheet of nickel that capped and closed the otherwise open bottom of a cylindrical glass cell. The electrolyte was a solution of Li₂SO₄ in ordinary water. A large particle shower containing about 150,000 energetic particles was detected in the H₂ + O₂ vapor above the electrolyte. Below the cathode was clamped a second length of glass cylinder containing a mixture of air and such quantity of hydrogen as may have diffused through the nickel cathode. In a second experiment [4] Oriani placed a detector in the vapor below the cathode. During electrolysis the detector recorded tracks from a shower of about 150 energetic particles that emanated from a point in the gas below the cathode and above the surface of the detector.
FIGURE 2. Latent tracks in detector chips as received from the manufacturer. The histogram shows the numbers of detector chips having counts in 20-pit intervals from 240 to 400 pits per chip. The mean number of pits per chip is 314.

The present experiments employ a modified cell that is closed at the bottom by a glass microscope slide. The cathode is a nickel wire whose lower end is shaped like the letter W that rests on the glass closure. The electrolyte was a solution of 2.2 g Li$_2$SO$_4$ in 100 ml ordinary water, sometimes enriched with D$_2$O. It was in contact with the glass cell wall, the glass bottom closure, and a Viton rubber O-ring that lies between the cell and the closure to prevent leakage of electrolyte. The upper end of the cell remains open to permit the escape of hydrogen and oxygen electrolysis products. All system components with the exception of the O-ring were made of commercial materials that had not previously been associated with electrolysis. The O-ring had been used by Oriani in his experimental work. Any nuclear particles that reach the outside air during electrolysis must pass through the glass cell wall, the glass closure, or the Viton O-ring; or must have exited the open end of the cell along with the effluent gases.
FIGURE 3. Density of etch pits as a function of distance from the cell. Chips measuring 1 cm × 2 cm were placed with long edges in contact on a horizontal surface about 1 cm below the level of the O-ring. Exposures of 4 days were made in an indoor laboratory and in an outdoor ice chest. The indoor exposure suggests that energetic particles may reach out to a distance of about 8 cm from the cell (the solid horizontal line is a background level determined from 6 remote detectors at a distance of about 200 cm). The ice chest exposure suggests a weakened or dead cell as discussed in the text.

An experiment was designed to detect energetic particles in the air surrounding the cell. Ordinary water was used in the electrolyte. Sixteen CR39 detectors (approximately 2 cm × 1 cm) were aligned lengthwise face-up with long edges in contact, on a flat surface extending out about 16 cm from the glass wall of the cell. This surface was about 1 cm below the bottom level of the electrolyte. Electric power was supplied by a low-capacity 6 volt battery. The apparatus was assembled in a closed ice chest that was placed outdoors to avoid the possibly higher level of radon in laboratory air. Exposure time was 96 hours. The system was unattended except for occasional brief opening of the chest for addition of distilled water to maintain the level of electrolyte. During the experiment the battery voltage dropped from 6 V to 3.5 V. The variation of etch pit density with distance from the cell is shown in the dashed curve in Fig. 3. The number of etch pits per 1.5 cm²
of measured detector chip area rose from about 500 pits/chip at a distance of 0.5 cm from the cell to a maximum of about 800 pits/chip at a distance of 3.5 cm, then fell to a background level of about 500 pits/chip at a distance of 6–8 cm.

The level of cell activity appeared to be significantly reduced after the ice chest experiment, or perhaps even to have disappeared before or during the experiment. In an attempt to bring the cell back to health the cathode was sanded to disturb the surface layers and a small amount of D₂O was added to the electrolyte, increasing the D₂O concentration to perhaps 5% of the fluid (I did not keep an accurate record).

Cell activity appeared to have been restored, and a distance experiment was conducted indoors. This experiment exposed 14 chips in line extending out from the cell as in the ice chest experiment, plus six chips at a distance of about 200 cm to serve as controls. The variation of etch pit density with distance from the cell is shown in the upper curve in Fig. 3. The pits/chip ratio rose from about 1200 at a distance of 0.5 cm to about 1400 at 1.5 cm, then declined to the level of the controls at about 8–11 cm. The indoor experiment suggests that charged particle tracks in excess of background level can be observed out to a distance of about 8 cm from the cell wall. The ice chest result is puzzling because the concentration of pits is at background level near the cell, passing through a maximum about 2 cm from the cell.

In addition to reducing the background from airborne radon relative to the indoor level, the ice chest protects the system from laboratory air currents while subjecting it to the currents associated with convection flow powered by about 1 watt of electrolysis power. An air flow experiment was conducted to explore the possibility that air currents may influence the particle flux. The electrolyte was ordinary water with addition of approximately 5% D₂O, the same electrolyte as used in the indoor distance experiment. The D₂O concentration declined throughout the experiment owing to the periodic addition of distilled water to maintain the level of electrolyte in the cell. A fresh nickel cathode was employed.

In the indoor air flow experiment 2 or 3 detector chips were placed face up on a surface near the cell about 1 cm below the bottom level of the electrolyte. The centroid of their combined areas was about 3 cm from the cell wall. An electric fan was placed about 25 cm from the detectors, set on “low”, blowing air across the detectors toward the cell. After 2 days the fan was turned off and the chips were etched and counted. These chips then were replaced by a second set and the experiment was continued with the fan off for another 2 days after which the second set of chips was etched and counted. Two additional alternating 2-day fan-on and fan-off runs were made. Finally a fan-on run was
made with the detector chips separated by a distance of 80 cm from the cell while maintaining the 25 cm spacing between fan and chips.

The results of this experiment are plotted in Fig. 4. When the fan is on the flux of particles in excess of preexisting background increases by a factor of about 7 compared with when the fan is off. Furthermore, when the fan is on its influence overwhelms and masks that of electrolysis. It is clear that flow velocity is a major contributing factor to the density of tracks that form in CR39 detectors exposed to air. This confirms the observation of R. R. Engel [5] of an order of magnitude increase in recorded tracks in a CR39 detector chip mounted on the end of a ceiling fan blade.

**FIGURE 4.** Influence of air flow on track density. The experiment consisted of 7 consecutive 2-day runs during which the electrolysis cell remained on. In each run 2 or 3 chips were placed either 3 or 80 cm from the cell, and a fan directed at the chips was either on or off. Track density in excess of background is an order of magnitude greater when the fan is on compared with when it is off, independent of the separation of the chips and the cell.
Although the current of air from the fan exceeds that from various currents of room air and of convection currents from the warm cell in a closed ice chest, it is necessary to consider the influences of these smaller currents. They may be sufficiently large that if unrecognized and uncontrolled they could mask the experimental signals being sought. In the ice chest a stable circulating flow of air can be maintained by the \( \sim 1 \) W power of the electrolysis cell. Air warmed by the cell will rise, spread laterally, cool, descend, and flow back toward the cell where it again becomes heated. There will be a region of stagnation close to the cell below the bottom of the column of warm electrolyte, in which the air velocity will be small and in consequence the density of new tracks will be small. The velocity will be a maximum at a distance from the cell comparable with the dimensions of the column of electrolyte, at which distance the density of new tracks will also be a maximum. Beyond this distance air velocity and track density will decline to a background level. For a weak or dead cell this may provide an interpretation of the dashed curve in Fig. 3.

In the indoor experiment the pattern of air flow is complex and uncontrolled. To the convective current associated with the warm cell must be added currents from the circulation system that warms the laboratory, to currents from opening and closing doors, from personnel walking close to the equipment, and from convection currents from a nearby hotplate intermittently used for heating the etchant. In aggregate these currents may be roughly independent of distance from the cell. For this reason the solid curve in Fig. 3 may provide a fair approximation to a flux of particles from the cell. This is not strong evidence but it is the best presently available from these experiments. It suggests that a flux of radiation may extend outward from an active cell and weaken with distance.

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References

Abstract

I suggest that neutron clusters of sufficient size are bound and stable against strong decay; and that they can react with ordinary nuclei by transferring neutrons to them, accepting neutrons from them, and binding with them to form composite nuclei. Implications of this enlarged scope of nuclear physics are explored, including a chain reaction with nuclear fuel $^2$H that produces energy, $^4$He, $^3$H, and a wide range of nuclear transmutations. Natural explanations emerge for these and other nuclear phenomena for which evidence has been accumulating over the past two decades.

1. Introduction

Over the past two decades many room-temperature experiments have demonstrated nuclear phenomena that lie outside the purview of present nuclear theory. These include generation of energy in amounts not attributable to non-nuclear sources, production of helium and tritium, generation of high energy alpha particles, and transmutations of ordinary nuclei. Here I propose that massive neutron isotopes, or polyneutrons, are key reactants in this new family of nuclear phenomena.

One widely studied experimental system consists of a glass-walled electrolysis cell containing a palladium or nickel cathode, a platinum anode, and an electrolyte of LiOD, Li$_2$SO$_4$ or D$_2$SO$_4$ dissolved in D$_2$O or H$_2$O. Beginning with the pioneering work of Fleischmann, Pons and Hawkins [2] this system has provided evidence for the generation of energy in excess of amounts that are explicable by electrochemical Processes [10,12] and for production of substantial amounts of $^4$He [11]. Small amounts of $^3$H have been observed [19]. Energetic charged particles have been observed by means of detectors immersed in the electrolyte [13,14] and in the vapor over the electrolyte [15]. The review prepared by Storms [18] provides a broad overview of this research. A different experimental system employs flow of deuterium through a thin layer of target element on the surface of a palladium/CaO foil. Transmutations of a number of target elements have been observed [5,6].

In seeking explanations for the foregoing observations we can first rule out deuterium fusion as a contributor because the required reaction products are not observed. Theory rules it out as well because at room temperature there is insufficient thermal energy to overcome the coulomb barrier. Indeed the coulomb barrier rules out every low-temperature nuclear reaction between charged particles, leaving only neutral particles as
possible mediators. Neutrons play this role in the commercial reactors that provide energy for electric power generation and ship propulsion, but neutrons cannot be mediators in electrolysis experiments because searches show that they are not present in sufficient numbers. Neutral particles of a different kind are required. Here I explore the possibility that they are polyneutrons.

Polyneutrons can be understood as liquid droplets of neutrons, just as ordinary nuclei have been understood as mixed droplets of neutrons and protons. I propose that they are key reactants in a new family of nuclear phenomena. Based on evidence obtained from particle showers recorded on detector chips exposed to the vapor from electrolysis cells, supplemented by evidence from transmutations and from tritium generation, many of their properties have been deduced and many of their reactions with ordinary nuclei have been quantified.

It emerges that the polyneutrons typically encountered in shower and transmutation experiments contain hundreds of neutrons. They are held together by binding energies of about 7 MeV per neutron, nearly half as strongly as nucleons are bound in ordinary nuclei. A portion of the binding energy is associated with collective pairing of neutrons having opposite spins and momenta, in analogy with electron pairing in superconductors.

Polyneutrons are highly reactive with ordinary nuclei, able to exchange neutrons with them and to catalyze their beta decay. They are beta unstable and transform to massive hydrogen nuclei in which a proton shares the nuclear symmetry of the parent polyneutron. Subsequent beta decays generate polyneutron-derived isotopes of helium and lithium and boron and so on until rising coulomb energy prevents further beta decay. Alpha particle emission then remains the favored decay channel. Exceptionally a rare alpha decay releases a free polyneutron that can ignite a chain reaction in an appropriate environment. The chain reaction may die out, or it may continue at a bounded rate depending on environmental factors.

Polyneutrons can form strongly bound composites with some ordinary nuclei. The composites are stable against beta decay and against flow of neutrons between the polyneutron and the ordinary nucleus. Their decay channels are coordinated double beta and alpha decays of the polyneutron component. Such decays play important roles in shower and transmutation experiments.

2. The theory

The theory is based on three assumptions:
1. Polyneutrons containing six or more neutrons are bound.
2. Polyneutrons undergo beta decay with unchanged nuclear symmetry.
3. Polyneutrons and their decay products obey the laws of nuclear physics.
I employ notation in which $^A n$ is a polynutron containing $A$ neutrons, and in which $^A H_p$ is a cluster of $A-1$ neutrons and 1 proton that has the same nuclear symmetry (isospin) as $^A n$, the same nuclear interaction energy as $^A n$, and the same excitation spectrum as $^A n$. The subscript p on $^A H_p$ is a reminder that its nuclear symmetry is identical with that for the polynutron $^A n$. Similarly $^A He_p$ is a cluster of $A-2$ neutrons and 2 protons, and so on. I write $\Delta(^A n)$, $\Delta(^A H_p)$, $\Delta(^A He_p)$, … for their mass excesses in MeV. The mass excesses $\Delta(^A H_p)$, $\Delta(^A He_p)$, … differ from $\Delta(^A n)$ only by the mass difference $\Delta(^1 H) - \Delta(n) = -0.782$ MeV per proton and by the coulomb energy of multiple protons.

The challenge to theory is to find numerical values for these mass excesses that can account for the observations of energy, helium, tritium, energetic particles, transmutations, particle showers, and other new low-temperature nuclear phenomena.

The present state of the theory is embodied in the following expression for the mass excesses in MeV:

$$\Delta(^A n) = 104.7 A^{-1} + 1.088 A + 0.698 A^{2/3} \quad (+4.2 \text{ if } A \text{ is odd}),$$

$$\Delta(^A H_p), \Delta(^A He_p), \ldots = \Delta(^A n) - 0.782 Z + 0.57 Z (Z-1) A^{-1/3}$$

where $Z$ is the number of protons in the nucleus.

The following sections review the evidence supporting the mass excess formula and explore the extent to which the theory provides understanding of the new nuclear phenomena.

3. Chain reaction

High energy particles whose tracks are permanently recorded in CR39 detector chips provide irrefutable evidence for nuclear reactions and provide clues to the nature of the nuclear processes involved. One experiment in particular stands out in this regard. Oriani and I observed and analyzed a giant particle shower in the vapor over an active electrolysis system [16]. The electrolyte was a solution of lithium sulfate in ordinary water, and the cathode was nickel. A pair of opposing detector chips was hung in the vapor above the liquid surface. The shower contained about 150,000 alpha particles, of which about 30,000 were recorded on one detector chip and about 11,000 on the other. The particle energies were about 2 MeV indicating release of about $10^{-8}$ joules. Examination of the pattern of tracks indicates that the shower source was closer to the chip with 30,000 tracks than to the one with fewer tracks, and that it evolved rapidly before convection currents in the vapor carried it away. There was a very rapid initial portion that took place in a fraction of a second, followed by a slower portion that lasted for several seconds as the source moved along with the vapor.
Figure 1 is a photograph of the tracks recorded on one of nearly 300 areas that cover the surface of the 30,000-track chip. Figure 2 shows a plot of the variation of track density over the entire surface of the chip. The location of the initial rapid reaction is clearly visible at the large peak, as is the evolution of the slower reaction that drifts with convection currents. Theory must provide an explanation for these observations.

I assume that the particle shower in Figures 1 and 2 resulted from a polyneutron chain reaction that began with a single polyneutron in the vapor. (The source of this polyneutron is identified below.) Chain reaction requires that polyneutrons grow and divide in interaction with ordinary nuclei in a series of exothermic reactions, leading to exponential growth in their numbers. Potential fuels are limited to isotopes of hydrogen and oxygen present in the vapor. The isotopes $^2$H (0.015%), $^{17}$O (0.038%), and $^{18}$O (0.200%) are among potential exothermic reactants because being more massive than their sibling isotopes $^1$H and $^{16}$O they can provide the required reaction energies. Their isotopic percentages are shown in parentheses.

Figure 1. Etch pits on the surface of a CR39 plastic detector chip suspended in the vapor over an active electrolysis cell. Each pit marks the location of a track of damaged material where a charged particle has penetrated the chip. A roughly conical pit has developed during etching because the etchant attacks the damaged material of the track more rapidly than it attacks the adjacent undamaged material. The area shown measures approximately 0.58mm x 0.44mm. The mean diameters of the darker circular pits are approximately 24 microns.

Consider $^2$H as a fuel. The known mass excesses $\Delta(^2H) = 13.136$ MeV and $\Delta(^1H) = 7.289$ MeV together with the polyneutron mass excesses from Formula 1 lead to the polyneutron growth reaction
\[ {^2H + \textit{A}n \rightarrow ^1H + ^{\textit{A}+1}n + (0.504/8.905) \text{ (even } A/\text{odd } A), \ (A \approx 600). \quad (2) \]

(Reaction energy values are always given in MeV.) The size of the polyneutron is not critical; for \( A \approx 50 \) the energy release changes only slightly to \((0.474/8.873)\).

Polyneutron fission reactions are exothermic with energy \( E \) for a range of odd \( A \) values,

\[ {^2H + \textit{A}n \rightarrow ^1H + ^{\textit{B}}n + ^{\textit{A} - \text{B} + 1}n + E \quad (49 \leq \text{odd } A \leq 1235, \text{ even } B). \quad (3) \]

The energy \( E \) depends on the value of \( B \). I assume that the most likely value of \( B \) is that for which \( E \) is a maximum. Examples of the most likely fissions for selected values of \( A \) include the smallest polyneutron that can undergo fission

\[ {^2H + ^{49}n \rightarrow ^1H + ^{26}n + ^{24}n + 0.119}, \]

the largest polyneutron that fissions into equal parts

\[ {^2H + ^{151}n \rightarrow ^1H + ^{76}n + ^{76}n + 1.643}, \]

and larger polyneutrons that fission into unequal parts

\[ {^2H + ^{155}n \rightarrow ^1H + ^{92}n + ^{64}n + 1.608}, \]
\[ {^2H + ^{299}n \rightarrow ^1H + ^{260}n + ^{32}n + 0.369}, \]
\[ {^2H + ^{1235}n \rightarrow ^1H + ^{1204}n + ^{32}n + 0.000}. \]

Reaction 3 completes a chain reaction in which many repetitions of reaction (2) cause a polyneutron to grow substantially, after which reaction (3) causes it to fission. Then the same series of reactions causes the fission products to grow and fission, and so on, providing the elements for exponential polyneutron multiplication and a runaway chain reaction.
Figure 2. Density of tracks on the surface of a CR39 plastic detector chip suspended in the vapor over an active electrolysis cell. The chip area is about 0.64 cm$^2$ and the mean track density is about 45,000 cm$^{-2}$. White areas are areas where tracks could not be counted, including the hole for the supporting wire (cross shape at the top of the chip), factory-inscribed identifying numbers (bottom right of the chip), and a few areas with surface damage. The location of the initial reaction is clearly visible at the large peak, as is the evolution of the slower reaction that drifts with convection currents. Re-plotted from [16].

Yet the reaction in the shower experiment stopped before there was an explosion. Additional reactions must be considered. The hydrogen isotope $^1$H cannot participate in neutron-transfer reactions with polyeutrons because all such reactions are endothermic. In consequence a $^1$H nucleus and a polyeutron will maintain their unique identities even if they touch, and even if they bind through surface effects to form a composite nucleus. Evidence presented below suggests that nuclear composites play significant roles in polyeutron reactions. The composite that results from a polyeutron binding to $^1$H is written $^1$H$^A$n. Its components are written adjacent to each other in analogy with chemical molecules such as NaCl. Composites can be formed in the reactions
\[ 2H + ^A_n \rightarrow ^1H^Bn + ^{A-B+1}n + E + E_b \quad \text{(odd A, even B)} \]  

very similar to reaction (3) but where the reaction products \(^1H\) and \(^Bn\) form a composite with binding energy \(E_b\). (I assume \(^Bn\) to be the larger of the two product polyneutrons because I expect it to be more strongly bound to \(^1H\).)

Polyneutrons can interact with composites in reactions of the form

\[ ^1H^Bn + ^A_n \rightarrow ^1H^{B+A-C}n + ^Cn + E \quad \text{(A+B \geq 49).} \]

As a polyneutron grows larger through successive reactions (2) the free polyneutron \(^Cn\) in reaction (5) grows smaller and reaches \(^{32}n\) for very large composites. Reaction (3) shows that it must grow at least to \(^{49}n\) before it can fission, requiring as many as 17 successive growth reactions (2). When the concentration of large composites is large enough, a single reaction (5) will return a free polyneutron to \(^{32}n\) before the growth reactions have time to occur, in consequence of which all polyneutrons are reduced to sizes less than \(^{49}n\) and kept there, the chain reaction stops, and the residual reactions involving small polyneutrons gradually die out as polyneutrons undergo beta decay, become charged, and can no longer participate in nuclear interactions.

We are left with the composites that were created in reaction (4) and that grew to large size by repetition of reaction (5). These composites are unstable and decay by coordinated beta decay and alpha particle emission. As shown below each composite emits many alpha particles, and together the alpha particles from decay of all composites constitute the giant shower shown in Figure 2.

### 4. Liquid drop model

In deriving the mass excess formula (1) I begin with a liquid drop model which in its simplest form is

\[ \Delta(^A_n) = (\Delta(n) - a_v) A + a_s A^{2/3}. \]

In this expression the mass excess \(\Delta(^A_n)\) equals the mass excess of \(A\) neutrons, less a volumetric term proportional to \(A\) that represents the strength of the nuclear binding energy of the drop, plus a term proportional to \(A^{2/3}\) that represents the surface energy of the drop. Experimental evidence reviewed below requires that odd-\(A\) polyneutrons have an excess energy \(\epsilon\) that must be included in the formula,

\[ \Delta(^A_n) = (\Delta(n) - a_v) A + a_s A^{2/3} (+ \epsilon \text{ for odd } A). \]
The excess energy for odd \( A \) suggests that the neutrons in the droplet form a collective state with pair correlations similar to those in superconductivity where an odd electron has excess energy. Such correlations are long-range and extend over many neutrons. Let \( A_c \) be this correlation number. Then for \( A < A_c \) the coefficients \( a_v \) and \( a_s \) are no longer constant but approach zero for \( A = 4 \), where experiment [9] shows that \( \Delta(4n) \approx 4 \Delta(n) \). In an attempt to model the weakening of \( a_v \) and \( a_s \) for values of \( A \) less than the correlation number I introduce a term \( a_0 A^{-1} \) giving the final form of the polynutron mass excess

\[
\Delta(A^n) = a_0 A^{-1} + (\Delta(n) - a_v) A + a_s A^{2/3} \quad (+ \epsilon \text{ for odd } A).
\]

In order to obtain numerical values for the four unknown parameters \( a_0, a_v, a_s, \epsilon \) in this expression I require

1. \( \Delta(4^n) = 4 \Delta(n) \) to agree with the marginal binding of \( 4n \),
2. Growth reaction (2) and tritium reaction (26) to be exothermic,
3. The isotope \( ^{150}\text{Sm} \) to be unreactive with large polynutrons,
4. The parameter \( a_s \) to lie close to the maximum consistent with 1-3 above.

The first three requirements are objective but the fourth is subjective; smaller values of \( a_s \) are possible but seem less likely to me. The requirements are satisfied by parameters \( a_v = 6.983, a_s = 0.698, a_0 = 104.7, \) and \( 3.819 < \epsilon < 4.704 \). For definiteness I take \( \epsilon = 4.2 \) in the middle of its range and arrive at the poly neutron mass excess in formula (1). The electrostatic terms in formula (1) are derived below.

**5. Concerns**

Mass excess formula (1) raises serious concerns. In particular the volumetric binding energy coefficient \( a_v = 6.983 \) is very large, amounting to 45% of the 15.5 value for ordinary nuclei [8]. This strong binding is in complete disagreement with calculations based on n-n reaction strengths derived from the energetics of ordinary nuclei, which predict that neutron aggregates are unbound. In addition the experimental observations that \( ^2n \) is unbound and that \( ^4n \) is at best marginally bound [9] do not hint at stronger binding for larger neutron aggregates. Yet strong binding is a requirement for the theory I propose; with weaker binding polynutron growth cannot be exothermic and the theory collapses.

A second concern is the magnitude of the surface energy. In formula (1) the surface energy coefficient \( a_s = 0.698 \) is only 10% of the volumetric coefficient \( a_v \). In contrast the value of \( a_s = 16.8 \) for ordinary nuclei is 108% of the volumetric coefficient. Yet small surface energy is another requirement for the theory; with larger surface energy polynutron fission cannot be exothermic and the theory again collapses.
Rather than abandon the theory I note that the currently available n-n interaction strengths are phenomenological, not fundamental. They were designed to fit n-n interactions between neutrons that are constrained by the shell symmetry of ordinary nuclei. No interaction strengths have been published for aggregates of neutrons in mutual interaction free from shell model constraints. Mass excess formula (1) and supporting experimental evidence presented below suggest a cooperative neutron-pair interaction having symmetry related to electron pairing in superconductivity; one that does not reach full strength until the number of neutrons exceeds about 50. It then becomes possible to think that new interaction parameters apply. Then formula (1) can be viewed as a first step in determining the phenomenological interaction strengths for large clusters of neutrons. This is the spirit in which I proceed.

6. Correlation barrier

A significant feature of polynuclear reactions is the absence of neutrons among the reaction products. Neutron production cannot be ruled out by energetics. Consider polynuclear growth reaction (2),

\[ ^2\text{H} + ^A\text{n} \rightarrow ^1\text{H} + ^{A+1}\text{n} + E_A \]  

which transfers a neutron from \(^2\text{H}\) to polynuclear \(^A\text{n}\), promoting polynuclear growth and releasing energy \(E_A\) that depends only on the value of \(A\). The related reaction

\[ ^2\text{H} + ^A\text{n} \rightarrow \text{n} + ^{A+1}\text{H}_p + E_A \]

which transfers a proton to a polynuclear is also exothermic with exactly the same energy, but the near absence of neutrons in electrolysis experiments shows that it seldom occurs. Since it cannot be suppressed by energetics or by quantum selection rules I assume that it is kinetically inhibited by a potential barrier, similar in effect to the coulomb barrier which inhibits alpha decay.

Such a barrier can arise if the neutrons in a polynuclear participate in a collective condensation of pairs analogous to the electron-pair condensation in superconductivity. In this case a barrier is associated with the initial localization of the proton from \(^2\text{H}\) as it merges into \(^A\text{n}\) to form \(^{A+1}\text{H}_p\). The wave function for the integrating proton corresponds initially to a localized proton at the surface of the polynuclear \(^A\text{n}\) and finally to a distributed proton that is paired uniformly throughout \(^{A+1}\text{H}_p\). In getting from the initial to the final configuration it has to pass through configurations where it is paired with a few neighboring neutrons and then with an increasing number of neutrons as it spreads out. The energy associated with pairing with only a few neutrons corresponds to the energies of \(^2\text{H}_p\), \(^4\text{H}_p\), \(^6\text{H}_p\), and perhaps beyond, all of which are unbound or nearly so and have
energies comparable to the same numbers of free nucleons. This is the correlation barrier that must be penetrated by a proton. In the present analysis I consider that reactions involving proton localization are strongly suppressed.

This is my justification for the assertion in Section 7 that alpha decay of polyneutron-derived nuclei is strongly suppressed: in these decays a correlation barrier must be overcome as distributed protons become localized to form \(^4\text{He}\). On the other hand there is no correlation barrier for beta decay because a distributed neutron transforms to a distributed proton without the necessity for localization.

By accepting the concept of a correlation barrier as necessary to suppress neutron generation, we must also accept collective neutron pairing and the consequence that an unpaired neutron does not share the binding energy of the fully paired state, leading to an excess energy for odd-\(A\) polyneutrons.

### 7. Polyneutron decay

Beta decay is the transformation of a neutron into a proton plus an electron plus an antineutrino. Reactions are often written with the proton and the electron combined in a hydrogen atom and with the antineutrino implicit: \(n \rightarrow ^1\text{H}\). Following this practice I consider beta decay of a polyneutron that emits a free proton. This reaction is endothermic even for odd \(A\) and the maximum value of \(\varepsilon\), and cannot occur spontaneously:

\[
^{A}n \rightarrow ^{A-1}n + ^1\text{H} - 5.088 \quad (\text{odd } A \approx 600).
\]  

(8)

Polyneutron beta decay can be exothermic only if the proton is incorporated into the transmuted polyneutron where it can participate in the nuclear symmetry, maintaining an unchanged nuclear interaction energy. Symbolically the transmuted polyneutron is \(^{A}\text{H}_p\), a massive hydrogen isotope that has the same paired spin structure as \(^{A}n\), the same nuclear interaction energy as \(^{A}n\), and the same excitation spectrum as \(^{A}n\).

Let \(^{A}Z_p\) represent any of the polyneutron-related nuclei \(^{A}n\), \(^{A}\text{H}_p\), \(^{A}\text{He}_p\), \(^{A}\text{Li}_p\), \(\ldots\), where \(Z\) reflects the number of protons in the nucleus. The liquid drop model for the mass excesses of ordinary nuclei contains the coulomb energy term \(0.72Z(Z-1)A^{-1/3}\) [8]. Assuming that the densities of \(^{A}Z_p\) are about half that of ordinary nuclei the coulomb contribution to their mass excesses is about \(2^{-1/3}\) times as great. The overall mass excess for \(^{A}Z_p\) then is

\[
\Delta(^{A}Z_p) = \Delta(^{A}n) - 0.782Z + 0.57Z(Z-1)A^{-1/3}.
\]  

(9)

This is the source of the electrostatic terms in formula (1). The \(-0.782Z\) term is the energy associated with a loss of \(Z\) neutrons and a gain of \(Z\) protons and electrons.
Beta decay of polyneutron-related nuclei proceeds in the series of reactions $^A\text{n} \rightarrow ^A\text{H}_p \rightarrow ^A\text{He}_p \rightarrow ^A\text{Li}_p \rightarrow ^A\text{Be}_p \rightarrow ^A\text{B}_p \rightarrow \ldots$ which continues until the buildup of coulomb energy from the increasing numbers of protons turns the reaction endothermic. Beta decay $^A\text{Z}_p \rightarrow ^A(Z+1)_p$ is exothermic provided that $\Delta(^A\text{Z}_p)$ is greater than $\Delta(^A(Z+1)_p)$. If $^A\text{Z}_p$ is less than $^A(Z+1)_p$ beta decay is endothermic. However alpha decay of $^A\text{Z}_p$ is possible in the reaction $^A\text{Z}_p \rightarrow \rightarrow ^A-4(Z-2)_p + ^4\text{He}$ where a double arrow is used for alpha decays. In consequence we have several reaction chains, each corresponding to a distinct range of values of A, including

\begin{align*}
^A\text{Li}_p & \rightarrow ^A\text{Be}_p \rightarrow ^A\text{B}_p \rightarrow \rightarrow ^A-4\text{Li}_p + ^4\text{He} \quad (198<A<388) \quad (10) \\
^A\text{He}_p & \rightarrow ^A\text{Li}_p \rightarrow ^A\text{Be}_p \rightarrow \rightarrow ^A-4\text{He}_p + ^4\text{He} \quad (84<A<198) \quad (11) \\
^A\text{H}_p & \rightarrow ^A\text{He}_p \rightarrow ^A\text{Li}_p \rightarrow \rightarrow ^A-4\text{H}_p + ^4\text{He} \quad (24<A<84). \quad (12)
\end{align*}

A polyneutron with A in the range $198<A<388$ undergoes successive beta decays until it reaches $^A\text{B}_p$ in reaction series (10). It then undergoes alpha decay to $^A-4\text{Li}_p$ which recycles in the same reaction chain through two beta decays and an alpha decay to $^A-8\text{Li}_p$ and so on losing four neutrons each cycle until the value of A drops below 198. The decay particle then cycles through reaction series (11) until A drops below 84, and then through series (12) until A drops below 24.

The half-life for alpha decay of polyneutron-related nuclei is expected to be much longer than the half-life for beta decay; alpha decay is slow because it must overcome the correlation barrier for distributed protons to localize in a helium nucleus (see section 6). Nuclei decay rapidly through the beta portions of chains (10-12) until they reach $^A\text{B}_p$, $^A\text{Be}_p$, or $^A\text{Li}_p$, at which point they lie dormant awaiting the slower alpha decay. A dormant $^A\text{B}_p$, $^A\text{Be}_p$, or $^A\text{Li}_p$ that reaches the vapor will intermittently emit alpha particles as it cycles through successive iterations of reaction chains (10-12). I suggest that these particles are responsible for the random scatter of tracks recorded on detectors in the vapor[13].

Reaction chains (11) and (12) cycle through $^A\text{He}_p$ which exceptionally can liberate a polyneutron in the slow alpha decay reaction

$$^A\text{He}_p \rightarrow \rightarrow ^A-4\text{n} + ^4\text{He} + 1.365 .$$

I suggest that this is the origin of the initial polyneutron that ignited a chain reaction in the vapor.
8. Particle showers

In addition to the giant shower pictured in figures 1 and 2 which contained about 150,000 alpha particles, Oriani and I have observed significantly smaller showers that contain at most a few hundred alpha particles [17]. I propose that both types of showers result from decay of $^{16}\text{O}^An$ composites formed in reactions of polyneutrons with $^{17}\text{O}$ or $^{18}\text{O}$ such as

$$^{18}\text{O} + B\text{n} \rightarrow ^{16}\text{O}^An + B^{-A+2}n$$

(14)

where $B^{-A+2}n$ is smaller than $^An$. The related reaction in which both product polyneutrons are free is endothermic for all values of A and C. However reaction (14) can be exothermic provided that the binding energy $E_b$ is sufficiently large. I assume this to be so.

In order to understand the decay of $^{16}\text{O}^An$ it is desirable first to consider the role of polyneutron excitations in the decay of composite nuclei. I assume that polyneutrons have a spectrum of low-energy phonon-like excitation levels, and that partition of energy among these levels thermalizes in the strong-interaction time of about $10^{-20}$ s. These excitations can influence reaction rates on the same time scale because they are coupled by strong forces to other degrees of freedom in composites, and to reaction products as they are being formed. Partition between excitation and kinetic energies assures that polyneutrons absorb a portion of the energy released in every reaction in which they participate. I denote a hot polyneutron by $^An^*$ and a hot composite by $^{16}\text{O}^An^*$ and where desirable distinguish between hot and cold nuclei because they can have different reaction rates.

Turning now to consideration of $^{16}\text{O}^An$ composite decay, beta decay that releases a free proton in the reaction $^{16}\text{O}^An \rightarrow ^{16}\text{O}^{A-1}n + ^1\text{H}$ is endothermic and cannot occur. The reaction $^{16}\text{O}^An \rightarrow ^{16}\text{O}^An^p$ is also endothermic because of the coulomb energy associated with the proximity of the proton in $^An^p$ to the eight protons in $^{16}\text{O}$. The composite also is stable against double beta decay $^{16}\text{O}^An \rightarrow ^{16}\text{O}^An^p$ in which both protons of $^An^p$ share the collective pair correlations with $(A-2)$ neutrons. However exothermic decay can be accomplished by coordinated double beta decay and alpha particle emission. Decay of a cold composite is

$$^{16}\text{O}^An \rightarrow ^{16}\text{O}^{A-4}n + ^4\text{He} + (2.147 - E_T)$$

(15)

where $E_T$ is the thermal energy of the hot product composite and $(2.147 - E_T)$ is the kinetic energy of the products. Decay of a hot composite is

$$^{16}\text{O}^An^* \rightarrow ^{16}\text{O}^{A-4}n^* + ^4\text{He} + 2.147$$

(16)
where the excitation of the reactant is passed on to the product. The half life of reaction (16) is shorter than for reaction (15) because more kinetic energy is available.

It is suggested below that large numbers of $^{16}\text{O}^A_n^*$ composites are formed in the vicinity of the cathode during electrolysis. I assume that some of them cool to $^{16}\text{O}^A_n$ by photon emission before they decay. Because reaction (15) is relatively slow some of these cold composites survive long enough to reach the vapor. When finally they decay the initial reaction (15) is followed by closely spaced multiple instances of reaction (16), releasing a small shower of particles. The giant shower shown in figures 1 and 2 can then be understood as the aggregate decays of hundreds of $^{16}\text{O}^A_n^*$ composites that were created in the chain reaction.

Figure 3. Shower of etch pits on a detector chip supported in air under a nickel cathode. The width of the image is approximately 2mm. Arrows indicate the directions in which charged particles impinged on the chip. The electrolyte was Li$_2$SO$_4$ in H$_2$O. (The virgin chip was etched before beginning the experiment to
reveal pre-existing particle tracks. During the following etch they grew to twice the diameter of the experimental pits and can be distinguished by their large size.)

Figure 3 shows one of the small showers observed by Oriani [17]. In obtaining this shower he employed an electrolysis cell in which the electrolyte is contained within a vertically oriented glass tube and the cathode is a thin sheet of nickel that closes the bottom of the tube and provides a watertight seal. The upper cathode surface is in contact with the electrolyte and the lower surface is in contact with air. The shower was recorded on a CR39 plastic detector placed in air under the cathode. To understand how this may have occurred I note that polynutrons that enter the cathode from the electrolyte shrink in interactions with nickel. The most exothermic reaction involves $^{58}\text{Ni}$ (68%),

$$^{58}\text{Ni} + ^{100}\text{n} \rightarrow ^{62}\text{Ni} + ^{96}\text{n} + 11.230.$$  

(17)

The reaction products share the energy, and that of product polynutron $^{96}\text{n}$ exceeds 4 MeV. I assume that such energetic polynutrons have relatively long mean free paths between repetitions of reaction (17) and that some of them penetrate the cathode and emerge into the air below it. Although polynutrons in air can grow in interaction with $^{17}\text{O}$ in the reaction

$$^{17}\text{O} + ^{101}\text{n} \rightarrow ^{16}\text{O} + ^{102}\text{n} + 11.230$$  

(18)

they also can shrink in interaction with $^{40}\text{Ar}$ in the reaction

$$^{40}\text{Ar} + ^{101}\text{n} \rightarrow ^{42}\text{Ar} + ^{99}\text{n} + 1.739.$$  

(19)

Because the concentration of $^{40}\text{Ar}$ in air is so large the shrinkage reaction overpowers the growth reaction and a chain reaction cannot be sustained. However formation of a composite $^{16}\text{O}^\text{A}n$ is possible by reaction (14), after which the composite can decay in a small shower by multiple instances of reaction (16) as described above. Each alpha emission in these reactions reduces the size of the polynutron by four neutrons, in consequence of which the number of alphas emitted by a single composite is limited to 1/4 the number of neutrons in its initial polynutron component. The 46 particle tracks recorded in figure (3) suggest about 150 alpha particles in the full shower and about 600 neutrons in the parent $^{16}\text{O}^\text{A}n$ composite. About 1000 such small showers together comprise the large shower in figure 2.

9. Role of electrolysis

In the foregoing we must identify the source of the $^{16}\text{O}^\text{A}n$ composites whose decays produce small showers of alpha particles in the vapor, and we must identify a source of
polyneutron decay products $^A\text{B}_p$, $^A\text{Be}_p$, and $^A\text{Li}_p$ that release free polyneutrons in the vapor and ignite chain reactions. I propose that these precursors are formed in a region of extreme agitation near the cathode during electrolysis, and that a few are able to reach the vapor before they fully decay.

Hydrogen and deuterium atoms are generated at the cathode surface where they combine to produce molecules that supersaturate the electrolyte to a level that supports homogeneous bubble nucleation. Many tiny bubbles appear in the electrolyte near the cathode and trigger a maelstrom of competitive growth. Surface tension requires that bubbles of different sizes be in equilibrium with different levels of saturation, small bubbles with a high level and large bubbles with a lower level. At any given level bubbles larger than a critical size will grow and smaller bubbles will shrink. The situation is unstable. Minor differences in size and in local hydrogen or deuterium concentration enable a few bubbles to take the path of runaway growth while the majority shrink and vanish. Then growth of the large bubbles slows as they move away from the region of bubble nucleation.

Now consider the fate of a polyneutron in the electrolyte near the surface of a bubble in its rapid growth stage. There it ignites a chain reaction and the concentration of $^{16}\text{O}^{A}n^{*}$ reaction products begins to rise. The cloud of reaction products that would have built up and would have quenched the reaction in a quiescent fluid gets stretched tangentially and shrunken radially into a portion of a thin spherical shell. The thickness of the active region tends to increase because of the continuing chain reaction but it is held in check by the thinning action of bubble expansion. Reaction can persist as long as bubble growth is rapid, but ultimately a bubble moves into a region with a lower concentration of dissolved gas and the growth rate slows. The thinning rate becomes insufficient to stop buildup of composite nuclei poisons and reaction at that bubble is quenched. But this is not the end of the story. The reaction from an active bubble can be transferred by polyneutron diffusion to rapidly growing bubbles behind it, igniting them, and the process can continue indefinitely with the result that a bounded reaction rate can be maintained near the surface of the cathode where bubble nucleation and rapid growth occur. In summary, a single polyneutron that is released near a rapidly growing bubble in an electrolysis experiment can ignite a reaction that will persist near the cathode as long as electrolysis persists, whereas in contrast a chain reaction in a quiescent electrolyte is quenched by localized buildup of poisons. In this interpretation fluid agitation is the key contribution of electrolysis.

I assume that other means than electrolysis, including mechanical agitation, can maintain the high fluid shear rate required to disperse poisons and to provide a steady input of fresh reactant for maintaining a reaction. In consequence I expect that here and there in rapidly flowing streams and waterfalls where sufficiently high shear rates exist, chain reactions are proceeding with $^2\text{H}$ from water as fuel, and are providing ongoing sources for $^A\text{B}_p$, $^A\text{Be}_p$, and $^A\text{Li}_p$ nuclei. Chemically these nuclei are massive boron,
beryllium, and lithium isotopes that mix along with their decay products $^3\text{H}$ and $^4\text{He}$ into the hydrosphere and the atmosphere, where further decay via reactions (10-13) provides free polyneutrons that can ignite new chain reactions in nature and in the laboratory.


The most careful and instructive studies of transmutation have been conducted by Iwamura and associates [5-7]. They designed an apparatus in which an element to be transmuted, the target element, was deposited on the front surface of a specially constructed palladium diaphragm containing in its interior thin layers of CaO. Deuterium was passed through the diaphragm from a pressurized chamber on the front side to a vacuum chamber on the back side. During each experiment concurrent X-ray photoelectron spectroscopy (XPS) showed that a new chemical element appeared on the surface where none had been before, and that the concentration of the target element declined.

I discuss first the mechanism by which a nuclear reaction can be sustained in this system. Because the deuterium gas is quiescent, the mechanism that maintains the reaction cannot be mechanical agitation as proposed for electrolysis experiments. I suggest a second mechanism in which calcium plays a key role. I assume that the chain reaction persists primarily in the deuterium gas where polyneutron growth can be sustained. Polyneutrons that enter the palladium shrink rapidly because shrinkage reactions are exothermic and growth reactions are endothermic. Nevertheless some polyneutrons survive to reach the CaO films where they can react with calcium. The major calcium isotope $^{40}\text{Ca}$ (97%) reacts vigorously with small polyneutrons in reactions such as

$$^{40}\text{Ca} + \, ^{58}\text{n} \rightarrow \, ^{48}\text{Ca} + \, ^{50}\text{n} + 18.769.$$  \hspace{1cm} (20)

Polyneutrons composed of 50 or fewer neutrons exit reaction (20) with energies of 9 MeV or more. I assume that some of them penetrate back through the palladium film that lies between the CaO and the deuterium gas to where they ignite fresh volumes of deuterium that lie beyond the previously generated poisons $^1\text{H}^\text{m}$ that are flowing into and through the palladium with the general current of hydrogen isotopes.

It has been shown that calcium is essential for maintaining the reaction [6]. No reaction occurred when MgO was substituted for CaO in the layered foil. This is consistent with theory. The major magnesium isotope $^{24}\text{Mg}$ (79%) reacts with small polyneutrons in reactions such as

$$^{24}\text{Mg} + \, ^{54}\text{n} \rightarrow \, ^{28}\text{Mg} + \, ^{50}\text{n} + 5.781$$  \hspace{1cm} (21)
which produces polyneutrons with about a third of the energy of the calcium reaction. Few if any of these polyneutrons have sufficient energy to reach the deuterium gas before they thermalize and decay, and hence a chain reaction cannot be sustained when Mg is substituted for Ca.

**10. Transmutation 2. Selected reactions.**

The analysis in this section is based on the transmutation research of Iwamura et al. [5-7]. Their observations provide both qualitative and quantitative challenges to theory. Table 1 lists the transmutation reactions they have reported, together with additional reactions that have been deduced from their published results. The table also provides interpretations that are discussed in more detail below.

The transmutations

\[
\begin{align*}
\text{Sr} & \rightarrow \text{Mo} & \Delta Z &= 4 \\
\text{Cs} & \rightarrow \text{Pr} & \Delta Z &= 4 \\
\text{Ba} & \rightarrow \text{Sm} & \Delta Z &= 6
\end{align*}
\]  

were studied by several techniques and are firmly established. To good approximation the increase of Mo nuclei occurs simultaneously with the decrease of Sr nuclei as detected by X-ray photospectroscopy. Similarly the increase of Pr occurs simultaneously with the decrease of Cs as does the increase of Sm with the decrease of Ba. This strongly suggests that these transmutations do not proceed through intermediate steps of comparable duration, but in closely bunched multiple steps that lead to relatively long-lived isotopes that build up in concentration and reveal themselves as transmutation products.
TABLE 1

Transmutations of Sr, Cs, and Ba targets on a Pd substrate. Column 1 lists target elements and isotopes with references to the experiments. Column 2 lists the corresponding chemical signals observed for the transmuted elements. XPS stands for X-ray photoelectron spectroscopy and XRF for X-ray fluorescence spectroscopy. XPS signals are identified by the photoelectron energy levels employed for element identification. Column 3 lists the relative strengths of XPS signals observed. Column 4 lists mass numbers determined by secondary ion mass spectrometry (SIMS). The final column provides interpretations of the experimental observations. Interpretations based on polynutron theory are found in references 1, 20, 21, and 22.

<table>
<thead>
<tr>
<th>Target</th>
<th>Experimental Signal</th>
<th>Strength</th>
<th>Mass No.</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>88Sr → 96Zr + 100Mo [1]</td>
</tr>
<tr>
<td>Cs [5]</td>
<td>XPS: Pr3d5, Pr3d3</td>
<td>——</td>
<td>141</td>
<td>133Cs → 141Pr [5,1]</td>
</tr>
<tr>
<td>Cs [7]</td>
<td>XRF: La, Ba, or Ti</td>
<td>——</td>
<td>——</td>
<td>Cs → La, Ba, or Ti [7]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cs → La or Ba [1]</td>
</tr>
<tr>
<td>Ba [6]</td>
<td>XPS: Sm3d5, Sm3d3</td>
<td>9,6</td>
<td>——</td>
<td>138Ba → 150Sm [6,1]</td>
</tr>
<tr>
<td>Ba [6]</td>
<td>XPS: Xe3d5, Xe3d3</td>
<td>2, ½</td>
<td>——</td>
<td>137Ba → 136Xe [21]</td>
</tr>
<tr>
<td>137Ba [6]</td>
<td>——</td>
<td>——</td>
<td>138</td>
<td>137Ba → 138Ba [22]</td>
</tr>
</tbody>
</table>

It also suggests that transmutation reactions occur within composite nuclei that form in the initial polynutron reaction with a target nucleus. Then each further step can proceed rapidly without having to wait for a new polynutron. I assume that catalyzed beta decay
can drastically shorten lifetimes and allow rapid sequential beta decays within the composite nuclei $^{88}\text{Sr}\,\text{An}$, $^{133}\text{Cs}\,\text{An}$, and $^{138}\text{Ba}\,\text{An}$. One's imagination is stretched to contemplate that a weak reaction such as beta decay, with a half-life that can exceed many years for a free nucleus, can be catalyzed to a half-life on order of days, or perhaps seconds or less in a nucleus/polyneutron composite. Yet I see no other way that polyneutron theory can account for the experimental results, and I proceed on the assumption that such catalysis does occur. Perhaps it comes about because of an ability of polyneutrons to absorb energy in a spectrum of low-energy excitations on a nuclear timescale. This is a much shorter time scale than that for free beta decay and would allow a polyneutron to absorb much of the reaction energy, speeding the process and leaving a smaller proportion of energy for the emitted electron and neutrino. In turn this would diminish the energy of bremsstrahlung from the emitted electron, in agreement with the failure to detect energetic bremsstrahlung in transmutation experiments. X-rays emitted as the polyneutron cooled would also agree qualitatively with the observation of X-rays in the transmutation experiments [4].

The concentration of even polyneutrons in a chain reaction is expected to be much greater than that of odd ones. This follows from reaction (2) where reaction of an odd polyneutron with $^2\text{H}$ is exothermic by 8.905 MeV and the reaction of an even polyneutron to produce an odd one is exothermic by only 0.504 MeV. Odd polyneutrons are converted rapidly to even ones, which only slowly are converted to odd ones. Steady state corresponds to a preponderance of even polyneutrons. Because more of them are available I expect that most transmutation reactions will be initiated by even polyneutrons, and I temporarily neglect odd ones.

With the foregoing assumptions, transformation of a nucleus of $^{88}\text{Sr}$, $^{133}\text{Cs}$, or $^{138}\text{Ba}$ begins with formation of a nucleus-polyneutron composite. Within the composite neutrons flow from the polyneutron to the nucleus until the composite reaches its minimum energy. Beta decay then follows (or double beta decay if single beta decay is endothermic) and neutrons flow again until the transmuted composite reaches its minimum energy. We have a series of beta decays, each accompanied by an equilibrating flow of neutrons. The mass number of a nucleus grows as neutrons are added to it, but the mass number of the composite remains unchanged. I assume that beta decay of a nucleus in a composite is catalyzed by the polyneutron and occurs in a short time regardless of its lifetime as a free nucleus. Note in particular that some nuclei that are stable when free can undergo beta decay when bound in composites because of the associated flow of neutrons that can occur.

A transmuted composite can dissociate into a free transmuted nucleus and a free polyneutron provided that the reaction is exothermic. At any given time some transmuted nuclei remain bound in composites and some have been freed. Chemically and physically a composite such as $^{138}\text{Ba}\,^{600}\text{n}$ is a barium isotope with mass number 738. X-ray photospectroscopy (XPS), which measures electronic energy levels, will identify both
free nuclei and composites as barium. Secondary ion mass spectroscopy (SIMS), which measures mass, can identify only free nuclei. I assume that beta decay of bound nuclei that are stable when free is slower than decay of nuclei that are unstable when free. In consequence only stable nuclei survive long enough to accumulate in sufficient numbers to become observable by either XPS or SIMS.

The first few isotopes in the theoretical transmutation chains for $^{88}$Sr, $^{133}$Cs, and $^{138}$Ba that are stable when free, and that are expected to accumulate to an observable concentration, are

$$
^{88}\text{Sr} \rightarrow 2\beta \rightarrow ^{96}\text{Zr} \rightarrow 2\beta \rightarrow ^{100}\text{Mo} \rightarrow 12\beta \rightarrow ^{136}\text{Xe} \rightarrow \ldots \\
^{133}\text{Cs} \rightarrow \beta \rightarrow ^{137}\text{Ba} \rightarrow \beta \rightarrow ^{139}\text{La} \rightarrow 2\beta \rightarrow ^{141}\text{Pr} \rightarrow \beta \rightarrow ^{143}\text{Nd} \rightarrow 6\beta \rightarrow ^{163}\text{Dy} \rightarrow \ldots \\
^{137}\text{Ba} \rightarrow 2\beta \rightarrow ^{140}\text{Ce} \rightarrow 2\beta \rightarrow ^{144}\text{Nd} \rightarrow 2\beta \rightarrow ^{150}\text{Sm} \rightarrow \beta \rightarrow ^{156}\text{Eu} \rightarrow \ldots 
$$

(23)

The numbers of intermediate beta decays between stable (when free) nuclei are indicated in the arrows.

The parameters of the polyneutron mass excess $\Delta(^An)$ were selected to assure that $^{150}\text{Sm}$ is stable with respect to neutron transfers to or from a large polyneutron. This provides the tight constraint described in requirement 3 of Section 4 and leads to the chains of stable isotopes (23) that are inert to neutron transfers. The transmutation products listed in Table 1 are shown in bold face type in the transmutation chains. Every observed transmutation product is contained within these chains, and they tend to be the products that require the smallest numbers of beta decays. At present the theory is not capable of determining the rates of the steps in the various reaction chains, and cannot predict which products will accumulate to an extent that they can be detected.

Experimental evidence for strontium transmutation consists of an XPS signal for molybdenum and a SIMS signal for mass 96. It is natural to suggest $^{96}\text{Mo}$ as the transmutation product. However the theory identifies the XPS signal with $^{100}\text{Mo}$ and the SIMS signal with $^{96}\text{Zr}$. If $^{96}\text{Zr}$ were present one would expect an XPS signal for Zr; however this signal falls on top of the signal for the Pd substrate and would be undetectable if present. If $^{100}\text{Mo}$ were present one would expect a SIMS signal at mass 100, but the experimental SIMS measurement shows little if any enhancement at mass 100, suggesting that most $^{100}\text{Mo}$ is bound in composites leaving only a low concentration of free $^{100}\text{Mo}$. Theory does not yet provide means for determining the fraction of transmuted nuclei that have been freed. If further research should rule out $^{100}\text{Mo}$ as a transmutation product, the theory would have to be modified to include additional stable nuclei as transmutation products.

Reactions involving transfer of a single neutron can involve transmutation of a target nucleus into a free product, or into the initial composite of a reaction chain. Two reactions with free product nuclei are
\[ ^{137}\text{Ba} + ^{2A+1}n \rightarrow ^{138}\text{Ba} + ^{2A}n + 5.884 \]  \hspace{1cm} (24)

\[ ^{137}\text{Ba} + ^{2A+1}n \rightarrow ^{136}\text{Xe} + ^{4}\text{He} + ^{2A-2}n + 3.908. \]  \hspace{1cm} (25)

These reactions are both exothermic with comparable energy release, and there is experimental evidence for both as indicated in Table 1.

12. Deuterium reactions

Experiment suggests that deuterium plays a role in energy generation and in tritium production. These reactions provide bounds on the value of the excess energy \( \varepsilon \) associated with an odd neutron in an interacting polynutron. For energy generation we must have a chain reaction, and the polynutron growth reactions must be exothermic. The polynutron growth reaction (2) requires \( \varepsilon < 4.708 \text{ MeV} \). For tritium production we must have the exothermic reaction

\[ ^2\text{H} + ^{2A+1}n \rightarrow ^3\text{H} + ^{2A}n + (\varepsilon - 0.671) \]  \hspace{1cm} (26)

which requires \( \varepsilon > 0.671 \text{ MeV} \). These exothermic requirements provide constraints on the value of \( \varepsilon \) in mass formula (1).

The maximum rates of energy evolution during electrolysis have been obtained using heavy water D\textsubscript{2}O for the electrolyte and palladium for the cathode. During electrolysis the cathode absorbs large quantities of deuterium, amounting to nearly one deuterium atom per palladium atom. Under these circumstances a deuterium chain reaction can proceed within the cathode free of competition from oxygen and lithium fuels in the electrolyte, but subject to transmutation reactions between polynutrons and palladium isotopes. I assume that the primary energy-producing reactions are polynutron growth and decay. The sequential reactions

\[ ^2\text{H} + ^{A}n \rightarrow ^1\text{H} + ^{A+1}n \]
\[ ^2\text{H} + ^{A+1}n \rightarrow ^1\text{H} + ^{A+2}n \]
\[ ^2\text{H} + ^{A+2}n \rightarrow ^1\text{H} + ^{A+3}n \]
\[ ^2\text{H} + ^{A+3}n \rightarrow ^1\text{H} + ^{A+4}n \]
\[ ^{A+4}n \rightarrow ^A\text{n} + ^4\text{He} \]

lead to the overall reaction

\[ 4(^2\text{H}) \rightarrow 4(^1\text{H}) + ^4\text{He} + 21. \]  \hspace{1cm} (27)
(Note that the polynutron reactants are identical to the polynutron products and they cancel each other out.) This energy value is approximate. Neglected palladium transmutation reactions produce less helium per unit of energy released, and neglected chain reactions in the electrolyte produce more helium per unit energy. Overall I conclude that 21 MeV per helium atom is an approximate value for reactions between polynutrons and deuterium within a palladium cathode. This can be compared with the experimental value of approximately 24 MeV per helium atom [3].

13. Assessment

Polynutron theory offers natural explanations for many of the new low-temperature phenomena found to date, including large alpha particle showers in the vapor over an electrolyte, small alpha showers in the vapor, alpha particles in the electrolyte and in the air beyond, nuclear energy generation, transmutation, helium production and tritium production. Although the range of experiments available for verifying consistency of the theory is limited, a few cross-checks are possible. Theory suggested early on that energetic alpha particles could be detected in the vapor of an active electrolysis cell and in the air outside the cell, as subsequently verified by particle shower experiments. The mass formula, derived by fitting the theory to samarium and tritium reactions, implies an energy of 2.1 MeV for shower particles in agreement with the experimental value of 2 MeV. It also accounts for the positive role of calcium and the negative role of magnesium in supporting reactions in transmutation experiments. It suggests previously unrecognized transmutations for which evidence has been found in published experimental results. The theory also suggests energy and helium generation in the ratio of about 21 MeV per helium atom in palladium, in reasonable agreement with the experimental value of about 24 MeV.

We have here only a beginning toward reaching the level of quantification that has been achieved in neutron physics, but it is a beginning that I believe holds the seeds of true understanding of the nascent field of polynutron physics.

14. Acknowledgements

Immediately following the Fleischmann, Pons and Hawkins discovery, Thomas O. Paine and Barbara H. T. Paine urged me to investigate the subject and provided financial assistance for my early research. Unfortunately neither of these friends has lived to see the fulfillment of their hopes. Richard A. Oriani has been a supportive friend and colleague throughout, from his early confirmation of excess heat through our subsequent collaboration on the production of energetic particles. Without the support and encouragement of these three individuals I would not have attempted and persisted in this work. Others have provided encouragement and critical comments as the work progressed, in particular George H. Miley, William J. M. F. Collis, William J. Blythe, Jo
Ann Fisher and Mark E. Fisher. I am thankful for the support I have received from them all.

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21. Based on full XPS energy spectrum for barium transmutation [6]. A signal for Xe can be seen after subtracting a small overlapping Pd signal.

22. Based on SIMS data for $^{137}$Ba transmutation, adjusted for probable carbon contamination of the $^{137}$Ba measurement.
Theoretical Hypothesis of a Double Barrier Regarding the D-D Interaction in a Pd Lattice: A Possible Explanation of Cold Fusion Experiment Failures

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ABSTRACT

During the past 15 years, disputable experimental evidence has built up for low energy nuclear reaction phenomena (LENR) in specialized heavy hydrogen systems [1-4]. Actually, we cannot say that a new branch of science is beginning. In spite of experimental contributions, the real problem is that there is no theoretical explanation for LENR. In this work, we analyze the deuteron-deuteron reactions within palladium lattice by means of the coherence theory of nuclear and condensed matter [5] and, using this general theoretical framework accepted from ‘cold fusion scientists’, we will show the low occurrence probability of fusion phenomena. In fact, in the coherence approach, the D-D potential exhibits double barrier features and, in this way, the D-D fusion is inhibited.

1. Introduction

The Coherence Theory of Condensed Matter represents a general theoretical framework accepted by most of the scientists who work on cold fusion phenomena. In the coherence theory of condensed matter [5], it is assumed that the electromagnetic (e.m.) field due to elementary constituents of matter (i.e. ions and electrons) plays a very important role in a dynamic system. In fact, considering the coupling between e.m. equations, due to charged matter, and the Schrödinger equation of field matter operator, it is possible to demonstrate that, in proximity of e.m. frequency \( \omega_0 \), the matter system shows a coherence dynamics. For this reason, it is possible to talk about coherence domains whose length is about \( \lambda_{CD} = 2\pi/\omega_0 \). Of course, the simplest model of matter with coherence domain is the plasma system. In the usual plasma theory, we must consider the plasma frequency \( \omega_p \) and the Debye length that measures the Coulomb force extension, i.e. the coherence domain length. For a system with \( N \) charge \( Q \) of \( m \) mass within a \( V \) volume the plasma frequency can be written as:

\[
\omega_p = \frac{Q}{\sqrt{m}} \frac{N}{V} \quad (1)
\]
In this work, we will study the “nuclear environment”, that is supposed to exist within the palladium lattice D$_2$-loaded at room temperature as predicted by Coherence Theory. In fact, when the palladium lattice is loaded with deuterium gas, some people declared that it is possible to observe traces of nuclear reactions [1,2,3]. For this reason, many physicists talk about Low Energy Nuclear Reactions (LENR).

The more robust experiments tell us that, in the D$_2$-loaded palladium case, the more frequent nuclear reactions are [3,4]:

1.) $D + D \rightarrow ^3H + p + 4.03MeV$  \hspace{1cm} (2)

2.) $D + D \rightarrow ^4He + 23.85MeV$

In this work we also propose a “coherence” model by means of which we can explain the occurrence of reactions 1 and 2 and their probability according to the more reliable experiments. First, we will start from the analysis of the environment; i.e. of plasmas present within palladium (d-electron, s-electron, Pd-ions and D-ions) using the coherence theory of matter. Finally, we will use the potential reported in ref. [6,7] adding the role of lattice perturbations by means of which we compute the D-D tunneling probability.

2. The plasmas present within unloaded palladium

According to the Coherence Theory of Condensed Matter, in a palladium crystal at room temperature the electron shells are in a coherent regime within coherent domain. In fact, they oscillate in tune with a coherent e.m. field trapped in the coherent domains. For this reason, in order to describe the lattice environment, we must take into account the plasma of s-electron and d-electron.

a) The plasma of the d-electrons

The plasma is formed by electrons of palladium d-shell. We start by computing:

$$\omega_d = \frac{e}{\sqrt{m}} \sqrt{\frac{n_e N}{V}}$$  \hspace{1cm} (3)

as d-electrons plasma frequency. But, according to the coherence theory of matter, we must adjust this plasma frequency by a factor 1.38. We can understand this correction observing that the formula (3) is obtained assuming a uniform d-electron charge distribution. But, of course, the d-electron plasma is localized in a shell of radius R (that is about 1Å), so the geometrical contribution is:

$$\sqrt{\frac{6}{\pi}} = 1.38$$  \hspace{1cm} (4)
Labeled with $\omega_{de}$ the renormalized d-electron plasma frequency, we have [5]:

$$\omega_{de} = 41.5 eV/\hbar$$  \hspace{1cm} (5)

and the maximum oscillation amplitude $\xi_d$ is about 0.5 Å.

b) The plasma of delocalized s-electrons

The s-electrons are those that, in the lattice, neutralize the adsorbed deuterons ions. They are delocalized and their plasma frequency depends on the loading ratio (D/Pd percentage) by means of the following formula (5):

$$\omega_{se} = \frac{e}{\sqrt{m}} \sqrt{\frac{N}{V}} \sqrt{x} \lambda_a$$  \hspace{1cm} (6)

where

$$\lambda_a = \left[ 1 - \frac{N}{V} V_{pd} \right]$$  \hspace{1cm} (7)

and $V_{pd}$ is the volume effectively occupied by the Pd-atom. As reported in reference [5] we have:

$$\omega_{se} \approx x^{1/2} 15.2 eV/\hbar$$  \hspace{1cm} (8)

For example, for $x=0.5$, we have $\omega_{se} \approx 10.7 eV/\hbar$.

c) The plasma of Pd-ions

Finally, we must consider the plasma due to palladium ions that forms the lattice structure. In this case, it is possible to demonstrate that the frequency is [5]:

$$\omega_{pd} = 0.1 eV$$  \hspace{1cm} (9)

3. The plasmas present within D$_2$-loaded palladium

We know that the deuterium is adsorbed when placed near a palladium surface. This loading can be enhanced using electrolytic cells or vacuum chambers working at opportune pressure [8,9]. By means of Preparata’s theory of Condensed Matter it is assumed that, according to the ratio $x=D/Pd$, three phases concerning the D$_2$-Pd system exist:

1) $\alpha$ phase for $x<0.1$
In the \( \alpha \)-phase, the \( D_2 \) is disordered and not in a coherent state (\( D_2 \) is not charged!). Regarding the other phases, we must remember that on the surface, due to lattice e.m., the following ionization reaction takes place:

\[
D_{\text{lattice}} \rightarrow D^+ + e^-
\]  

(10)

Then, according to the loading percentage \( x=D/Pd \), the deuterium ions can enter octahedral sites (Fig. 1) or in the tetrahedral (Fig. 2) in the \((1,0,0)\)-plane. In the coherence theory, the deuterons plasma in the octahedral site can be called \( \beta \)-plasma, whereas those in the tetrahedral one can be called \( \gamma \)-plasma.
Regarding to $\beta$-plasma, it is possible to affirm that the plasma frequency is given by [5]:

$$\omega_\beta = \omega_{\beta 0} (x + 0.05)^{1/2}$$  \hspace{1cm} (11)

where

$$\omega_{\beta 0} = \frac{e}{\sqrt{m_D}} \left( \frac{N}{V} \right)^{1/2} \frac{1}{\lambda_{a}^{1/2}} = \frac{0.15}{\lambda_{a}^{1/2}} \text{eV} / \hbar$$  \hspace{1cm} (12)
For example, if we use $\lambda_a=0.4$ and $\chi=0.5$ it is obtained $\omega_p=0.168 \text{ eV}/\hbar$. In the tetrahedral sites the D$^+$ can occupy the thin disk that encompasses two sites (Fig. 3). The D$^+$ ions form a barrier.

Note that the electrons of the d-shell oscillate past the equilibrium distance $y_0$ (about 1.4 Å), thus embedding the ions in a static cloud of negative charge (which can screen the coulomb barrier). So, as reported in [5], we have:

$$\omega_\gamma = \sqrt{\frac{4Z_{\text{eff}} \alpha}{m_D y_0^2}} \approx 0.65 \text{eV}/\hbar$$  \hspace{1cm} (13)

Of course, this frequency depends also on the chemical condition of palladium (impurities, temperature etc…)

Due to a large plasma oscillation of d-electrons, in the disk-like tetrahedral region (where the $\gamma$-phase D$^+$s are located) a high density negative charge condenses, giving rise to a screening potential $W(t)$ whose profile is shown in Fig. 4.

*Fig. 3. Possible d-electron plasma oscillation in a Pd lattice*
We emphasize that the $\gamma$-phase depends on $x$ value and that this new phase has been experimentally observed [11].

The new phase $\gamma$ is very important in the LENR investigation. In fact, many “cold fusion scientists” declare that the main point of cold fusion protocol is that the loading D/Pd ratio must be higher than 0.7, i.e. the deuterium must take place in the tetrahedral sites.

4. The D-D potential

In reference [6], it was shown that the phenomena of fusion between nuclei of deuterium in the crystalline lattice of a metal is conditioned by the structural characteristics, by the dynamic conditions of the system, and also by the concentration of impurities present in the metal under examination.

In fact, studying the curves of the potential of interaction between deuterons (including the deuteron-plasmon contribution) in the case of three typical metals (Pd, Pt and Ti), a three-dimensional model showed that the height of the Coulomb barrier decreases on varying the total energy and the concentration of impurities present in the metal itself.

The potential that takes into account the role of temperature and impurities is given by the expression [6]:

$$V(r) = k_0 \frac{q^2}{r} \cdot M_d \left( V(r)_M - \frac{J \cdot kT \cdot R}{r} \right)$$

\( (14) \)
In (14), $V(r)_M$, the Morse potential, is given by:

$$V(r)_M = \left( \frac{J}{\zeta} \right) \left\{ \exp \left( -2\phi \left( r - r_0 \right) \right) - 2 \exp \left( -\phi \left( r - r_0 \right) \right) \right\} \tag{15}$$

Here parameters $\phi$ and $r_0$ depend on the dynamic conditions of the system, $\zeta$ is a parameter depending on the structural characteristics of the lattice, i.e. the number of “d” band electrons and the type of lattice symmetry, varying between 0.015 and 0.025.

Of course the Morse potential is used in the interval that includes the inner turning point $r_a$ and continues on towards $r=0$, that is strictly linked to the coulomb potential (Fig 5).

![D-D potential features using a Morse potential](image)

**Fig.5 - D-D potential features using a Morse potential**

In reference [6] by means of the following formula ($\alpha$ is the zero crossing r-value of potential):

$$|P|^2 = \exp \left( -2 \int_0^\alpha K(r) \, dr \right) \tag{16}$$

where:

$$K(r) = \sqrt{2\mu \left[ E - V(r) \right] / \hbar^2} \tag{17}$$

This is obtained (using for the nuclear rate the reasonable value of $10^{21}$ min$^{-1}$) a fusion probability normalized to the number of events per minute of $10^{-25}$ for $\alpha=0.34$ Å, $E=250$ eV, $T=300$ K and $J=0.75$ (a case of high impurities). Many experiments confirmed these fusion rate values regarding reaction (1 and 2) in Ref. [10].
In this work, according to the coherence theory of condensed matter, we will study the role of potential (14) in the three different phases: $\alpha$, $\beta$ and $\gamma$.

So, in this theoretical framework we need to clarify:

1) What is $KT$?
2) What is the role of electrons, ions plasma?

Regarding the first point, according to the different deuteron-lattice configurations, $KT$ can be:

i) the lattice temperature, if we consider the deuterons in the $\alpha$-phase

ii) $\omega_{\beta}$, if we consider the deuterons in $\beta$-phase

iii) $\omega_{\gamma}$, if we consider the deuterons in the $\gamma$-phase

The second point raises a more complicated question.

In fact, the lattice environment is a mixing of coherent plasmas (ion Pd, electron and deuterons plasma) at different temperatures, due to different masses. Thus, describing an emerging potential is a very hard office. The method that in this work we propose is the following: considering the total contribution of lattice environment at D-D interaction (i.e. $V_{tot}$) as random potential $Q(t)$. So, in this model we can write:

$$V_{tot}(t) = V(r) + Q(t)$$

(18)

Of course we assume that:

$$\langle V_{tot}(t) \rangle \neq 0$$

(19)

that is, we suppose that $Q(t)$ (a second order potential contribution) is a periodic potential (the frequency will be labeled by $\omega_Q$) that oscillates between the maximum value $Q_{max}$ and 0.

The role of potential $Q(t)$ could increase or decrease the barrier. In Fig. 6 we show the plot of potential $V_{tot}$ for two different values of $Q(t)$. 
This means that, according to $\omega_Q$ and to the energy of particles incoming to the barrier, we can have the following main cases:

1) the particle crosses the barrier in the point $\alpha$
2) the particle crosses the barrier in the $\alpha'$

For this reason, we can talk about scenario 2 as the worst case to have high tunneling probability, and scenario 1 as the best case.

To determine the model parameters, we must make some hypothesis regarding $Q(t)$ and $\omega_Q$. In this work, we will limit ourselves to approximate $Q(t)$ as the screening potential $W(t)$ due to d-electrons reported in Fig. 5.

This means that $\omega_Q \sim \omega_d$.

Of course, there is a strong dependence between the scenario and the deuteron phase since $Q(t)$ is, at first order, only the d-electrons screening potential.

To summarize, we can have the following cases in a palladium lattice according to loading ratio:

i) $\alpha$-phase
In the phase $\alpha$ the deuterons are in a molecular state and the thermal motion is about:

$$0.02 \text{ eV} < \hbar \omega_\alpha < 0.2 \text{ eV}$$

This phase takes places when $x$ is less than 0.1, and since $W(t)$ is zero, the D-D potential is:
\[ V(r) = \text{const} \frac{q^2}{r} \cdot M_d \left( V_M(r) - \frac{J \hbar \omega \alpha R}{r} \right) \]  

(20)

Expression (20) has been partially evaluated in a previous paper [6] but, in that case, we were interested only in the dependence of tunneling probability on impurities present within lattice. In this work, we will examine the correlation between potential features and loading ratio. In paragraph 6, we will show some numerical results.

ii) \(\beta\)-phase

When \(x\) is bigger than 0.1 but less 0.7, the phase \(\beta\) happens. The interaction takes place between deuteron ions that oscillate between the following energy values:

\[ 0.1 \text{ eV} < \hbar \omega_{\beta} < 0.2 \text{ eV} \]

In this case \(W(t)\) is zero, so the potential is given by the expression (21):

\[ V(r) = \text{const} \frac{q^2}{r} \cdot M_d \left( V_M(r) - \frac{J \hbar \omega_{\beta} R}{r} \right) \]  

(21)

Comparing expressions 20 and 21, it clearly seems that the weight of impurities is more important in the \(\beta\)-phase. Of course, this conclusion is in accordance with the previous papers [6,7] where we had studied the role of temperature on tunneling effect.

iii) \(\gamma\)-phase

Finally, when the loading ratio is higher than 0.7, the deuteron-palladium system is in the \(\gamma\)-phase. According to the synchronism between phase oscillations of deuteron and d-electron plasmas, we must consider the following two cases:

\textit{Case 1: } \(Q(t)=0\)

In this case the potential is a natural extension of formula (14), than it can be written as:

\[ V(r) = \text{const} \frac{q^2}{r} \cdot M_d \left( V_M(r) - \frac{J \hbar \omega_{\gamma} R}{r} \right) \]  

(22)
Case 2: Q(t)\neq 0

This is the more interesting case. It happens when \( \omega_\gamma \) is about \( \omega_Q \) and, of course, when the respective oscillations are in phase. The deuterons undergo the screening due to d-electrons shell, so we suppose that the D-D potential must be computed assuming that the well present in potential (14), due to Morse contribution, disappears. In fact, if we use a classical plasma model where the D\(^+\) ions are the positive charge and the d-electrons the negative one, it is very reasonable to suppose that we must use the following potential:

\[
V(r,t) = \text{const} \frac{q^2}{r} M_d \left( \frac{\alpha}{|\mathbf{r}|} e^{-\frac{|\mathbf{r}|}{\lambda_D}} - \frac{J h \omega_\gamma R}{r} \right) + Q(t) \tag{23}
\]

Where

\[
V_c(\tilde{r}) = \frac{\alpha}{|\tilde{r}|} e^{-\frac{|\tilde{r}|}{\lambda_D}} \tag{24}
\]

And \( \lambda_D \) is the Debye length of this classical plasma.

We emphasize that Q(t) is not known as a perturbative potential. About it, we can only say that:

\[
\langle Q(t) \rangle_t \approx \frac{W_{\text{max}}}{\sqrt{2}} \tag{25}
\]

As previously said, we suppose that it is the screening potential due to d-electron and its role that reduces the repulsive barrier.

5. The barrier crossing treatment

Now we proceed to discuss how we can handle the crossing of barrier in the \( \gamma \)-phase and for \( Q(t) \) different to zero. The starting point in any case is the Scrödinger equation:

\[
\frac{\hbar^2}{2\mu} \Psi^\prime(r) \left[ E - V_{\text{tot}}(r,t) \right] \Psi(r) = 0 \tag{26}
\]

but solving this problem is very difficult.
So, to handle in a very simple way this topic, we can start observing that when we use \( V_{tot}(r,t) = V(r) + \frac{W_{max}}{\sqrt{2}} \), the main energy values that interest our problem are four (see Fig. 7) \( E_1, E_2, E_3 \) and \( E_4 \) and the problem is equivalent to the treating of a double barrier case.

![Fig. 7. Features of \( V(r) \) and \( V(r) + \frac{W_{max}}{\sqrt{2}} \)](image)

From reference [12] we know that:

\[
E_1 = \text{a few eV}; \quad (27)
\]

\[
E_2 = -D \left( 1 - \frac{\gamma \hbar}{2 \mu D} \left( \mu + \frac{1}{2} \right)^2 \right) \quad (28)
\]

\[
E_3 \sim \left( \frac{m_2}{M_N} \right) E_1 \sim \frac{1}{1000} \text{eV} \quad (29)
\]

\[
E_4 = D' \quad (30)
\]

\( \gamma \) is the constant of metal anharmonicity and \( \nu \) the vibrational constant. Another important quantity is \( D' \) that is the depth of the potential well. According to the Morse potential (15) it is \( J/\zeta \).

Now we can build an energy tensor \( E_{ij} \):
\[ E_{11} = E_1, \ E_{22} = E_2, \ E_{33} = E_3, \ E_{44} = E_4, \ E_{ij} = E_i - E_j, \ E_{ij} = -E_{ji} \]

So, in this way, we can define a square quadratic energy value:

\[
\langle E \rangle = \sqrt{\frac{\text{tr}E_{ij}E_{ji}}{4}}
\]

(31)

and a dispersion:

\[
\sigma = \sqrt{\frac{\sum_{i \neq j} E_{ij}E_{ji}}{4}}
\]

(32)

If we neglect the term \(Q(t)\) and consider only the random characteristic of deuteron energy, a reasonable value of \(K(r)\) can be:

\[
K(r) = \frac{1}{\hbar} \sqrt{2\mu \left[ V(r) - \left( \sqrt{\frac{\text{tr}E_{ij}E_{ji}}{4}} + \sigma \right) \right]}
\]

(33)

And finally:

\[
P(\alpha) = \exp \left( -2 \int_0^\alpha K(r) dr \right)
\]

(34)

But according to statistical treatment we can observe that:

\[
P = P(\alpha, \langle E \rangle, \sigma)
\]

(35)

where we remember that in the \(\gamma\)-phase

\[\alpha = \alpha[Q(t)]\]

(36)

Since we supposed that the greater contribution to \(Q(t)\) is due to the screening effect of \(d\)-electrons (i.e. of random potential) in the \(\gamma\)-phase, we can limit ourselves to consider the two following cases (i.e. double barrier approximation):

3) \(Q(t) = 0 \rightarrow \alpha = 0.34 \ \text{Å}.
4) \(Q(t) \neq 0 \rightarrow \alpha = 0.16 \ \text{Å} \)
Of course, case 4 is the more advantageous to obtain high tunneling probability.

6. Result and Discussion

Now we will present the D-D fusion probability normalized to the number of events per minute for the D-D interaction in all different phases. More exactly, we will compare the fusion probability in the α, β and γ phases using a reasonable square average value of 200 eV and 50 eV.

In order to cross the potential (14) in all four points \(E_1, E_2, E_3\) and \(E_4\). We will also consider the role of d-electron screening as perturbative lattice potential. This treatment, that interests us only the case where \(Q(t)\) is different from zero, involves that we turn the time-dependent problem of a tunneling effect into a double barrier problem. To summarize, we can say that in the γ-phase the new ‘physics fact’ is the emerging of a double barrier. Note that the new phase γ is invoked by cold fusion scientists, because the screening enhances the fusion probability. From an experimental point of view, in the cold fusion phenomenology it is possible to affirm that there are three typologies of experiments [13]:

1) Those that have given negative results.
2) Those that have given some results (faint evidence with respect to the background, fusion probability about 10\(^{-25}\)) using a very high loading ratio.
3) Those that have given clear positive results as Fleishmann and Pons experiments.

Nevertheless, we think that the experiment in category 3 are little accurate from an experimental point of view. For this reason, we believe that a theoretical model of controversial phenomenon of cold fusion can explain only the experiments in categories 1 and 2. In this case, the role of the loading ratio on the experimental results needs to be considered. Now, let us begin from α-phase.

In Table 1 we show the results about the α-phase. In this case, we can observe that the theoretical fusion probability is very low, less than 10\(^{-74}\). It is possible to affirm that if we load the deuterium with a percentage \(x < 0.2\) we do not observe any fusion events! The same absence of nuclear phenomenon is consistent with a loading ratio of about 0.7 (Table 2) since in this case the predicted fusion probability is less than 10\(^{-42}\). These predictions, of course, are consistent with the experimental results. But for \(x > 0.7\) a set of valid experiments do show some background spikes (for example see reference [10]).

The remarkable result of our model is that in the γ-phase, as shown in Table 3, we can really observe some background fluctuations, since we predict a fusion probability about 10\(^{-25}\) due to a very high loading ratio. This represents a new result compared to reference [6,7] since, in that case, the fusion probability was independent of loading ratio.
In order to predict very noteworthy nuclear evidence (about $10^{-17}$), we must have $\omega_\gamma$ comparable to $\omega_Q$ (Table 4). In fact, only in this condition the screening potential can enhance the tunneling probability, and the D-D interaction becomes a like-Debye potential.

The condition by means of which $\omega_\gamma$ is equal to $\omega_Q$ will be discussed in another paper, but in this work we will limit ourselves to observing that it is a very improbable condition!

To conclude, we show that the model proposed in this paper can explain some anomalous nuclear trace reactions in the solid state, but closes any hopes on the possibility of controlled fusion reactions in solid matter.

**Table 1.** For “Impure” Pd ($J \approx 0.75\%$), using the $\alpha$-potential (potential 20), has been computed the fusion probability normalized to the number of event/min for different values of energy ($\sigma = \pm 50$ eV).

| Palladium | $J \approx 0.75\%$ $\alpha \approx 0.34$ Å $\langle E \rangle = 200$eV |
|-----------|----------------------------------|-----------------|-----------------|-----------------|
| $\omega_\alpha \approx 0.05$ eV | $\omega_\alpha \approx 0.1$ eV | $\omega_\alpha \approx 0.15$ eV | $\omega_\alpha \approx 0.2$ eV |
| $\sigma \approx -50$ P $\approx 10^{100}$ | $\sigma \approx -50$ P $\approx 10^{103}$ | $\sigma \approx -50$ P $\approx 10^{100}$ | $\sigma \approx -50$ P $\approx 10^{99}$ |
| $\sigma \approx -40$ P $\approx 10^{99}$ | $\sigma \approx -40$ P $\approx 10^{101}$ | $\sigma \approx -40$ P $\approx 10^{98}$ | $\sigma \approx -40$ P $\approx 10^{97}$ |
| $\sigma \approx -30$ P $\approx 10^{97}$ | $\sigma \approx -30$ P $\approx 10^{100}$ | $\sigma \approx -30$ P $\approx 10^{96}$ | $\sigma \approx -30$ P $\approx 10^{96}$ |
| $\sigma \approx -20$ P $\approx 10^{95}$ | $\sigma \approx -20$ P $\approx 10^{99}$ | $\sigma \approx -20$ P $\approx 10^{94}$ | $\sigma \approx -20$ P $\approx 10^{93}$ |
| $\sigma \approx -10$ P $\approx 10^{94}$ | $\sigma \approx -10$ P $\approx 10^{97}$ | $\sigma \approx -10$ P $\approx 10^{91}$ | $\sigma \approx -10$ P $\approx 10^{90}$ |
| $\sigma \approx 0$ P $\approx 10^{92}$ | $\sigma \approx 0$ P $\approx 10^{96}$ | $\sigma \approx 0$ P $\approx 10^{90}$ | $\sigma \approx 0$ P $\approx 10^{86}$ |
| $\sigma \approx 10$ P $\approx 10^{91}$ | $\sigma \approx 10$ P $\approx 10^{94}$ | $\sigma \approx 10$ P $\approx 10^{87}$ | $\sigma \approx 10$ P $\approx 10^{86}$ |
| $\sigma \approx 20$ P $\approx 10^{90}$ | $\sigma \approx 20$ P $\approx 10^{92}$ | $\sigma \approx 20$ P $\approx 10^{85}$ | $\sigma \approx 20$ P $\approx 10^{83}$ |
| $\sigma \approx 30$ P $\approx 10^{89}$ | $\sigma \approx 30$ P $\approx 10^{90}$ | $\sigma \approx 30$ P $\approx 10^{82}$ | $\sigma \approx 30$ P $\approx 10^{78}$ |
| $\sigma \approx 40$ P $\approx 10^{88}$ | $\sigma \approx 40$ P $\approx 10^{89}$ | $\sigma \approx 40$ P $\approx 10^{80}$ | $\sigma \approx 40$ P $\approx 10^{74}$ |
| $\sigma \approx 50$ P $\approx 10^{84}$ | $\sigma \approx 50$ P $\approx 10^{87}$ | $\sigma \approx 50$ P $\approx 10^{79}$ | $\sigma \approx 50$ P $\approx 10^{71}$ |
Table 2. For “Impure” Pd ($J \approx 0.75\%$), using the $\beta$-potential (potential 21), has been computed the fusion probability $P$ normalized to the number of event/min for different values energy ($\sigma = \pm 50 \text{ eV}$).

**Palladium $J \approx 0.75\% \alpha \approx 0.34 \text{ Å} \langle E \rangle = 200\text{eV}**

<table>
<thead>
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<th>$\omega_\beta \approx 0.33 \text{ Å}$</th>
<th>$\omega_\beta \approx 0.68 \text{ Å}$</th>
<th>$\omega_\beta \approx 1.03 \text{ Å}$</th>
<th>$\omega_\beta \approx 1.38 \text{ Å}$</th>
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<td>$\sigma \approx 50 \text{ P} \approx 10^{-70}$</td>
<td>$\sigma \approx 50 \text{ P} \approx 10^{-65}$</td>
<td>$\sigma \approx 50 \text{ P} \approx 10^{-42}$</td>
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</table>
Table 3. For “Impure” Pd ($J \approx 0.75\%$), using the $\gamma$-potential with $Q(t) = 0$ (potential 22), has been computed the fusion probability normalized to the number of event/min for different values of energy ($\sigma = \pm 50$ eV).

<table>
<thead>
<tr>
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<th>$\omega_\gamma \approx 0.7$ eV</th>
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<td>$\sigma \approx 160$ P $\approx 10^{-52}$</td>
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<td>$\sigma \approx 160$ P $\approx 10^{-31}$</td>
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<td>$\sigma \approx 170$ P $\approx 10^{-47}$</td>
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<td>$\sigma \approx 180$ P $\approx 10^{-70}$</td>
<td>$\sigma \approx 180$ P $\approx 10^{-45}$</td>
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<td>$\sigma \approx 180$ P $\approx 10^{-25}$</td>
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<tr>
<td>$\sigma \approx 190$ P $\approx 10^{-69}$</td>
<td>$\sigma \approx 190$ P $\approx 10^{-43}$</td>
<td>$\sigma \approx 190$ P $\approx 10^{-31}$</td>
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<td>$\sigma \approx 200$ P $\approx 10^{-42}$</td>
<td>$\sigma \approx 200$ P $\approx 10^{-30}$</td>
<td>$\sigma \approx 200$ P $\approx 10^{-25}$</td>
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<td>$\sigma \approx 250$ P $\approx 10^{-31}$</td>
<td>$\sigma \approx 250$ P $\approx 10^{-25}$</td>
</tr>
</tbody>
</table>
Table 4. For “Impure” Pd ($J \approx 0.75\%$), using the Debye potential (potential 24), has been computed the fusion probability normalized to the number of event/min for different values of energy ($\sigma = \pm 50$ eV).

**Palladium** $J \approx 0.75\%$ $\alpha \approx 0.16\; \text{Å}$ $\langle E \rangle = 200\text{eV}$

<table>
<thead>
<tr>
<th>$\lambda_D \approx 0.3175; \text{Å}$</th>
<th>$\lambda_D \approx 0.635; \text{Å}$</th>
<th>$\lambda_D \approx 0.9525; \text{Å}$</th>
<th>$\lambda_D \approx 1.27; \text{Hz Å}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma \approx -50 ; P \approx 10^{-65}$</td>
<td>$\sigma \approx -50 ; P \approx 10^{-62}$</td>
<td>$\sigma \approx -50 ; P \approx 10^{-53}$</td>
<td>$\sigma \approx -50 ; P \approx 10^{-53}$</td>
</tr>
<tr>
<td>$\sigma \approx -40 ; P \approx 10^{-62}$</td>
<td>$\sigma \approx -40 ; P \approx 10^{-58}$</td>
<td>$\sigma \approx -40 ; P \approx 10^{-50}$</td>
<td>$\sigma \approx -40 ; P \approx 10^{-52}$</td>
</tr>
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<td>$\sigma \approx -30 ; P \approx 10^{-56}$</td>
<td>$\sigma \approx -30 ; P \approx 10^{-46}$</td>
<td>$\sigma \approx -30 ; P \approx 10^{-50}$</td>
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<td>$\sigma \approx -20 ; P \approx 10^{-55}$</td>
<td>$\sigma \approx -20 ; P \approx 10^{-42}$</td>
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<tr>
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<td>$\sigma \approx 20 ; P \approx 10^{-49}$</td>
<td>$\sigma \approx 20 ; P \approx 10^{-32}$</td>
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<tr>
<td>$\sigma \approx 30 ; P \approx 10^{-49}$</td>
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<td>$\sigma \approx 30 ; P \approx 10^{-31}$</td>
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<tr>
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References

Common Mechanism of Superconductivity, Superfluidity, Integer and Fractional Hall Effects, and Cold Fusion

F.A. Gareev ***, G.F. Gareeva * and I.E. Zhidkova **
* Joint Institute for Nuclear Research, Dubna, Russia
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1. Introduction

The experimental existence of low energy nuclear reactions (LENR) is well established and obtained results have been published in over 3000 scientific papers. Nevertheless there is no widely accepted theoretical mechanism for LENR.

We [1, 2] have discussed the cooperative resonance synchronization enhancement mechanisms of LENR. Some of the low energy external fields can be used as triggers for starting and enhancing of exothermic LENR. It is natural to expect that in the case of beta-decay (capture) the external electron flux with high density, or the laser of high intensity, or any suitable external fields should play this role. Any external field shortening distances between protons in nuclei and electrons in atoms should enhance beta-decay (capture) or double-beta decay (capture). We proposed a new mechanism of LENR: cooperative processes in whole system —nuclei+atoms+condensed matter+gaseuos+plasma medium — can occur at smaller threshold than corresponding ones on free constituents. The cooperative processes can be induced and enhanced by low energy external fields. The excess heat is the emission of internal energy, and transmutations are the result of redistribution inner energy of whole system.

The investigation of LENR requires knowledge of different branches of science: nuclear and atomic physics, chemistry, and electrochemistry, condensed matter and solid state physics. This means that the problem of LENR is an interdisciplinary one. Yet the differentiation of science in the beginning of the 20th century may have brought about a situation in which the necessary interdisciplinary unification of different science branches has been lost.

We established a detailed mutually-simple correspondence between the properties of hydrogen atom states and other physical systems. We successfully applied the Bohr method to analyze different systems using the established isomorphism of hydrogen atom properties and system being investigated.
The definition of isomorphism from Wikipedia, the free encyclopedia (http://en.wikipedia.org/wiki/Isomorphism) is:

Informally, an isomorphism is a kind of mapping between objects, which shows a relationship between two properties or operations. If there exists an isomorphism between two structures, we call the two structures ISOMORPHIC. In a certain sense, isomorphic structures are STRUCTURALLY IDENTICAL, if you choose to ignore finer-grained differences that may arise from how they are defined.

According to Douglas Hofstadter:

"The word 'isomorphism' applies when two complex structures can be mapped onto each other, in a such way that to each part of one structure there is a corresponding part in the other structure, where 'corresponding' means that the two parts play similar roles in their respective structures" (Godel, Escher, Bach, p. 49).

PURPOSE: Isomorphism is studied in mathematics in order to extend insights from one phenomenon to others: if two objects are isomorphic, then any property which is preserved by an isomorphism and which true of one of objects are also true of the other. If isomorphism can be found a relatively unknown part of mathematics into some well studied division of mathematics, where many theorems are already proved, and any methods are already available to find answers, then the function can be used to map whole problems out of unfamiliar territory over to "solid grounds" where the problem is easier to understand and work with.

We will discuss isomorphism phenomena as between microscopic systems as between micro and macro systems.

2. The Quantum Hall effect

The Hall effect was discovered in 1879 by Edwin Hall. The resistance $R_H$ (called now as the Hall resistance) depends linearly on the strength $B$ of the magnetic field.

2.1. The Integer Quantum Hall Effect

Klaus von Klitzing [3] in 1980 observed that in a low-temperature liquid $He$ ($\approx 4K$) in a very high magnetic field ($\approx 10T$) a step-wise dependence of the Hall resistance $R_H$ on magnetic field, rather than Edwin Hall's linear relationship. The value of $R_H$ at the position of the plateaus of the steps is quantized:

$$R_H = \frac{h}{ve^2}, \nu = 1, 2, 3,...$$  \hspace{1cm} (1)

and the magneto resistance have a deep minima (is equal practically to zero in the plateau). This is the integer quantum Hall effect, where $\nu$ takes on integer values ($\nu = 1, 2, 3,...$).
Interpretation [3]: *the integer Hall quantization is the magnetic flux quantization* \(\hbar/e\) and the quantization of the charge into elementary charge \(e\).

\[
R_H = \frac{\hbar}{ne^2} = \frac{\hbar}{e\nu e^2} = \phi_0, \tag{2}
\]

where \(\phi_0 = \frac{\hbar}{e}\) is the magnetic flux quanta. This interpretation is accepted now as standard one.

### 2.2. The Fractional Quantum Hall Effect

The fractional quantum Hall effect was experimentally discovered by Daniel Tsui, Horst Stormer and Arthur Gossard, in which \(\nu\) can occur as a fractions

\[
\nu = \nu_0 \frac{2}{3}, \nu_0 \frac{1}{3}, \nu_0 \frac{2}{5}, \nu_0 \frac{3}{5}, \nu_0 \frac{5}{2}, \ldots \tag{3}
\]

Interpretation [3]: *By analogy, the fractional quantum Hall effect is interpreted on the basis of elementary excitations of quasiparticle with a fractional charge*

\[
\epsilon^* = \frac{e^3}{3}, \frac{e^3}{5}, \frac{e^3}{7}, \ldots \tag{4}
\]

This interpretation is a very strange one. Horst Stormer wrote [4]:

*The fractional quantum Hall effect is a very counterintuitive physical phenomenon. It implies, that many electrons, acting in correct, can create new particles having a charge SMALLER than the charge of any individual electron. This is not the way things are supposed to be. A collection of objects may assemble to form a BIGGER object, or the parts may remain their size, but they don't create anything SMALLER. Not only are they smaller than the charge of any constituent electron, but they are exactly 1/3 or 1/5 o1/7, etc. of an electronic charge, depending on the conditions under which they have been prepared. And yet we known with certainty, that none of these electrons has split up into pieces.*

*Fractional charge is the most puzzling of the observation, but there are others. Quantum numbers – usually integers or half-integers – turn out to be also fractional, such as 2/5, 4/9, and 11/7, or even 5/25.*

The quantization of Hall resistance (1) and (2) is incredibly precise. The Hall conductance has been found to be integer or fractional numbers of \(\epsilon^2/\hbar\) to one part in a billion which are now called "exact quantization". The high precision measurements of the quantized Hall resistance are used as a resistance standard or for a determination of \(\hbar/e^2\) (a determination of the inverse fine structure constant \(\alpha^{-1}\)) which are important for all areas in physics connected with the fine structure constant.

Therefore, the Hall conductance (the inverse Hall resistance (1)) obeys the "exact quantization" conditions
\[ V_H = v \frac{e^2}{\hbar} \equiv v v_e, \ n = 1, 2, 3, \ldots \text{ or } v = \frac{n_1}{n_2}, n_i = 1, 2, 3, \ldots \]  \hspace{1cm} (5)

where \( v_e \) is the electron velocity in the hydrogen ground state.

\[ v_e = \frac{e^2}{\hbar}. \]  \hspace{1cm} (6)

\[ p_H = v p_e, \ \lambda_e = v \lambda_H. \]  \hspace{1cm} (7)

- We come to the conclusion [5] that the integer and fractional Hall effects demonstrate only the commensurability ratios between velocities, impulses and the de Broglie wave lengths of electrons in ground state hydrogen atom and corresponding ones for two-dimensional electron gas. So there is no room for interpretation of the fractional Hall effect in terms of the fractional charge. Nobody has observed a fractional charge in nature. Our interpretation of the integer and fractional Hall effects is simple and unique, physically grounded, and does not require a violation of the fundamental laws of Nature.

We know that the interaction between the elementary particles guided by some strong conservation laws. One of the conservation laws requires that the total electrical charge be preserved at any interactions. So, if this law is true then the total electrical charge in the aggregate electrons should always be an integer.

The mystery of fractional quantum numbers in discussing the effect get a very simple explanation: they demonstrated the commensurability relations for velocities, impulses and the de Broglie wave lengths of electrons in hydrogen atom and in two-dimensional experimental device. The hydrogen atom in ground state represents a superconducting dipole. Therefore the two-dimensional experimental device becomes a superconductor at the quantum Hall effect.

3. Superfluidity

P. L. Kapitza in 1937 discovered that the viscosity of the liquid helium at temperature below 2.19 K becomes zero. It was established that the motion of liquid helium obeys to the conditions

\[ vr = N \frac{\hbar}{m_{He}}, \ n = 1, 2, 3, \ldots \]

This means that sectorial velocities of liquid helium are quantized, therefore the phenomenon of superfluidity is a consequence of quantum mechanics on a macroscopic scale. Superfluids can flow through narrow channels without viscosity. The motion of the
superfluids through narrow channels submits to the same quantum conditions as electron motion in hydrogen atom do.

Remember the Bohr quantization conditions for hydrogen atom:

\[ vr = N \frac{\hbar}{m}, \quad N = 1, 2, 3, \ldots \]

The condition of full transparency for waves (see below) coincides with the Bohr quantization condition.

What quantity is \( vr \)? It is a double sectorial velocity of the body having periodical motion. So, we see that the quantization of sectorial velocities of liquid helium (macro system) is isomorphic to the quantization of the Bohr orbit in hydrogen atoms (micro system).

Let us briefly consider the quantization of planet and satellite sectorial velocities. There are some arguments that this phenomenon plays a fundamental role in the formation of stable dynamic systems similar to Solar system.

It was established [6] that quantization of sectorial velocities of Solar system elements is isomorphic to the quantization of the Bohr orbits in hydrogen atom. The same quantization for solar system [6]

\[ VR = N \frac{\hbar_G}{m_G}, \quad N = 1, 2, 3, \ldots \]

Here is a quotation from a Nobel Lecture, December 8, 1998, by Robert B. Laughlin [8]:

*Superfluidity, like the fractional quantum effect, is an emergent phenomenon – a low energy collective effect of huge numbers of particles that cannot be deduced from the microscopic equations of motion in a rigorous way and that disappears completely when the system is taken apart.... There are prototypes for superfluids, but these are all approximate and in the end not deductive at all, but fits to experiment...*

*...there is a regrettable tendency in solid-state physics to equate an understanding of nature with the ability to model, an attitude that sometimes leads to overlooking or misinterpreting the higher organizing principle actually responsible for an effect. In the case of the integral or fractional quantum Hall effects the essential thing is the ACCURACY of quantization. No amount of modeling done on any computer existing or contemplated will ever explain this accuracy by itself. Only thermodynamic principle does this.*
4. The isomorphism of atom, molecule, crystal, ... structures

We have proved [5] the isomorphism and homology of atom, molecule (in living molecules too including DNA) and crystal structures. So interatomic distances in molecules, crystals and solid-state matter can be written in the following way:

\[ d = \frac{n_1}{n_2} \lambda_e, \]

(8)

where \( \lambda_e = 0.3324918 \text{nm} \) is the de Broglie electron wavelength in a hydrogen atom in the ground state (\( \lambda_e = \lambda_p \) in a hydrogen atom in the ground state) and \( n_1(n_2) = 1, 2, 3, \ldots \). So the de Broglie electron (proton) wavelength in a hydrogen atom in the ground state can be considered as a standard of dimensions for atoms and interatomic distances in molecules, crystals and living cells [5]. There are huge examples of commensurable ratios between the interatomic distances and \( \lambda_e \) in superconductors, nanomaterials, DNA, protein, and living molecules [5]. The parameter–free formula for interatomic distances in biomolecules, superconductors and size of nanostructures has been obtained. This establishes some bridge between the structures of different phenomena (conductivity, superconductivity, insulator–metal transmission, quantum Hall effect, superfluidity, quantization of nanostructure cluster size, size of biomolecules). This connection can be considered as indication of existence of some physical phenomena in the structures of the superconducting and living systems.

We have shown below only a small part of our calculations by formula (8) and the corresponding comparison with experimental data [7] for interatomic distances in some molecules. One can see surprising by high accuracy description of existing experimental data.
Table 1.
Interatomic semi-wave $\lambda / 2 = 0.1662 nm$ distances $d$ in molecules, $\Delta = |d(\text{exp}) - \lambda / 2|$.

<table>
<thead>
<tr>
<th>Molecules</th>
<th>Distances</th>
<th>$\Delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[\text{GdH}]$</td>
<td>$d(\text{Gd-H}) = 0.1664$</td>
<td>0.002</td>
</tr>
<tr>
<td>$\text{B}_2\text{H}_6$</td>
<td>$d(\text{B-H}) = 0.166$</td>
<td>0.000</td>
</tr>
<tr>
<td>$[\text{UO}_2]^+$</td>
<td>$d(\text{U-O}) = 0.167$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_2\text{O}_2\text{Si}_2$</td>
<td>$d(\text{Si-O}) = 0.166$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_2\text{O}_2\text{Si}_2$</td>
<td>$d(\text{Si-O}) = 0.166$</td>
<td>0.000</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_2\text{O}_2\text{Si}_2$</td>
<td>$d(\text{Si-O}) = 0.167$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{GeF}_4$</td>
<td>$d(\text{Ge-F}) = 0.167$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{S}_2\text{F}_2\text{O}_2\text{Si}_2$</td>
<td>$d(\text{S-O}) = 0.166$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{RuO}_4$</td>
<td>$d(\text{Ru-O}) = 0.166$</td>
<td>0.000</td>
</tr>
<tr>
<td>$\text{OsO}_4$</td>
<td>$d(\text{Os-O}) = 0.166$</td>
<td>0.000</td>
</tr>
<tr>
<td>$\text{CClN}$</td>
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<td>0.001</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_2\text{Cl}_2$</td>
<td>$d(\text{C-Cl}) = 0.167$</td>
<td>0.001</td>
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<tr>
<td>$\text{C}_2\text{H}_2\text{N}_2\text{S}_2$</td>
<td>$d(\text{C-S}) = 0.166$</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Table 2.
Interatomic quarter-wave $3\lambda / 4 = 0.2494 \text{nm}$ distances $d$ in molecules, $\Delta = |d (\exp) - 3\lambda / 4|$.

<table>
<thead>
<tr>
<th>Molecules</th>
<th>Distances</th>
<th>$\Delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[\text{CHO}]^{-}$</td>
<td>$d (O - C - O) = 0.250$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{C}_4\text{H}_4\text{BrSn}$</td>
<td>$d (\text{Sn} - \text{Br}) = 0.249$</td>
<td>0.000</td>
</tr>
<tr>
<td>$[\text{C}_2\text{O}]^{-}$</td>
<td>$d (O - C - O) = 0.250$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_4\text{O}_2$</td>
<td>$d (O - C - O) = 0.250$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_4\text{O}_4$</td>
<td>$d (O - C - O) = 0.250$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_4\text{N}_2\text{O}_4$</td>
<td>$d (O - C - O) = 0.250$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_4\text{NO}_3$</td>
<td>$d (O - C - O) = 0.249$</td>
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<td>0.000</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_4\text{N}_2\text{O}_3$</td>
<td>$d (O - C - O) = 0.249$</td>
<td>0.000</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_4\text{O}_4$</td>
<td>$d (O - C - O) = 0.250$</td>
<td>0.001</td>
</tr>
<tr>
<td>$[\text{C}_4\text{H}_1\text{O}]^{-}$</td>
<td>$d (O - C - O) = 0.249$</td>
<td>0.000</td>
</tr>
<tr>
<td>$\text{C}_4\text{H}_1\text{ON}$</td>
<td>$d (O - C - N) = 0.249$</td>
<td>0.000</td>
</tr>
<tr>
<td>$\text{C}_4\text{H}_1\text{NO}_4$</td>
<td>$d (O - N - O) = 0.249$</td>
<td>0.000</td>
</tr>
<tr>
<td>$\text{C}_4\text{H}_1\text{AuBrP}$</td>
<td>$d (P - A u) = 0.250$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{C}_4\text{H}_1\text{Cl}_2\text{Sb}$</td>
<td>$d (\text{Sb} - \text{Cl}) = 0.249$</td>
<td>0.000</td>
</tr>
<tr>
<td>$\text{C}_4\text{H}_1\text{Hg}$</td>
<td>$d (C - C + C - H) = 0.2495$</td>
<td>0.0001</td>
</tr>
<tr>
<td>$\text{C}_4\text{H}_1\text{ClHgO}$</td>
<td>$d (\text{Hg} - \text{Cl}) = 0.250$</td>
<td>0.001</td>
</tr>
<tr>
<td>$\text{C}_4\text{H}_1\text{AsCuI}$</td>
<td>$d (\text{As} - \text{Cu}) = 0.250$</td>
<td>0.001</td>
</tr>
</tbody>
</table>

- Note that the quantization conditions for the fractional Hall effect [5] are the same as (8). It means that the fractional Hall effect demonstrates only the commensurable velocities of electrons in hydrogen atoms and GaAs -type heterostructures (two-dimensional electron gas). So there is no room for interpretation of the fractional Hall effect in terms of the fractional charge. Nobody has observed a fractional charge in nature.

5. Electrical conductivity

Formula (8) gives the real method for increasing of the electrical conductivity.
Table 3. Geometrical parameters of metals, $d$ is a parameter of cell or distances between nearest atoms, 
\[ \Delta = |d_{\text{exp}} - d_{\text{cal}}|. \]

<table>
<thead>
<tr>
<th>Conf</th>
<th>$d_{\text{exp}}$</th>
<th>$d_{\text{cal}}$</th>
<th>$\Delta$</th>
<th>$n_1/n_2$</th>
<th>$\sigma$</th>
<th>$T_1(K)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu $4s^1$</td>
<td>$d = 0.25562$</td>
<td>0.25860</td>
<td>0.00298</td>
<td>7/9</td>
<td>5.88</td>
<td></td>
</tr>
<tr>
<td>K $4s^1$</td>
<td>$d = 0.4628$</td>
<td>0.46549</td>
<td>0.00269</td>
<td>7/5</td>
<td>1.39</td>
<td></td>
</tr>
<tr>
<td>Cr $4s^1$</td>
<td>$a = 0.28845$</td>
<td>0.29093</td>
<td>0.00248</td>
<td>7/8</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$d = 0.24980$</td>
<td>0.24937</td>
<td>0.00043</td>
<td>3/4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ag $5s^1$</td>
<td>$d = 0.2889$</td>
<td>0.29093</td>
<td>0.00203</td>
<td>7/8</td>
<td>6.21</td>
<td></td>
</tr>
<tr>
<td>Rh $5s^1$</td>
<td>$a = 0.3803$</td>
<td>0.38791</td>
<td>0.00761</td>
<td>7/6</td>
<td>2.08</td>
<td></td>
</tr>
<tr>
<td>Rb $5s^1$</td>
<td>$d = 0.494$</td>
<td>0.49874</td>
<td>0.00474</td>
<td>3/2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Nb $5s^1$</td>
<td>$a = 0.3294$</td>
<td>0.33249</td>
<td>0.00309</td>
<td>1</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>Au $5s^1$</td>
<td>$d = 0.28840$</td>
<td>0.29093</td>
<td>0.00253</td>
<td>7/8</td>
<td>4.55</td>
<td></td>
</tr>
<tr>
<td>Pt $5s^1$</td>
<td>$a = 0.392$</td>
<td>0.38791</td>
<td>0.00409</td>
<td>7/6</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>Al $3p^1$</td>
<td>$d = 0.28569$</td>
<td>0.29093</td>
<td>0.00424</td>
<td>7/8</td>
<td>3.65</td>
<td></td>
</tr>
<tr>
<td>Ga $4p^1$</td>
<td>$a = 0.244$</td>
<td>0.24937</td>
<td>0.00537</td>
<td>3/4</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>In $5p^1$</td>
<td>$c = 0.49467$</td>
<td>0.49874</td>
<td>0.00407</td>
<td>3/2</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td>He $1s^2$</td>
<td>$c = 0.583$</td>
<td>0.58186</td>
<td>0.00114</td>
<td>7/4</td>
<td>2.17</td>
<td></td>
</tr>
<tr>
<td>Be $2s^2$</td>
<td>$a = 0.25515$</td>
<td>0.24937</td>
<td>0.00478</td>
<td>3/4</td>
<td>3.08</td>
<td></td>
</tr>
<tr>
<td>V $4s^2$</td>
<td>$d = 0.2619$</td>
<td>0.25860</td>
<td>0.00330</td>
<td>7/9</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Ca $4s^2$</td>
<td>$d = 0.394$</td>
<td>0.38791</td>
<td>0.00609</td>
<td>7/6</td>
<td>2.78</td>
<td></td>
</tr>
<tr>
<td>Fe $4s^2$</td>
<td>$a = 0.286645$</td>
<td>0.29093</td>
<td>0.00329</td>
<td>7/8</td>
<td>1.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$d = 0.248242$</td>
<td>0.24937</td>
<td>0.00113</td>
<td>3/4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ti $4s^2$</td>
<td>$a = 0.2951$</td>
<td>0.29093</td>
<td>0.00417</td>
<td>7/8</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$c = 0.4697$</td>
<td>0.46549</td>
<td>0.00421</td>
<td>7/5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn $4s^2$</td>
<td>$c = 0.49468$</td>
<td>0.49874</td>
<td>0.00406</td>
<td>3/2</td>
<td>1.69</td>
<td></td>
</tr>
<tr>
<td>Co $4s^2$</td>
<td>$a = 0.2505$</td>
<td>0.24937</td>
<td>0.00113</td>
<td>3/4</td>
<td>1.72</td>
<td></td>
</tr>
<tr>
<td>Ni $4s^2$</td>
<td>$d = 0.24917$</td>
<td>0.24937</td>
<td>0.00020</td>
<td>3/4</td>
<td>1.43</td>
<td></td>
</tr>
<tr>
<td>Pd $5s^8$</td>
<td>$a = 0.38902$</td>
<td>0.38791</td>
<td>0.00111</td>
<td>7/6</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>Cd $5s^2$</td>
<td>$a = 2979$</td>
<td>0.29093</td>
<td>0.00697</td>
<td>7/8</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>Y $5s^2$</td>
<td>$c = 0.57306$</td>
<td>0.58186</td>
<td>0.00880</td>
<td>7/4</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. Superconductivity

It is well known in optics (and in quantum mechanics too) that the transition coefficient of light through the layer is equal to one if the following relations between the thickness $R$ of the layer and wave length $\lambda_e$ exist

$$R = \frac{n_1}{n_2}\lambda_e, \ n_1 = 1, 2, 3, \ldots, \ n_2 = 2, 4.$$  \hspace{1cm} (9)

It is interesting to note that: 1) the Bohr quantization conditions $\lambda_N = N\lambda_e$ for a hydrogen atom; 2) the quantization conditions $\lambda_N = N\lambda_{4He}$ for superfluid $^4$He coincide with (9); and 3) the Tomasch quantization conditions for tunneling are the same as (9).

We have carried out a systematic analysis of interatomic distances for a huge number of systems, using (9), in which $\lambda = \lambda_e$ is the electron wave length in the ground state of a hydrogen atom.

Table 4. Geometrical parameters of high temperature superconductor $YBa_2Cu_{x}O_{y}$, at temperature below $T_c$, $\Delta = |a_{up} - a_{up'}|$. 

<table>
<thead>
<tr>
<th></th>
<th>$d_{up}$</th>
<th>$d_{up'}$</th>
<th>$\Delta$</th>
<th>$n_1 / n_2$</th>
<th>$T(K)$</th>
<th>$x$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c$</td>
<td>1.164028(13)</td>
<td>1.163710</td>
<td>0.000318</td>
<td>7/2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$c$</td>
<td>1.16311(10)</td>
<td>1.163710</td>
<td>0.00060</td>
<td>7/2</td>
<td>8</td>
<td>0.04</td>
</tr>
<tr>
<td>$b$</td>
<td>0.388130(4)</td>
<td>0.387905</td>
<td>0.000125</td>
<td>7/6</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$b$</td>
<td>0.38786(3)</td>
<td>0.38791</td>
<td>0.00003</td>
<td>7/6</td>
<td>8</td>
<td>0.004</td>
</tr>
<tr>
<td>$Ba - O(1)$</td>
<td>0.28660(11)</td>
<td>0.29093</td>
<td>0.00333</td>
<td>7/8</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$Ba - O(1)$</td>
<td>0.2878(3)</td>
<td>0.29093</td>
<td>0.00313</td>
<td>7/8</td>
<td>8</td>
<td>0.04</td>
</tr>
<tr>
<td>$Ba - O(2)$</td>
<td>0.29806(14)</td>
<td>0.29093</td>
<td>0.00703</td>
<td>7/8</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$Ba - O(3)$</td>
<td>0.29573(17)</td>
<td>0.29093</td>
<td>0.00480</td>
<td>7/8</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$Ba - O(5)$</td>
<td>0.28892(11)</td>
<td>0.29093</td>
<td>0.00101</td>
<td>7/8</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$Cu(2) - O(4)$</td>
<td>0.23760(5)</td>
<td>0.23274</td>
<td>0.00486</td>
<td>7/10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$Y - O(3)$</td>
<td>0.23760(5)</td>
<td>0.23274</td>
<td>0.00486</td>
<td>7/10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$Cu(1) - O(1)$</td>
<td>0.19406(0)</td>
<td>0.19400</td>
<td>0.00006</td>
<td>7/12</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$Cu(1) - O(1)$</td>
<td>0.1939</td>
<td>0.19400</td>
<td>0.00010</td>
<td>7/12</td>
<td>8</td>
<td>0.04</td>
</tr>
<tr>
<td>$Cu(2) - O(2)$</td>
<td>0.19258(2)</td>
<td>0.19400</td>
<td>0.00142</td>
<td>7/12</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$Cu(2) - O(2)$</td>
<td>0.1939(1)</td>
<td>0.19400</td>
<td>0.00010</td>
<td>7/12</td>
<td>8</td>
<td>0.60</td>
</tr>
<tr>
<td>$Cu(2) - O(3)$</td>
<td>0.19599(3)</td>
<td>0.19400</td>
<td>0.00199</td>
<td>7/12</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$Cu(2) - O(3)$</td>
<td>0.1940(1)</td>
<td>0.19400</td>
<td>0.00000</td>
<td>7/12</td>
<td>8</td>
<td>0.04</td>
</tr>
<tr>
<td>$Cu(2) - O(3)$</td>
<td>0.1939(1)</td>
<td>0.19400</td>
<td>0.00010</td>
<td>7/12</td>
<td>8</td>
<td>0.60</td>
</tr>
<tr>
<td>$Cu(2) - O(4)$</td>
<td>0.1940(1)</td>
<td>0.19400</td>
<td>0.00000</td>
<td>7/12</td>
<td>8</td>
<td>0.04</td>
</tr>
<tr>
<td>$Cu(2) - O(4)$</td>
<td>0.1939(1)</td>
<td>0.19400</td>
<td>0.00000</td>
<td>7/12</td>
<td>8</td>
<td>0.60</td>
</tr>
</tbody>
</table>
Table 5. Critical temperature $T_c$ as function $a$ (in nm) for superconductor Nb$_x$Al$_{y}$, $\Delta = |a_{exp} - a_{cal}|$.

<table>
<thead>
<tr>
<th>$T_c$</th>
<th>$a_{exp}$</th>
<th>$a_{cal}$</th>
<th>$\Delta$</th>
<th>$n_1/n_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.6</td>
<td>0.5183(1)</td>
<td>0.5172</td>
<td>0.0011</td>
<td>14/9</td>
</tr>
<tr>
<td>17.6</td>
<td>0.5185(1)</td>
<td>0.5172</td>
<td>0.0013</td>
<td>14/9</td>
</tr>
<tr>
<td>13.6</td>
<td>0.5191(1)</td>
<td>0.5172</td>
<td>0.0019</td>
<td>14/9</td>
</tr>
<tr>
<td>9.6</td>
<td>0.5172(1)</td>
<td>0.5172</td>
<td>0.0023</td>
<td>14/9</td>
</tr>
<tr>
<td>&lt;1.4</td>
<td>0.5200(1)</td>
<td>0.5172</td>
<td>0.0028</td>
<td>14/9</td>
</tr>
</tbody>
</table>

We come to the conclusion that superconductivity can be explained by the following assumption: channel motions in systems like that of electron motion in the ground state of a hydrogen atom are exactly synchronous. Therefore, superconductivity systems represent a coherent synchronized state — a complex of coupled resonators with the commensurable frequencies.

- This means that we have in principle found out the possibility to achieve superconductivity at room temperature (Gareev 2000).

The parameter-free formula for interatomic distances in biomolecules, superconductors, and size of nanostructures has been obtained [5]. This establishes some bridge between the structures of different phenomena (conductivity, superconductivity, insulator-metal transmission, quantum Hall effect, superfluidity, quantization of nanostructure cluster size, size of biomolecules). This connection can be considered as an indication of the existence of some physical phenomena in the structures of the superconducting and living systems.

We have shown [25] only a small part of our calculations by formula (9) and the corresponding comparison with experimental data for interatomic distances in some molecules. One can be surprised by a high accuracy description of the existing experimental data.

Understanding of the origin and evolution of the genetic code must be the basis for a detailed knowledge of the relationship between the basic building blocks of DNA and environment. As is widely accepted today, essentially all the DNA in an eukaryotic nucleus are formed of histones and different chromatin structures folded hierarchically. At least five orders of DNA and chromatin organization and folding (nucleotid, helix, nucleosome, solenoid and chromat fibre loop) have been described in the literature. A DNA chain is a long unbranched polimer composed of only four types of subunits. These are nucleotides containing the basis adenin (A), cytozine (C), guanin (G), and thymine (T). These nucleotides form complementary flat pairs and the distances between these plains are equal to $\lambda_e$.  

123
• This means that the structures, formed in DNA molecules by nucleotides, produce the two- and three-dimensional superconductors (wave guides).

All proteins look like dimers in which the two copies of the recognition helix are separated by exactly one turn of the DNA helix:

$$3.4\text{nm} \Leftrightarrow 10\lambda_e = 3.325\text{nm}.$$  

DNA is packaged with histones into regularly repeating nucleosomes that are packed into 30 nm (diameter) fibers:

$$30 \Leftrightarrow 90\lambda_e = 29.92\text{nm},$$

it is also elaborated, folded and organized by other proteins into a series of subdomains of distinct character. This higher-order packing is the most fascinating and also most poorly understood aspect of chromatin.

Molecules of DNA, amino acids, proteins, … contain tetrahedral blocks $H_3C-C$ with the angles $\angle HCH = \angle HCH = 109.47^\circ$, with the bond length

$$3d (H-C) = \lambda_e = 0.3325\text{nm} \text{ and } 3d (H-C) + d (C-C) = 3/2\lambda_e = 0.4987\text{nm}.$$  

Note that these molecules of amino acids and DNA have planar blocks $H_2N-C$, whose bond length is equal to

$$2d (H-N) + d (N-C) = \lambda_e = 0.332\text{nm}.$$  

Pentagonal rings in adenine and guanine have the bond length equal to 0.668 and 0.666 nm, respectively, which is close to $2\lambda_e = 0.665$ nm.

• Many distances in living molecules are commensurable with the de Broglie wave length $\lambda_e$ of an electron (proton) in the ground state of a hydrogen atom. This means that $\lambda_e$ play the role of the standard distance in molecules, especially in living molecules. Hence, the electron and proton motions in a hydrogen atom and in living molecules are synchronized and self-consistent. A hydrogen atom represents radiating and accepting antennas swapping the information with the surrounding substance. Atoms, molecules represent wave antennas.

7. Cold Fusion

It is well known in optics (and in quantum mechanics too) that the transition coefficient of light through a layer is equal to one if the following relations between the thickness $R$ of the layer and wave length $\lambda$ exist
\[ R = \frac{n}{n_2} \lambda, \quad n_1 = 1, 2, 3, \ldots, \quad n_2 = 2, 4 \]  

(10)

- In this case the light does not feel the layer: the layer does not exist for the light in such conditions. The layer is invisible and transparent.
- The same mechanism can be for cold fusion or LENR when cell sizes and corresponding wavelengths obey the conditions (10) — maximal effectiveness for nuclear processes.

8. Crystallographic Picture of Universe

- M. Gryzinski \([9, 10, 11]\) has proved that atoms are the quasi-crystal structure with definite angles: 90°, 109° and 120°, which are the well-known angles in crystallography. It was assumed \([12]\) that electrons on atomic orbital have the form of correct systems on the sphere (the Platon and Arxmed bodies, ...). The system of the same particles is STABLE only in the cases when the particles are situated on the very top of isogon – polyhedron.

- From the point of view of academic science, the crystallographic structure in nuclei is not accepted due to the large kinetic energies of nucleons in nuclei. Nevertheless the crystallographic models of nuclei have been constructed with success \([14, 15]\). A. Dudek \textit{et al.} \([16]\) confirmed the existence of tetrahedral and octahedral forms of rare earth nuclei.

- D.D. Ivanenko and R.V. Galiulin \([13]\) come to conclusion that the structures all states of matter (FROM THE ELEMENTARY PARTICLES to THE LARGE SCALE of THE UNIVERSE) can be describe by Delone sets in the spaces of constant curvature.

For example, V.F. Weisskopf \([17]\) comes to conclusion that the maximum height \(H\) of mountains in terms of the Bohr radius \(a\) is equal to

\[ \frac{H}{a} \approx 2.6 \cdot 10^{14} \]

and water waves lengths \(\lambda\) on the surface of a lake in terms of the Bohr radius is equal to

\[ \frac{\lambda}{a} \approx 2\pi \cdot 10^7. \]
The greatness of mountains, the finger sized drop, the shiver of a lake, and the smallness of an atom are all related by simple laws of nature – Victor F. Weisskopf [17]. He considers the three spectroscopies (atomic, nuclear and subnuclear) to be on common ground [18].

We have proved the ISOMORPHISM of hydrogen atom, molecule, and crystal structures (Gareev 2000).

We have proved the ISOMORPHISM of hydrogen atom and solar system structures (Gareev 1996).

V. Krivitski [19] confirmed that the form of Earth is a triacontahedron with 5-fold symmetry.

N. Yabuuchi and A. Takahashi [20] came to the conclusion that nuclei exist in similar structures as structures of Pythagoras-Platonic polyhedrons in universe, molecules and atomic clusters. Furthermore, there exist in the universe the form of self-organization to arrange these materials (from large one to small one) into regular polyhedrons in realizing stars, molecules, atoms and elementary particles.

J. Kepler (1596) found that each of five Platonic solids could be uniquely inscribed and circumscribed by spherical orbs; nesting these solids, each encased in a sphere, within one another would produce six layers, corresponding to the six known planets – Mercury, Venus, Earth, Mars, Jupiter, and Saturn. By ordering the solids correctly – octahedron, icosahedron, dodecahedron, tetrahedron, cube. (Wikipedia)

So the resonance synchronization principle is substantiated at the micro and macro level as the consequence of the energy conservation law and resonance character of any interaction between wave systems. The commensurability and self-similarity result in the very unity of the world.

This means that our method can be used in different fields of fundamental research and also in applications: construction of new materials, say, high-temperature superconductors, new drugs in medicine, new methods in diagnostics of diseases, and new devices by analogy with biomolecules.

It is interesting to note that there is SYMMETRY between the order of the spectra of the hydrogen atom and the electronic levels of different atoms [23]. This means that the homology and isomorphism of the hydrogen atom and many-electron atom structures exists.
In 1953 Schwartz [24] proposed considering the nuclear and the corresponding atomic transitions as a unified process. This process contains the $\beta$ -decay which represents the transition of nucleon from state to state with emission of electron and antineutrino, and simultaneously the transition of atomic shell from the initial state to the final one. A complete and rigorous solution to this problem is still needed.

9. Conclusions

The structures of elementary particles, nuclei, atoms, molecules … and the Universe are topologically the same.

References


I. Introduction

A review of possible stimulation mechanisms of LENR (low energy nuclear reaction) is presented in [1, 2, 3]. We have concluded that transmutation of nuclei at low energies and excess heat is possible in the framework of the known fundamental physical laws, the universal cooperative resonance synchronization principle [1], and different enhancement mechanisms of reaction processes [2]. The superlow energy of external fields, the excitation, and ionization of atoms may play the role of a trigger for LENR. Superlow energy of external fields may stimulate LENR [3]. We give strong arguments that the cooperative resonance synchronization mechanisms are responsible for explanation of how the electron volt world can influence the nuclear mega electron volt world.

Nuclear physicists are absolutely sure that this cannot happen. Almost all nuclear experiments were carried out in conditions when colliding particles interacted with the nuclear targets which represented a gas or a solid body. The nuclei of the target are in the neutral atoms surrounded by orbital electrons. All existing experimental data under such conditions teach us that nuclear low energy transmutations are NOT OBSERVED due to the Coulomb barrier.

LENR with transmutation of nuclei occurs in different conditions and different processes but these processes have common properties: interacting nuclei are in the ionized atoms or completely without electrons (bare nuclei). Therefore, LENR with bare nuclei and nuclei in ionized atoms demonstrated drastically different properties in comparison with nuclei in neutral atoms [2].

- LENRs take places in open systems in which all frequencies and phases are coordinated, according to the universal cooperative resonance synchronization principle. Poor reproducibility of experimental results and extreme difficulties of their interpretation in the framework of modern standard theoretical physics are the main problems of LENR.

Recent progress in both the directions is remarkable and this phenomenon is a key point for further success in the corresponding fundamental and applied research. The results of this research field can provide new ecologically pure sources of energy, substances, and technologies.
The possibilities of inducing and controlling nuclear reactions at low temperatures and pressures by using different low-energy fields and various physical and chemical processes were discussed in [2, 3]. The aim of this paper is to present the results of phenomenological quantization of atomic and nuclear masses and their differences which can bring new possibilities for inducing and controlling nuclear reactions by atomic processes and new interpretation of self-organization of the hierarchical systems in the Universe.

**HOW DO ATOMS and NUCLEI HAVE PERPETUAL MOTION?**

**II. Hydrogen Atom in Classical Mechanics**

Is it possible to understand some properties of a hydrogen atom from classical mechanics? The Hamiltonian for a hydrogen atom is

\[ H = \frac{m_p \dot{r}_p^2}{2} + \frac{m_e \dot{r}_e^2}{2} - \frac{e^2}{|r_p - r_e|}. \]  

(1)

All notation is standard. The definition of the center of mass is

\[ m_p \bar{r}_p + m_e \bar{r}_e = 0, \]  

(2)

and the relative distance between electron and proton is

\[ \bar{r} = \bar{r}_p - \bar{r}_e. \]  

(3)

Equations (1) – (3) lead to the results

\[ \frac{\dot{r}_p}{m_p + m_e} = \frac{\dot{r}_e}{m_p + m_e}, \]  

(4)

\[ H = \frac{\mu \dot{r}^2}{2} - \frac{e^2}{r}, \]  

(5)

where

\[ \mu = \frac{m_pm_e}{m_p + m_e}. \]  

(6)

The Hamiltonian (5) coincides with the Hamiltonian for the fictitious material point with reduced mass \( \mu \) moving in the external field \(-e^2/r\). If we known the trajectory of this fictitious particle \( \bar{r} = \bar{r}(t) \) then we can reconstruct the trajectories of electron and proton using equations (4):
\[
\bar{r}_p(t) = \frac{m_e}{m_p + m_e} \bar{r}(t), \quad \bar{r}_e(t) = -\frac{m_p}{m_p + m_e} \bar{r}(t).
\] (7)

It is evident from (7) that the proton and electron move in the opposite directions synchronously.

SO THE MOTIONS OF PROTONS, ELECTRONS and THEIR RELATIVE MOTION OCCUR WITH EQUAL FREQUENCY

\[
\omega_p = \omega_e = \omega_\mu.
\] (8)

We can derive from (7) that

\[
\bar{P}_p = \bar{P}, \quad \bar{P}_e = -\bar{P},
\] (9)

where \(\bar{P}_i = m_i \bar{v}_i\). All three impulses are equal to each other in absolute value, which means the equality of

\[
\lambda_D(p) = \lambda_D(e) = \lambda_D(\mu) = h / P.
\] (10)

- Therefore, the motions of proton and electron and their relative motion in the hydrogen atom occur with the same FREQUENCY, IMPULSE (linear momentum) and the de Broglie WAVELENGTH. All motions are synchronized and self-sustained. Therefore, the whole system-hydrogen atom is nondecomposable into independent motions of proton and electron.

III. Quantization of Nuclear and Atomic Rest Masses

Almost all quantum mechanical models describe excited states of nuclei, atoms, molecules, condensed matter,... neglecting the structure of the ground state of the investigated systems. Therefore, we have very restricted information about the properties of nuclei, atoms,... in their GROUND STATES. Note that the mutual influence of the nucleon and electron spins (the superfine splitting), the Mossbauer effect, and so on are well-known. The processes going in the surrounding matter of nuclei change the nuclear moments and interactions of nucleons in nuclei.

- We proved that the motions of proton and electron in the hydrogen atom in the ground state occur with the same frequency; therefore, their motions are synchronized. The cooperation in motion of nucleons in nuclei and electrons in atoms in their ground states is still an open problem. We formulate a very simple and audacious working hypothesis: the nuclear and the corresponding atomic processes must be considered as a unified entirely determined whole process. The nucleons in nuclei and the electrons in atoms form open nondecomposable whole systems in which all frequencies and phases of nucleons and electrons are
coordinated, according to the universal cooperative resonance synchronization principle.

This hypothesis can be checked at least partly by investigation of the difference between nuclear and atomic rest masses. We performed this analysis for the first time (details in [4]).

The rest mass differences of atoms in the $\beta$-decay (single and double) and electron capture (single and double) processes, $\alpha$-decay, the differences between nuclear and atomic rest masses are quantized by the formula [4] (in $\frac{MeV}{c^2}$)

$$\Delta M = 0.0076293945 \cdot \frac{n_1}{n_2}, \quad n_1 = 1, 2, 3, \ldots, n_2 = 1, 2, 4, 8.$$  \hspace{1cm} (11)

The accuracy of this formula (to seven significant digits) can be increased if we take into account in our calculations all masses of atoms and nuclei (3177) to ten significant digits. The experimental data were taken from P. Moller, et al.: http://t2.lanl.gov/data/astro/molinx96/massd.html

$$M = 0.0076293945312 \cdot \frac{n_1}{n_2}, \quad n_1 = 1, 2, 3, \ldots, n_2 = 1, 2, 4, 8.$$  \hspace{1cm} (12)

Note that this quantization rule is justified for atoms and nuclei with different $A, N$ and $Z$, and the nuclei and atoms represent coherent synchronized systems — a complex of coupled oscillators (resonators). This means that nucleons in nuclei and electrons in atoms contain all necessary information about the structure of other nuclei and atoms. This information is used and reproduced by simple rational relations, according to the fundamental conservation law of energy. Remember that the following relations exist:

$$E = Mc^2 = h \nu,$$  \hspace{1cm} (13)

where $E$ is energy, $h$ is the Planck constant, and $\nu$ is frequency. Schrodinger wrote that an interaction between microscopic physical objects is controlled by specific resonance laws. According to these laws, any interaction in a microscopic hierarchic wave system exhibits resonance character

$$\sum_{j=1}^{N} q_j v_j = 0,$$  \hspace{1cm} (14)
where \( i=1,2,3,\ldots \) is a number of linear independent relations, \( q_{ij} \) is the matrix consisting of only integer numbers. Note that the binary relations from (14) can be rewritten in the following way:

\[
v_i = \frac{n_j}{n_i} v_j, \quad n_i(n_j) = \pm 1, \pm 2, \pm 3,\ldots, \quad (15)
\]

In the classical case the resonance occurs only when the frequency of the external field is close to the proper frequency of the system. The commonly accepted point of view is that the integer numbers in resonance conditions (15) must be small numbers. In the case of the argumental pendulum of D.B. Douboshenski and Ya.A. Duboshinsky [5] stable oscillations are maintained by an efficient coupling between subsystems whose frequencies can differ by two or more orders of magnitude. We come to the conclusion that the integer numbers \( n_i \) and \( n_j \) can be any numbers:

\[
1 \pm 10^9.
\]

We originated the universal cooperative resonance synchronization principle and this principle is the consequence of the conservation of energy.

The cooperative resonance synchronized processes occur in the whole system: cooperative processes including all nucleons and electrons in atoms; in condensed matter; and in the surroundings when the resonance conditions (15) are fulfilled for all subsystems and the whole system. In this case, the threshold energy \( Q \) can be drastically decreased by internal energy of the whole system or even more — for example, the electron capture by proton in nuclei can be accompanied by emission of internal binding energy (which is forbidden in the case of the electron capture by free protons) — main source of excess heat phenomenon in LENR. A half-life of neutron in nuclei changes dramatically and depends on the isotopes.

As a final result, the nucleons in nuclei and electrons in atoms have commensurable frequencies and the differences between those frequencies are responsible for creation of beating modes. The phase velocity of standing beating waves can be extremely high; therefore, the nucleons in nuclei and electrons in atoms should get information from each other almost immediately (instantaneously) using phase velocity. Remember that the beating (modulated) modes are responsible for radio and TV-broadcasting.

The universal cooperative resonance synchronization principle is responsible for the unity of the nuclei and atoms. The quantization atomic and nuclear masses (12) with the same quanta of mass confirmed our working hypothesis: atoms and nuclei are open systems in which all motions are self-coordinated.
III. Conclusion

Note that the quantization rule (11, 12) is justified for atoms and nuclei with different $A, \ N$ and $Z$, and the nuclei and atoms represent coherent synchronized systems – a complex of coupled oscillators (resonators). It means that nucleons in nuclei and electrons in atoms contain all necessary information about the structure of other nuclei and atoms. This information is used and reproduced by simple rational relations, according to the fundamental conservation law of energy-momentum. We originated the universal cooperative resonance synchronization principle and this principle is the consequence of the conservation law of energy-momentum. As a final result, the nucleons in nuclei and electrons in atoms have commensurable frequencies and the differences between those frequencies are responsible for creation of beating modes. The phase velocity of standing beating waves can be extremely high; therefore, all objects of the Universe should get information from each other almost immediately (instantaneously) using phase velocity [1, 3]. Remember that the beating (modulated) modes are responsible for radio and TV-broadcasting.

Therefore, we come to understand the Mach principle. There are different interpretations of the Mach principle. The Mach principle can be viewed as the entire universe being altered by the changes in a single particle and vice versa.

- The universal cooperative resonance synchronization principle is responsible for the very unity of the Universe.

We have shown only a very small part of our calculations by formula (11, 12) and the corresponding comparison with experimental data for atomic and nuclear rest mass differences. This formula produces a surprisingly high accuracy description of the existing experimental data. Our incomplete tentative analysis has shown that the quantization of rest mass differences demonstrate very interesting periodical properties in the whole Mendeleev periodic table. We hope that it is possible to create an analog of the Mendeleev periodic table describing atomic and nuclear properties of the atomic and nuclear systems simultaneously.

We bring some arguments [1, 2] that the homology of atoms, molecules (in living molecules too, including DNA) and crystal structures exists. So inter-atomic distances in molecules, crystals and solid-state matter can be written in the following way:

$$d = \frac{n_1}{n_2} \lambda_e,$$

where $\lambda_e = 0.3324918$ nm is the de Broglie electron wavelength in a hydrogen atom in the ground state ($\lambda_e = \lambda_p$ in a hydrogen atom in the ground state) and $n_1(n_2) = 1, 2, 3, \ldots$
In 1953 Schwartz [6] proposed considering the nuclear and the corresponding atomic transitions as a unified process. This process contains the beta-decay which represents the transition of nucleon from state to state with emission of electron and antineutrino, and simultaneously the transition of atomic shell from the initial state to the final one. A complete and strict solution of this problem is still needed.

We did the first step to consider the nuclear and atomic rest masses as unified processes (coupled resonators) which led us to establish the corresponding phenomenological quantization formula (11), and can bring new possibilities for inducing and controlling nuclear reactions by atomic processes and new interpretation of self-organization of the hierarchial systems in the Universe including living cells.

LENR can be stimulated and controlled by superlow energy external fields. If frequencies of an external field are commensurable with frequencies of nucleon and electron motions, then we should have a resonance enhancement of LENR. Anomalies of LENR in condensed matter (in plasma) and many anomalies in different branches in science and technologies (for example, homoeopathy, influence of music in nature, rhythms, nanostructures…) should be results of cooperative resonance synchronization frequencies of subsystems with open system frequencies, with surrounding and external field frequencies. In these cases threshold energy can be drastically decreased by internal energy of the whole system — the systems are going to change their structures if more stable systems result. Therefore, we have now real possibilities to stimulate and control many anomalous phenomena including LOW ENERGY NUCLEAR REACTIONS and even SUPER-CONDUCTIVITY [1].

We have in principle found a possible way to ACHIEVE SUPER-CONDUCTIVITY AT ROOM TEMPERATURE [1].

References

Observation of $^3$He and $^3$H in the volcanic crater lakes: possible evidence for natural nuclear fusion in deep Earth

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Abstract

Mantle helium and other volatiles may be released to volcanic crater lakes. This paper presents the observation of $^3$H and mantle helium in the crater Lakes Nemrut (Turkey), Laacher (Germany) and Pavin (France). The presence of excess $^3$H in the lakes can be explained as material released from mantle sources because of the correlation of excess $^3$H with mantle $^3$He and $^4$He. The helium concentration was much higher in the bottom layers of the lakes. The $^4$He and $^3$He concentrations in Lakes Nemrut, Laacher, and Pavin were determined to be 25 and 190; 10 and 50; and 70 and 500 times larger than the atmospheric saturation value, respectively. The isotopic ratio of the excess helium, $^{3}\text{He}_{ex}/^{4}\text{He}_{ex}$, in Lakes Nemrut, Laacher and Pavin was $(1.032\pm0.006)\times10^{-5}$, $(7.42\pm0.03)\times10^{-6}$ and $(9.09\pm0.01)\times10^{-6}$ respectively. The ratios clearly indicate that large amounts of helium isotopes are released to the lakes from a mantle source. The excess $^3$H at the bottom of Lakes Nemrut, Laacher and Pavin is estimated to be $3.7\pm1.4$ TU, $\sim1.4$ TU and $\sim4$ TU respectively. Detection of tritium in the Earth’s interior is key evidence for natural nuclear fusion in the Earth.

We conclude that the excess $^3$H in the lakes, after the origin of the excess $^3$H from atmosphere and conventional nuclear reactions are excluded, and the correlation of the excess $^3$H and mantle $^3$He is considered, might be from a mantle source. We also conclude that the $^3$H and $^3$He are produced by nuclear fusion (d-d reaction) in an environment (condensed matter or plasma) rich in H atoms and (U+Th) at high temperature and high pressure conditions in deep Earth.

1. Introduction

In 1969, Clarke et al. discovered mantle $^3$He released to the deep Pacific Ocean water$^{[1]}$. This excess $^3$He was attributed to the leakage of primordial $^3$He into the oceans at active spreading centers such as the East Pacific Rise. Then, Krylov et al.$^{[2]}$ found an elevated $^3\text{He}/^4\text{He}$ ratio of $\sim9$ RA in oceanic basalt glass, where RA is the $^3\text{He}/^4\text{He}$ ratio in the atmosphere.

The atomic ratio of the two stable helium isotopes, $^3\text{He}/^4\text{He}$, varies considerably between different components of the geosphere. In the troposphere and hydrosphere the ratio is on the order of $1.4 \times 10^{-6}$. The mantle is characterized by a $^3\text{He}/^4\text{He}$ ratio of $\sim10^{-5}$,
while the continental crust is characterized by a $^{3}\text{He}/^{4}\text{He}$ ratio of $\sim10^{-7} - 10^{-8}$. The analysis of helium isotopes in fluids can help to identify the origin of gas fluxes from the interior of the Earth.

Seeking the source of $^{3}\text{He}$ in the Earth’s interior, Gerling et al.\textsuperscript{[3]} and Mamyrin and Tolstikhin\textsuperscript{[4]} investigated various nuclear processes for $^{3}\text{He}$ ($^{3}\text{H}$) production, including spontaneous fission of U and Th, and nuclear reactions induced by neutrons, $\alpha$-particles and $\gamma$-rays. However, the results show the $^{3}\text{He}/^{4}\text{He}$ ratios to be less than $10^{-8}$, values much lower than the $^{3}\text{He}/^{4}\text{He}$ ratios in the mantle. High $^{3}\text{He}/^{4}\text{He}$ ratios could be induced by the spallation reaction from cosmic rays in terrestrial rock\textsuperscript{[5]}, but the effect should be negligible deep under the earth. Therefore, the $^{3}\text{He}$ in ocean basalts has been explained as having a primordial origin (i.e. $^{3}\text{He}$ trapped underground at the time of Earth’s formation). This is the default explanation, given that no radiogenic or nucleogenic mechanism can be found to produce such high $^{3}\text{He}/^{4}\text{He}$ ratio over broad regions of the Earth’s mantle.

In recent years, the hypothesis that the $^{3}\text{He}$ is of primordial origin has been challenged. It seems paradoxical that there is such a narrow distribution of $^{3}\text{He}/^{4}\text{He}$ ratios (8±1 RA) in the Mid-Ocean Ridge Basalts (MORB) and in the hydrothermal vent fluids at Mid-Ocean Ridge (MOR)\textsuperscript{[6]}. Also, the $^{3}\text{He}/^{4}\text{He}$ ratio in diamonds is extraordinarily high\textsuperscript{[7]}, exceeding the planetary value of $1.4\times10^{-4}$.

The hypothesis of natural nuclear fusion occurring in the deep Earth (geo-fusion) goes back to 1980s. Jones et al.\textsuperscript{[8]} supposed that under non-equilibrium conditions, d-d and p-d fusion reactions might occur in the deep Earth with the reactions:

$$p + d \rightarrow ^{3}\text{He} + \gamma (5.4 \text{ MeV})$$
$$d + d \rightarrow p (3.02 \text{ MeV}) + ^{3}\text{H}(1.01 \text{ MeV})$$
$$d + d \rightarrow n (2.45 \text{ MeV}) + ^{3}\text{He} (0.82 \text{ MeV})$$

Here $^{3}\text{H}$ and $^{3}\text{He}$ are the products of a d-d reaction. $^{3}\text{He}$ is already known to be released from deep Earth, but this could be of primordial origin. Since tritium decays with a half-life of 12.4 years, a good test of the hypothesis that d-d reactions occur in the Earth would be the detection of tritium emanating from deep Earth and found in magmatic gases and fluids\textsuperscript{[9]}. $^{3}\text{H}$ induced by other nuclear reactions in the Earth was estimated to be less than 0.01 TU (1 TU=1 tritium atoms per $10^{18}$ hydrogen atoms), a value which is under the detectable limit.

Extensive tritium measurements in volcanic products were made to search for evidence for natural nuclear fusion in the Earth. Quick et al.\textsuperscript{[10]} tried to measure the tritium concentration in the active P’pO’o crater at Kilauea in Hawaii, they found that the tritium concentration of the samples from inner crater was lower than that of the samples taken simultaneously from the nearby upwind crater rim. The results provide no evidence in support of natural fusion in the Earth’s interior. In another experiment, Goff and McMurtry\textsuperscript{[11]} collected magmatic water samples from 11 active volcanoes around the
world. They found that magmatic tritium values were generally as small as the background level, and they concluded there is no evidence that natural fusion in the Earth emits \(^3\)H at a concentration above 0.05 TU. However, from measured data\(^{11}\) Jones et al. noticed that there were “positive \(^3\)H anomalies” in two sites, Kilauea in Hawaii and the Alcedo “geyser” in the Galapagos Archipelago\(^9\).

2. Mantle helium and excess tritium in volcanic lakes

The analysis of helium isotopes in lakes can help us to identify the origin of gas fluxes from the interior of the Earth. The ability of volcanic lakes to store magmatic gases can be used to detect mantle degassing. In this work, we report observations of helium isotopes and tritium in volcanic crater lakes Nemrut, Laacher and Pavin

2.1 Lake Nemrut

Lake Nemrut (2247 m a.s.l., in Turkey) is formed from a caldera. It is located at the western border of Lake Van, and has a surface area of 11 km\(^2\), a maximum depth of 167 m and volume of 0.98 km\(^3\). Lake Van is the fourth largest closed-basin lake and the largest alkaline lake on Earth, and it is surrounded by several active volcanoes, situated along a fault running from the north-east to the south-west\(^{12}\).

2.1.1 Mantle helium

The most striking feature of the helium concentration measured in Lake Nemrut is the large increase of both helium isotopes with depth (Fig. 1). At the depth of 150 m the \(^4\)He concentration is 25 times larger than the atmospheric saturation value. For \(^3\)He the supersaturation reaches a factor of about 190. The \(^3\)He/\(^4\)He ratio at the bottom of the lake equals 10.1×10\(^{-6}\) and decreases from the bottom to the surface due to mixing. However, the helium excess of both isotopes at different depths are linearly related: \(\frac{\text{He}_{\text{ex}}}{\text{He}} = (1.032 \pm 0.006)\times10^{-5}\) (Fig. 2). The ratio is about 7.5 times larger than the ratio in the atmosphere and clearly excludes the possibility that the excess helium could be of atmospheric origin\(^{12}\). The \(\frac{\text{He}_{\text{ex}}}{\text{He}}\) ratio is consistent with the ratios in MORB and hydrothermal fluids from MOR.
Figure 1. Vertical profile of $^{3}\text{He}/^{4}\text{He}$ ratio in Lake Nemrut. Due to mixture of water, the ratios decrease with depth. Data are adopted from Ref. 12.
Figure 2. Vertical profile of $^3$He$_{ex}/^4$He$_{ex}$ in Lake Nemrut. $^3$He$_{ex}$ and $^4$He$_{ex}$ are excess $^3$He and $^4$He respectively. Data are adopted from Ref. 12.

2.1.2 Tritium anomalies in vertical profiles

Tritium is usually added to a lake from the surface by precipitation. When the water is well mixed vertically, nearly homogeneous tritium distribution is found from the surface to the bottom of the lake, as shown in Lake Issyk-kul (Kyrgyzstan)\textsuperscript{13}. On the other hand, with a non-uniform vertical mixture, the tritium concentration will decrease with depth, as observed in the vertical profiles of $^3$H concentration in Lakes Van \textsuperscript{12} and Baikal (Russia)\textsuperscript{14}.

The different patterns seen in the vertical profiles of $^3$H concentration in Lake Nemrut and Lake Van is observed from experimental data in reference 12. The $^3$H concentration in Lake Van decreases with increasing depth (Fig. 3a). It decreased by about 20% and 15% respectively in 1989 and 1990 from the surface to the bottom of the lake\textsuperscript{12}. This could be due to the fact that the water in the bottom is not completely mixed. The dashed line in Fig. 3 indicates the $^3$H concentration in the surface layer. Unlike the situation when tritium is added to the lake from precipitation, the $^3$H concentration in Lake Nemrut was about 10% higher ($>3\sigma$) at the bottom than at the surface (Fig. 3b), and all the values below the depth of 10 m were larger than the surface value. These results suggests
that in addition to normal atmospheric tritium added to the surface, excess $^3$H may also be injected from the bottom of the lake.

Figure 3. The vertical profiles of $^3$H concentration in Lakes Van and Nemrut are given in Fig. 7a and Fig. 7b respectively. The dash line indicates the $^3$H concentration in the surface layer; error bar at 1 $\sigma$. Data is adopted from Ref. 12.
The $^3$H concentration is 33.3 ± 0.9 TU at the bottom layer of Lake Nemrut (150 m), and 30.0 ± 1.0 TU at the surface, an error at 1 $\sigma$ level. The difference of the values between the bottom and surface is about +10%, > 3 $\sigma$. The tritium at the surface is mainly from the atmosphere, and the tritium in the deep water is a mixture of tritium from the surface and the bottom. The difference of mean $^3$H concentration between the depth of 90 to 150 m and the surface value is about 3.7±1.4 TU, which implies an excess of $^3$H. We suppose that $^3$H, similar to $^3$He, might originate from a mantle source [15].

2.2. Lake Laacher

Lake Laacher is located at the east Eiffel volcanic district of the Rhenish Massif with a nearly circular surface [16]. The main volcanic activity in the East Eiffel occurred during the Tertiary Quaternary volcanic activity started about 0.7 Ma ago and was essentially confined to the west East Eiffel. The typical craters called maars were formed by steam explosions due to contact of water with a magma chamber near the surface. Some of these maars formed lakes, especially in the West Eiffel. The largest maar lake, Lake Laacher, was found in the East Eiffel as a result of the most recent eruption of a huge volcano, about 11,000 years BP. Lake Laacher caldera has a maximum depth of 52 m and a surface area of 3.31 km$^2$.

2.2.1 Mantle helium

In Lake Laacher, the concentration of $^4$He and $^3$He increase with depth and at the bottom layer of the lake, they reach values up to 10 times (for $^4$He) and 50 times (for $^3$He) that of the atmospheric equilibrium concentration. The isotopic ratio of the excess helium, $^3$He/$^4$He is (7.42±0.03)$\times 10^{-6}$. This indicates the presence of helium from the sub-continental mantle. A plume of bubbles emerging from a funnel was observed at the sediment surface at depth of 31 m, to the eastern shore. The strong mantle helium near station LA2 was detected [16]. The helium isotopes and other rare gases emerging from the funnel are from the mantle, which is confirmed by the $^3$He/$^4$He ratios in the gases (from 7.23$\times 10^{-6}$ to 7.33 $\times 10^{-6}$) and very low $^{20}$Ne concentration (3 - 60 ppb) compared with atmospheric (16.4 ppm).

The measured $^3$He/$^4$He ratios (station LA1, near the center of the lake) as a function of the depth present a peak at around 25 m of depth (Fig. 4), which is caused by the existence of a large amount of local helium emerging from the funnel near station LA2. Also, the fact that the helium concentration increases below 30 m implies the presence of additional and deeper mantle sources.
2.2.2 Excess $^3$H in the lake

As mentioned above, the vertical profile of measured $^3$He/$^4$He ratios presents a peak at a depth of around 25 m (Fig. 4). A similar peak can be also observed in the vertical distribution of $^3$H concentration (station LA1) (Fig. 5).
The peak is consistent with existence of the funnel, and also consistent with the peak of $^3\text{He}/^4\text{He}$ ratio at 25 m (see Figure 4).

We consider it likely that the excess $^3\text{He}$ and $^3\text{H}$ at both peaks is all released from the funnel\cite{16}. Therefore, the excess $^3\text{H}$, like the $^3\text{He}$, might also originate from the mantle. The excess $^3\text{H}$ concentration released from the funnel is estimated to be about 1.1 TU. The 3 data points taken from below 30 m are widely scattered (Fig. 5), making it difficult to estimate the vertical variation trend of $^3\text{H}$ concentration in the deep parts of the lake. However, the fact that the $^3\text{He}/^4\text{He}$ ratio increases below 30 m implies the presence of an additional and deeper mantle source (Fig. 4).

In Fig. 6, we summarize all the tritium data listed in Table 1 of reference 16, including all data from LA1, LA2 and LA3, collected in May and September 1991. The tritium concentration measured in September is normalized to that of May. It can be seen that the $^3\text{H}$ concentration in the surface water is consistent for LA1 and LA2 in May and LA1 in September. The average value is 32.2 TU for surface water, shown as a dashed line (Fig. 6). The $^3\text{H}$ concentration between depth 10 and 50 m is higher than that in the surface on average. The data indicate that the excess $^3\text{H}$ concentration (at 20 - 30 m depth) is nearly constant with an average value of 1.1 TU. This excess $^3\text{H}$ correlate well with gases emerging from the funnel. The average value for total excess $^3\text{H}$ concentration between 10 - 50 m depth is 1.4 TU. The result indicates that the residual excess $^3\text{H}$ may be injected into the lake from the bottom and correlates well with mantle $^3\text{He}$.
2.3. Lake Pavin

Lake Pavin is a small (0.44 km$^2$), but deep (92 m), nearly circular lake located at an altitude of 1197 m in the French Massif Central\cite{17}. It occupies a maar crater which formed about 6000 years ago. A peculiar property of Lake Pavin is the presence of a stagnant deep water layer; that is, a permanently stratified layer, or “monimolimnion.” The monimolimnion is not affected by seasonal mixing. It is separated from the overlying seasonally mixed layer, or mixolimnion, by a chemocline between about 60 and 70 m in depth. This type of permanently stratified lake is referred to as “meromictic.”

2.3.1 Mantle helium

The $^4$He concentration is nearly at atmospheric equilibrium only in the surface layer of lake (the epilimnion). In the hypolimnion (depths between about 20 and 60 m), the $^3$He concentration is higher by up to a factor of 3, and in the monimolimnion by a factor of 70\cite{17}. The vertical profiles of the $^3$He/$^4$He ratios and $^3$He concentration are show in Figs. 7a and 7b respectively. The $^3$He concentration in the monimolimnion is higher than the surface layer by a factor of 300. The $^3$He/$^4$He ratio of excess helium is deduced to be $(9.09\pm0.17)\times10^{-6}$, or 6.57±0.01 RA. The value clearly indicates its origin from mantle source and a flux of mantle-derived magmatic gases into the monimolimnion.
Figure 7. Vertical profiles of $^{3}$He/$^{4}$He ratio (Figure 7a) and $^{3}$He concentration (Figure 7b) in Lake Pavin. The mantle helium was injected to the lake from the bottom and remained nearly constant in the monimolimnion. Data are adopted from Ref. 17.
2.3.2 Tritium concentration in the deep part of Lake Pavin

Lake Pavin is a meromictic crater lake. The chemocline (60-70 m) separates the seasonally mixed mixolimnion (the upper part of the lake) from the monimolimnion, which leads to a long deep-water residence time\(^{[17]}\).

The data listed in Refs. 18 and 19 show clearly the influence of tritium from nuclear testing on the surface water of the lake. The atmospheric tritium input into the lake is from the surface. The tritium concentration had large difference in the upper layer of the lake (mixolimnion) between 1981 and 1996, the tritium concentration varying from \(~53\) TU to \(~12\) TU in the mixolimnion. But the tritium concentration in the deep layer of the lake (monimolimnion) appeared to be more or less uniform around 5 TU (Fig. 8). The approximate constant tritium concentration in the deep part of the lake indicates no visible correlation with the variation of tritium concentration in the mixolimnion. Due to separation by chemocline, the \(^4\)He concentration in the monimolimnion is higher than the concentration in the surface layer by a factor of \(~70\)\(^{[17]}\). If separation of tritium by the chemocline is similar to \(^3\)He and \(^4\)He, the mixture of atmospheric tritium in the monimolimnion should be less than 1 TU. Therefore, an additional tritium source in the monimolimnion must be considered. A large amount of excess helium with \(^3\)He/\(^4\)He ratio of \((9.09\pm0.01)\times10^{-6}\) in the monimolimnion clearly indicate the input of mantle gases from the bottom. Thus, the presence of a large amount of mantle helium in the monimolimnion suggests that the excess \(^3\)H (about 4 TU) is also from a mantle source.

![Figure 8. The vertical profiles of \(^3\)H concentration in Lake Pavin, measured in 1996, 1987, 1986 and 1981, data adopted from Ref. 18 and 19. The approximate constant \(^3\)H concentration in the monimolimnion shows no obvious correlation with the large variation of \(^3\)H concentration in the mixolimnion.](image)
3. Discussion

Both mantle $^3$He and excess $^3$H in Lakes Nemrut, Laacher and Pavin are observed. The data are summarized in Table 1.

<table>
<thead>
<tr>
<th>Lake</th>
<th>$^{3} \text{He}<em>{\text{ex}}/^{3} \text{He}</em>{\text{ex}}, 10^{-6}$</th>
<th>$^3\text{He},\text{ concentration, } C_{\text{air}}$</th>
<th>$^3\text{He\ flux, mol/m}^2\cdot\text{s}$</th>
<th>Excess $^3\text{H, TU}$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laacher</td>
<td>7.42</td>
<td>50</td>
<td>$1.2 \times 10^{-16}$</td>
<td>~1.4</td>
<td>[16]</td>
</tr>
<tr>
<td>(Germany)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nemrut</td>
<td>10.1</td>
<td>190</td>
<td>~$1 \times 10^{-16}$</td>
<td>3.7</td>
<td>[12]</td>
</tr>
<tr>
<td>(Turkey)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Van</td>
<td>12</td>
<td>1.5</td>
<td>$6 \times 10^{-18}$</td>
<td>~0.9</td>
<td>[12]</td>
</tr>
<tr>
<td>(Turkey)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panvin</td>
<td>9</td>
<td>500</td>
<td>$9 \times 10^{-18}$</td>
<td>~4</td>
<td>[17, 18, 19]</td>
</tr>
<tr>
<td>(France)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$C_{\text{air}}$: $^3$He atmospheric saturation value in the water.

Global average $^3$He flux: $6.6 \times 10^{-20}$ mol/m$^2$·s.

* Volcanic lake

The volcanic crater lakes enrich mantle helium. For example, the excess $^3$He concentration at the bottom of Lake Nemrut is about 1-2 orders of magnitude higher than the $^3$He concentration in the volcanic crater at Kilauea. If the excess $^3$H comes from the mantle, together with $^3$He, the high $^3$He concentration might indicate high $^3$H concentration in the end-member magmatic fluid. Therefore, the concentration of mantle $^3$H in Lake Nemrut should be higher than the volcano areas (e.g. Kilauea). Thus, the volcanic lakes with high mantle-helium concentration are idea sites for testing magmatic gases released from the mantle source.

4. Conclusions

"$^3$H anomalies" in the vertical profiles are observed in Lakes Nemrut, Laacher and Pavin. These profiles have different shapes. The excess $^3$H correlate fairly well with mantle helium ($^3$He) in each lake. Therefore, the excess $^3$H is believed to be injected into the lakes from the bottom. We conclude that excess $^3$H in the three lakes, after the origin of the excess $^3$H from atmosphere and conventional nuclear reactions are excluded, and the correlation of the excess $^3$H and mantle $^3$He is considered, might be from a mantle
source. We suppose that the $^3$H and $^3$He might be produced by nuclear fusion (d-d reaction) occurring in an environment of enriched H atoms and (U+Th) deep in the earth, at high temperatures and pressure$^{[15]}$. The physical mechanism of natural nuclear fusion in the deep Earth, however, remains an open question. Nuclear mechanisms that can explain the excess $^3$H released from deep Earth are called for.

Acknowledgements

We would like to express our thanks to the authors for the published data that are used in this research.

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On emission of nuclear particles caused by electrolysis

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ABSTRACT

Numerous tracks of charged nuclear particles, emitted during electrolysis, were discovered by Oriani and Fisher (1). More recently, emission of such particles after electrolysis was discovered by Oriani (2). This presentation is based on ten experiments conducted to replicate the reported results. Seven clusters of tracks were found in two out of six electrolysis experiments. Three clusters were also found in one of four experiments conducted to study emission of nuclear particles after electrolysis. Arguments are presented against prosaic explanations for the clusters, such as natural radioactivity and cosmic rays.

1) Introduction

The field of so-called “cold fusion,” also known as CANR (chemically assisted nuclear reactions), belongs to the realm of protoscience. The accepted paradigm is that chemical processes – interactions involving outer electrons in atoms and molecules – are too weak to produce emission of nucleons from atomic nuclei. Yet, several qualified researchers, such as A. Lipson (3), R. Oriani (1) and S. Jones (4), have for many years been reporting unexpected emission of nuclear particles. Experimental facts that conflict with existing theories should be studied rather than rejected. A flowchart illustrating the evolution of protoscience toward science is shown in Figure 1.
This study, prompted by recent reports (2,5), confirms that an unexpected nuclear process seems to be occasionally triggered by a chemical process. According to Oriani (2), whose protocol was used in my investigation, nuclear particles are emitted during and after electrolysis. The high level of reproducibility, he believes, is due to residual activity. Each consecutive electrolysis experiment presumably benefits from what happens during the previous experiment. The probability of triggering a CANR effect in a new electrolytic cell is said to be very low, but it becomes very high after the first success. The probability is also said to be high in a new cell containing o-rings used in successful experiments. That is why my experiments were performed with o-rings previously used by Oriani.

According to (2), the distributions of tracks left by nuclear particles on CR-39 detectors are uniformly random. But sometimes tracks appear in the form of clusters, as illustrated in Figure 2.

Figure 4. Schematic illustration of evolution of protoscience toward accepted science.
I was able to confirm occasional production of clusters at local densities much higher than the background. The densities of uniformly distributed tracks, however, were found to be consistent with the background. Can radioactivity acquired by these rings in Oriani’s cell be responsible for the clusters produced in my experiments? My answer to this question will be negative. But the issue is far from being resolved, as indicated in the appendix. What follows describes my simple apparatus and results. In the closing section I will argue against the idea that clustered tracks are due to natural radioactivity or cosmic rays.

2) Experimental setup

The electrolytic cell used in my experiments was identical to one of Oriani’s cells, as schematically illustrated in Figure 3A. The electrolyte was Li$_2$SO$_4$ in ordinary distilled water at a concentration of 22 grams per liter. The anode was Pt and the cathode was Ni. The cell consisted of a set of glass tubes containing about 10 cc of the electrolyte. The bottom of the cell was made from a replaceable 3 cm $\times$ 3 cm piece of CR-39 plastic material. That piece (thickness about 1 mm) was separated from the electrolyte by a layer of Mylar whose thickness was 6 microns. The Ni-wire cathode, in the form of a spiral pancake, was in contact with the Mylar while the Pt-wire anode, also in the form of a
spiral pancake, was about 15 mm above the cathode. The cell was designed in anticipation of experiments in which CR-39 would be removed and a silicon detector, placed below the Mylar window, would be used to measure energies of charged nuclear particles.

Potential differences applied to the cell were between about 5 and 12 volts, depending on the desired current (between 30 mA and 150 mA during preliminary experiments). At 3 volts the current was close to zero. The concentration of the electrolyte was allowed to double (approximately) during experiments because water lost via electrolysis was usually not replaced until the volume of the electrolyte was reduced by approximately one half. The current, however, was kept constant, usually 42 mA, by an electronic stabilizer outside the power supply.

The CR-39 chips were cut from a Fukuvi Chemical sheet purchased from Landauer Inc. (6). One of the well known properties of CR-39 material is its ability to record nuclear projectiles, such as protons or alpha particles (7). Tracks of such particles become microscopically visible after etching. Sizes of observed tracks increase with the duration
of etching and the temperature of the etching solution. A cluster consisting of over 100 tracks is shown in Figure 4. That figure is a microphotograph of a small area of CR-39 that was removed from the electrolytic cell after five days of electrolysis and etched for six hours. Round pits are tracks of particles that were intercepted at small angles of incidence; elliptical and conical pits are tracks of particles intercepted at larger angles. After twelve hours of etching nearly all tracks become round, as illustrated in Figure 5. Nuclear activity after electrolysis was studied by placing CR-39 chips on the o-rings removed from the cell, as illustrated in Figure 3B.

Figure 7. Cluster of tracks produced during five hours of electrolysis. The area of 1000 by 1300 microns was photographed under a magnification of X40, after six hours of etching. The mean track density, over the area of 1 mm², is about 11,000 tracks per cm². This is three orders of magnitude higher than in the areas outside the four clusters, on the same CR-39 chip. A section of this photo, under a higher magnification, is shown in Figure 6.

All CR-39 detectors were etched for six hours in a small beaker. The average etching solution temperature was close to 72°C. But local temperatures near individual detectors were probably not identical, because the solution was not stirred. The sizes of tracks are known to depend on the product of the etching time and temperature. It is reasonable to assume that the observed differences in the size and shapes of the tracks in different clusters were due to differences in local temperatures. The effect of etching time on the tracks appearance can be seen by comparing Figure 4 and Figure 5.
Control experiments with CR-39 chips in air showed that background track densities, after five days of exposure, fluctuated widely. The mean density was 15.5 tracks per square centimeter; the standard deviation was 9.7 tr/cm$^2$. Similar densities were found on CR-39 chips exposed to the electrolyte, and to other unused components of the cell (glass, o-rings, platinum and nickel). Note that even 25 tr/cm$^2$ density translates into about one track per three fields photographed under my low magnification. In other words, fluctuations of background densities are inconsequential; local densities within clusters are usually much higher than in the background.
3) Experimental results

Six experiments were performed to observe Oriani’s electrolysis effect. But only two of them were successful in terms of finding clusters of tracks. Two pictures of one post-electrolysis cluster are shown in Figures 4 and 5. Mean track densities, in the observed clusters, are described in Table 1.

One cluster from Experiment III, shown in Figure 7, was peculiar in its size and shape. Similar patterns of nearby tracks, named rosettes, were reported during Oriani’s experiments. He considers them to be part of background rather than clusters due to electrolysis. It is reasonable to assume that tracks in very small clusters are due to alpha particles emitted from a tiny grain of radioactive contamination, such as radium or uranium. This supposition is based on the fact that distances between radially oriented tracks are smaller than ranges of alpha particles in CR-39, and in the electrolyte (typically less than 50 microns). Peripheral tracks in Figure 4, on the other hand, are often separated by distances much larger than tracks of alpha particles. The significance of this observation will be discussed in the next section. It is remarkable that not a single cluster was found on more than twenty chips from control experiments. This is a strong but not irrefutable indication that larger clusters are not due to background activity.
### Table 1. List of Experiments

<table>
<thead>
<tr>
<th>Experiments to study nuclear particles emitted during electrolysis:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolysis in Experiment I lasted 5 days, producing four clusters. The o-rings used in that experiment were removed from Oriani’s successful cell. Numbers of tracks in these clusters were: 109, 75, 30, and 29. The corresponding mean track densities were: 11,000, 5000, 3000, and 4800, respectively, per square centimeter.</td>
</tr>
<tr>
<td>Electrolysis in Experiment II lasted 21 days, using the same o-rings as in Experiment I. The experiment started shortly after the end of Experiment I. Zero clusters were produced in experiment II.</td>
</tr>
<tr>
<td>Electrolysis in Experiment III lasted 5 days, using the same o-rings as in Experiment II. The experiment started shortly after the end of Experiment II. Three clusters were produced. Numbers of tracks in these clusters were: 85, 35, and 9. The corresponding mean track densities were 11,000, 4400, and 900, respectively, per square centimeter.</td>
</tr>
<tr>
<td>Electrolysis in Experiment IV lasted 5 days, using another set of o-rings from Oriani. The experiment started shortly after that o-ring was received. Zero clusters were produced.</td>
</tr>
<tr>
<td>Electrolysis in Experiment V lasted 5 days, using the same o-rings as in Experiment IV. The experiment started shortly after Experiment IV. Zero clusters were produced.</td>
</tr>
<tr>
<td>Electrolysis in Experiment VI lasted 5 days, using the same o-ring as in Experiment V. The experiment started shortly after the end of Experiment V. Zero clusters were produced.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiments to study nuclear particles emitted after electrolysis:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment VII was conducted outside the electrolytic cell. Several small CR-39 chips were exposed to the o-ring used in Experiment III. The exposure time was two days; zero clusters were produced.</td>
</tr>
<tr>
<td>Experiment VIII was also conducted outside the electrolytic cell. Two large CR-39 chips were applied to another o-ring sent to me by Oriani. Three clusters were produced during two days of exposure. Numbers of tracks in these clusters were: 110, 60 and 13 The corresponding mean track densities were 360, 300, and 2600, respectively, per square centimeter.</td>
</tr>
<tr>
<td>Experiment IX was similar to Experiment VIII, except that it started at the end of Experiment VIII. Zero clusters were produced during two days of exposure.</td>
</tr>
<tr>
<td>Experiment X was similar to Experiment IX, except that it started at the end of Experiment IX. Zero clusters were produced during two days of exposure.</td>
</tr>
</tbody>
</table>

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159
4) Discussion

It is clear that random fluctuations could not be responsible for zero clusters in Experiment II (electrolysis lasting 21 days) and for four clusters in Experiment I (electrolysis lasting five days). The same is true for clusters recorded after electrolysis. In both situations formation of clusters seems to be due to some uncontrollable factors. That is why further investigations are needed. In this section I hope to show that neither contamination nor cosmic rays can be responsible for clusters shown in Figures 1 and 4.

The main argument is trivial – ten clusters were produced on experimental chips and zero clusters were produced on all control chips. Another argument against contamination is based on the orientations of noncircular tracks. Orientations of these tracks, separated from each other by distances larger than ranges of alpha particles (in CR-39 and in water), would be random if clusters were due, for example, to large uranium particles. But orientations are certainly not random. Tracks near the centers of clusters are frequently round, while tracks near peripheries are mostly elliptical or conical. In fact, the average ellipticity seems to increase with the distance from the central region.

It is tempting to speculate that observed tracks result from collisions between protons in CR-39 ($C_{12}H_{18}O_7$) and some kind of neutral particles. Neutral particles do not ionize matter directly; that is why they can travel long distances before colliding with protons. I am not going to elaborate on this because my goal, at this stage, is to convince myself (and others) that Oriani-type clusters are due to electrolysis. In that context it is important to mention that clusters were also reported by John Fisher (9) and by Marissa Little (10).
The protocols used by these researchers were essentially the same as that used by Oriani. Clusters produced during electrolysis were also observed in SPAWAR experiments with sequential etching (11). Sequential etching was probably used to etch away myriads of chemically caused pits known to be present on the surface. Clusters with tracks deep inside the CR-39 material, if confirmed, would be highly significant. Note that SPAWAR experiments (5) were totally independent of Oriani’s experiments, and of his protocol. Also note that in all cases local track densities, within clusters, were much higher than in the background.

Is it possible that observed clusters are due to cosmic rays? Collisions in which relativistic heavy ions disintegrate, producing showers of nucleons, have been studied using high energy accelerators, for example, at Brookhaven National Laboratory. Suppose that most of the tracks in Figure 4 are due to nucleons resulting from disintegration of a single ultra-relativistic ion, somewhere near the detector. What is the probability that such an ion can be found at sea level? According to (12), the theoretically calculated flux, for ions with Z=25, at sea level, is $10^{-34}$ particles per square meter per second. This amounts to about $3 \times 10^{-21}$ particles per square kilometer per year. For particles with much higher Z the expected flux is many orders of magnitude smaller.

The second cosmic ray phenomenon to consider is showers. Primary cosmic ray charged particles, mostly protons, interact with the atmosphere by producing showers of pions and muons. Can a cluster seen in Figure 4 be due to such particles? The answer is a definite no. The ionization density of pions and muons is too low to produce tracks in CR-39 detectors. In one study (13), CR-39 chips were coated with fissionable material and exposed to beams of pions with several energies between 500 MeV and 2300 MeV. The purpose was to measure cross sections of fission induced by pions. This was done by counting tracks due to fission fragments. The reported cross sections indicate that billions of pions traverse CR-39 chips for each set of fission fragments. Observation of fission-fragment tracks would not be possible if individual pions could form tracks in CR-39 detectors.

On that basis I am inclined to conclude that the clusters observed in my experiments were not due to cosmic rays, or to alpha-radioactive substances. Something interesting is going on, and research in this controversial area should continue. The goal should be to identify hidden factors responsible for irreproducibility of experimental results. Unfortunately, present investigations of clusters belong to protoscience, as defined in Figure 1. Protoscience should not be confused with pseudoscience, such as astrology. Methods of validation in protoscience are not different from methods used in science.

**Appendix (November 2007)**

Two important objections were made to my tentative conclusion that clusters could not be attributed to contamination with alpha-radioactive substances. The first objection was
made by Lipson and Rousetski, during a recent conference in Italy (14). Discussing my presentation, they invented the following scenario. A gas bubble sits on top of CR-39. A grain of alpha-radioactive material sits on top of the bubble. Ranges of alpha particles in the gas bubble are much larger than in the electrolyte. That is why a cluster can be much larger than ranges of alpha particles in the electrolyte. Furthermore, according to this assumption, most tracks would be circular near the central region and noncircular along cluster's peripheries. Tracks along peripheries would be radially-oriented, more or less, as in our experimentally-observed clusters.

Commenting on the above, S. Little wrote (15) “. . . The electrolyte does not wet the CR-39. Grains of radioactive material could easily be trapped between the Mylar film and the CR-39. . .” In other words, not only bubbles can produce clusters with radially oriented tracks. I agree with this speculation.

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(14) The 8th International Workshop on Anomalies in Hydrogen- and Deuterium-Loaded Metals in Catania, Italy (October 2007).
(15) Scott Little, Earthtech International, Inc. (in a message posted on the private Internet list for CMNS researchers, 11/8/07).
Analysis of #2 Winthrop Williams’ CR-39 detector after SPAWAR/Galileo type electrolysis experiment

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1. Introduction

The experimental goal of this work was to search for reality of nuclear tracks in SPAWAR/Galileo type experiment described by W. Williams in his APS March 2007 Meeting presentation. [1]

The experimental conditions of SPAWAR experiments are as follows. Electrolysis was carried out in solution 0.03 M PdCl₂ + 0.3 M LiCl in D₂O. The anode was a platinum wire (0.25 mm in diameter); the cathode was a palladium wire (0.25 mm in diameter). A CR-39 detector (Landauer 1 × 2 cm²) was attached to the cathode wire during electrolysis. Then it was etched in 6.5 NaOH for 3 h at 68°C.

2. Calibrations

From April to May 2007 we performed a manual analysis of Williams’ #2 CR-39 detector which had been subjected to a Galileo/SPAWAR type of electrolysis experiment at the University of California at Berkeley (UCB). The detector was attached to the wire cathode (without using a Mylar filter) during the Pd deposition experiment in deuterium electrolyte. After electrolysis, Williams etched the detector in NaOH solution. In order to estimate the etching conditions in UCB we have been supplied by Williams’ calibration detector irradiated with an Am-241 alpha source (Eα = 5.45 MeV) and etched in the same condition as the #2 detector.

In our first step we determined the track diameter of Williams’ calibration detector and found that it is underetched compared with our standard conditions of minimal required etch (6 N NaOH at T = 70°C, t = 7 hr) which is a starting point for our calibration curves. To achieve this goal we performed an additional etch in our standard conditions for 1 hr 45 min and then compared the obtained track diameters with our calibrations (Fig. 1).
It was found that under Williams’ etching conditions the mean track diameter for 5.45 alphas is 6.7 µm. In order to move to our standard condition (see Figure 2) we carried out an additional etch of this detector for 1 hr 45 min. After this additional etch the track diameter for Am-242 alphas was increased to 8.9 µm, which is within the measurement error, and is in satisfactorily agreement with our calibration data (at \( E_\alpha = 5.45 \text{ MeV} \) it should be \( \sim 8.7 \text{ µm} \)). Taking into account this result, the Williams’ Foreground detector #2 was additionally etched in 6 N NaOH at 70°C for 1.5 hr.

In the first approximation, the track diameters obtained after Williams’ etching plus our additional etching for 1 hr 45 min are quite similar to track diameters from our 7 hr etching conditions. To check the validity of this we preformed an etch of Williams’ alpha-detector for additional 7, 14 and 21 hr and compared the results with our Landauer calibration curves for alpha particles with energies of 5.15 and 6.0 MeV. The result is shown below and gives perfect agreement with our alpha curves (Fig. 2).
Alpha calibration curves within 7-28 hr etch time

\[ y = 1.1252x^{1.0393} \quad R^2 = 0.9971 \]
\[ y = 1.1945x^{0.105} \quad R^2 = 0.995 \]
\[ y = 1.2385x^{0.9734} \quad R^2 = 0.9984 \]

**Figure 2.** Comparison of Williams’ alpha track (5.46 MeV) distribution vs. etch time (D(t)) with our 5.15 and 6.0 MeV D(t) curves. As seen all curves are well fitted by power functions: the 5.46 MeV (Williams’) curve is located between 5.15 and 6.0 D(t) curves. This figure confirms that the additional etch during 1.5 hr in 6 N NaOH at T = 70°C provide the right conditions for further etch, enabling us to compare tracks/pits at Williams’ #2 detector with our calibration D(t) curves.

Thus, for Williams’ #2 detector analysis (starting at his 3 hr + our 1.5 hr etch) we will use our calibration curves.

Because the main goal of this analysis was to establish whether or not the pits at the surface of the #2 detector could be ascribed to nuclear tracks, we carried out a comparison of the Williams’ pit images and D(t) functions with our calibrations for alphas and protons. Figures 3a and 3b show the calibration curves of track diameters D vs. alpha and proton energies for etch time within 7-28 hr in 6 N NaOH at T = 70°C (bulk etch rate \( v_b = 1.32 \mu m/hr \)) for alphas in the range of 2-12.8 MeV and protons of 0.5-3.0 MeV.
Figure 3a, b Alpha (a) and proton (b) calibration curves (D vs. E) for etch time 7-28 hr.
This is how real nuclear tracks look. Tracks from 11.0 MeV α-beam at normal incidence with respect to CR-39 (Landauer) target: image area $S = 0.12 \times 0.09 \text{ mm}^2$, (× 600). The track density is about $10^6$ track/cm$^2$. The conic shape of alpha tracks is clearly visible as a small dark hole in the center of the pit.

Figure 4b. Proton tracks. Tracks from 2.5 MeV p-beam at normal incidence with respect to the CR-39 (Landauer) target: image area $S = 0.12 \times 0.09 \text{ mm}$, (× 600). The conic shape of proton tracks is also clearly seen as a small dark hole in the center of the pit (caviar effect).

3. #2 Detector Pit Analysis

The pit density at the etched scratch area produced by the contact of the cathode wire with the surface of CR-39 detector is very large ($N > 10^8$ pit/cm$^2$). In contrast, the back side of the #2 detector contains almost no pits. Most of the pits on the front side (which is attached to the cathode wire) are overlapped and cannot be analyzed properly in terms of their shape and diameter range. In order to provide such an analysis we have chosen only individual pits (that were not overlapped) in the area surrounding the scratch (total area $S = 2.0 \text{ mm}^2$), and we carried out measurements of their diameters at etching time $t = 7, 14$ and 21 hr (Figs. 5-7).

The total CR-39 etching must be similar to our standard conditions (Figs. 2, 3): 6 N NaOH, $T = 70^\circ \text{C}$, for 7 hr. Notice that for correct determination of track diameter we cannot take overlapping pits. So, only individual pits were chosen. The pits are located in the wide range of the diameters within 1- 20 µm. All of them are placed mainly along the scratch that is visible at the surface of CR-39 as a trace of the attached electrode. No tracks were found at the back side (opposite to the surface where the electrode was attached) of this Foreground detector.
Figure 5. Individual track diameter distribution for Williams’ Foreground detector after additional 1.5 hr etching in 6N NaOH solution at $T=70^\circ$C (equivalent to our etch time $t = 7$ hr).

Note also that many pits (about a third) have a diameter $d < 3$ µm. In reality the peak at $d = 3$ µm in the graph corresponds to all pits with $d < 3$ µm. These pits cannot be ascribed to nuclear tracks because they would only be consistent with protons with $E_p > 30$ MeV with very low critical angle, suggesting negligibly small detection efficiency. The pits at $d > 12$ µm cannot be ascribed to alphas because the detected alphas have track diameter $d \leq 12$ µm (see Fig. 3 a). No elliptically shaped pits were found, suggesting absence of particles with oblique incidence. (Yet, if the wire is the source of the pits, it would have to produce many pits with oblique incidence.) Moreover, 30 MeV protons can pass through the 0.85 mm thick CR-39 detector, assuming appearance of pits at the back side of this CR-39. The absence of tracks at the back side of the CR-39 also gives us a clue that no measurable neutron flux was emitted during this electrolysis run.
Figure 6. Individual track diameter distribution for Williams’ Foreground detector #2 after additional 7 hr (4.5 hr + 7 hr → 14 hr) etch in 6 N NaOH solution at T = 70°C (equivalent to our etch time t = 14 hr). Notice a full disappearance of the small diameter pits with d < 6.0 µm. If pits with d < 3 µm were high energy proton tracks, their diameters would be almost unchanged (very small increase in d). The disappearance of small pits thus shows that they are small, shallow surface defects caused by mechanical stress at the CR-39 surface. These defects will overetch very quickly and their images lose contrast with etching in depth, and become invisible.

Figure 7. Individual track diameter distribution for Williams’ Foreground detector #2 after additional 14 hr (4.5 hr + 14 hr → 21 hr) etch in 6 N NaOH solution at T =70°C (equivalent to our etch time t = 21 hr).
Notice the complete absence of tracks with \( d < 10 \, \mu m \) and \( d > 30 \, \mu m \) showing an absence of possible protons with energy \( E > 1.5 \, MeV \) and alphas (\( E < 4 \, MeV \)), respectively. No significant shift of pit diameter maximums (which could be ascribed to the effect of stopping power of CR-39 material) is seen compared to the 14 hr etch. (Compare maximum between 16-18 \( \mu m \) track range in 14 hr etched detector with that between 15 and 20 \( \mu m \) tracks in the 21 hr etched detector.)

Thus the analysis of pit diameter distributions on etching in depth show that majority of the pits in \#2 CR-39 are surface defects and cannot be ascribed to nuclear tracks.

![Image](image_url)

**Figure 8.** (a) The image of the front side of the #2 detector with the fixed coordinates \([x, y] = [1028, 1075]\). Etch time is \( t = 7 \) hr. (b) The same area at a higher magnification (\( \times 3 \)). The individual selected pits 1-4 of the right shape (in terms of smoothness) with the size ranging from 5 to 12 \( \mu m \) are indicated.
4. Images of Williams’ #2 detector and pits simulation

Figure 8 shows examples of pit agglomerations obtained from Williams’ Foreground detector. (In CR-39 jargon we call such pit agglomerations “ground beef” and never take them into consideration.) All of these pits are located along the scratch produced by the wire electrode tightly attached to the front side of CR-39 detector chip. The conic shape of track required for nuclear track is not observed. Below the images of the front face of #2 detector containing also individual pits (separated by space one from another) are depicted. Our long experience shows that massive overlapped pits can be seen at the CR-39 surface after intensive mechanical deformation of the detector chip. We show these examples too in order to provide additional clues as to how at least some of the SPAWAR pits could have originated. In all cases presented (unless otherwise noted) the size of the image is equal to $280 \times 220 \mu m^2$. 
Figure 9 (a,b) – The same as in Fig. 8a image with the fixed coordinates[1028,1075] after total etch time during 14 hr (a) and 21 hr(b). Note to the deviation of the pit shape from the smoothness (circular or elliptic shape) with increase in etch time (the pits become of a sharp shape and partially loose a contrast). This is also indicates that these pits are not from nuclear particles because nuclear tracks are keeping their smooth shape.
**Fig. 10.** The image of the front side of the #2 detector with the fixed coordinates [1028, 1075]; etch time is \( t = 28 \) hr. The same individual pits 1-4 as indicated in Fig. 8 b are marked.

**Figure 11.** Another example of the #2 detector image containing a lot of small pits (\( d < 4 \) \( \mu \)m): the spot with the coordinates [663,435]. Etch time is equivalent to \( t = 7 \) hr.
Figure 12. Track simulation with mechanical stress. The 200 μm Pt wire is attached tightly to the surface of the Landauer CR-39 detector (scratch in the left corner of the image) for 2 days before etching. Etch time is t = 7.0 hr. Lots of pits, mainly of small diameter (d < 4 μm) are appeared. Compare the size of small pits with that seen in [663,435] image of Williams’ detector.

Figure 13. Another example of pits simulation by mechanical stress: the rough 50 micron thick Pd foil is pressed tightly to the surface of the Landauer CR-39 detector (no electrolysis) with a hard clamp for one week. Etch time t = 7 hr. The size of majority of pits is 3 – 10 μm. Dark pit in the center is a real alpha-particle track.
Figure 14. The image of the [663,435] spot. Etch time $t = 7$ hr. The same area as in Fig. 11 with the higher magnification (x3); the individual selected circular pits 1-5 of the right (in terms of smoothness) shape with the size ranging of 5-12 micron are indicated (b).

Figure 15 (a-c). The image of the [663,435] spot at etch time $t = 14$ hr (a), 21 hr (b) and 28 hr (c), respectively. With increase of removed depth, majority of pits lose contrast and become of the sharp angle (noncircular) shape.
5. Etch rate of individual selected pits: comparison with the alpha and proton track diameter growth rate

Below, we extract quantitative information on the origin of some pits selected in spots [1028, 1075] and [663,435]. We have to select pits of the right shape and size. The dynamics of etching, reflecting the track etch rate, allow us to unambiguously identify the type and energy of nuclear particles. To this aim, in the present report we can use the slope of the D(t) curve (where D is the track diameter, and t is the etch time), which effectively reflects the etch rate inside the track (v_t).

The etch rate in the track is determined by the function v_t = \partial L/\partial t (where L is the track length). Noting that L = D/2 tg \delta, where \delta = const (at v_t = const) is the local developing angle of the track we obtain that v_t = A (\partial D/\partial t), where A is a constant. Thus, the slope of track diameter function vs. etch time t would effectively reflect the etch rate of the pit. A similar procedure of track identification, involving the comparison of selected track dynamics with that of alphas and protons with appropriate track diameter, was already demonstrated in our previous work (see A.S. Roussetski et al., Proc. ICCF-12, Japan, 2005).

To begin this procedure we take selected track with the measured initial diameter D corresponding to minimal removed detector depth (in our case at t = 7 hr) and we
compare its diameter growth with etching in depth to that of a nuclear particle with exactly the same initial diameter D as the selected track.

The graphs of the etching dynamics for each selected pit 1-4 from the [1028,1075] spot and for appropriate nuclear particles (with the same initial diameter at t = 7 hr) are presented below in Fig. 17 (a-c).

The graphs of the etching dynamics for each selected pit 1-5 from the [663,435] spot and for appropriate nuclear particles (with the same initial diameter at t = 7 hr) are presented below in Fig. 18 (a-c).

Thus all of the analyzed pits from both spots show the slope of dD/dt function that is a factor 2-10 smaller than corresponding alpha/proton tracks with the same initial diameter as for the selected pits. Moreover, the dD/dt function of the pits cannot be satisfactorily fitted by a power function (in most cases R^2 < 0.98), that normally describes charged particle diameter growth during etching in-depth. These findings unambiguously suggest that those selected pits have a lower etch rate (inside the “track”) than the nuclear particles producing the tracks of the same initial diameter at t = 7 hr. Thus, these selected pits of the right shape and size consistent with the nuclear particle tracks cannot be ascribed to the tracks of nuclear particles.
Figure 17 (a-c) Etch dynamics for pits 1-4 from the spot [1028,1075] as well as for appropriate nuclear particles (p-proton, α – alpha) of the same initial diameter. As seen, the slope of the pits 1-4 is about factor of 2 - 6 less than that for appropriate nuclear particles.
(a) Track diameter vs. Etch time for proton etching at 1.5 MeV and 2.0 MeV.

(b) Track diameter vs. Etch time for alpha etching at 7.7 MeV and 5.15 MeV.
Figure 18. Etch dynamics for pits 1-5 from the spot [663,435] as well as for appropriate nuclear particles (p-protons, a – alphas) of the same initial diameter. As seen, the slope of the pits 1-5 is about factor of 2 - 10 smaller than that for appropriate nuclear particles.

6. Conclusions

The total dataset obtained during our analysis of the #2 Williams detector do not show any signature of real nuclear tracks. The main peculiarities of the observed pits force us to come to the following negative conclusions:

- High density overlapping pits near the scratch from the cathode wire. During the etching in depth these pits lose their smooth circular shape (which is a signature of nuclear particles), and they lose contrast. The last factor indicates that these pits are shallow.
- The individual analyzed pits show three groups of diameters: D < 5 μm, D > 12 μm and 5 μm < D < 12 μm at etch time equivalent to t = 7 hr. The first two groups, according to our calibrations, cannot be ascribed to proton and alpha particles. The group with D < 5 μm totally disappeared after 14 hr etching, indicating shallow surface defects. The group of pits with D > 12 μm also cannot be ascribed to heavy nuclear particles (Li$^6$ or heavier ions) because these pits demonstrate very slow dynamics of their diameter growths, which is contrary to what is expected for heavy ions.
- Almost no elliptically shaped pits were found among either the overlapping or individual tracks, suggesting the absence of the projectile particles with oblique incidence. This is not possible if the source of these particles is at the cathode.
wire attached to the CR-39 surface. A source at this location would have to produce pits with oblique incidence.
- The group of pits with appropriate minimal diameter (5 μm < D < 12 μm) consistent with protons and alpha tracks at etch time t = 7 hr do not demonstrate the track etch rate required for those nuclear particles. The etch rate for these pits is 2-10 times lower, indicating that radiation destruction of CR-39 material inside the pits is significantly less than that from the nuclear particles.
- The similar high density pits of low and medium diameter range can be successfully simulated by mechanical stress. This generates a massive number of defects at the surface of the CR-39 detector with the attached wire. The application of magnetic/electric field to the detector would only enhance the mobility of charged defects and thereby intensify pit formation.

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References

Analysis of the CR-39 detectors from SRI’s SPAWAR/Galileo type electrolysis experiments #7 and #5. Signature of possible neutron emission

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Abstract

We performed a detailed analysis of two Landauer CR-39 detectors exposed to the cathode wire during palladium deposition experiments at SRI. (Experiments #BE013-7, #7; and BE010-5, #5.) The entire data set obtained from the analysis of the #7 CR-39 detector, including 1) track reading within three removed depths (8.7, 18 and 27 μm), 2) comparison of foreground #7 track densities and distributions of their diameters with similar parameters of the background, 3) the neutron calibration, as well as 4) the CR-39 efficiency estimate with respect to Cf-252 neutrons, present preliminary evidence for fast neutron emission. The neutron energy is estimated to be in the range of E_n ~2.2 – 2.5 MeV with a rate of I_n ~1-3 n/s accounting for the 4π solid angle. The data obtained from the analysis of detector #5 allow us to conclude that a weak neutron emission from the cathode took place during electrolysis, in addition to some mechanical and electric discharge damage to the front face of the detector.

I. CR-39 Reading

From April to October 2007 we carried out a reading of the #7 and #5 Landauer CR-39 detectors exposed in SPWAR type Pd electrodeposition experiments at SRI. This was the version of the experiment without an external electromagnetic field. [1,2] We examined the samples at three different removed depths, with three etching times, roughly corresponding to 7, 14 and 21 hr etch in 6 M NaOH at 70°C at v_b ≈ 1.3 μm/hr, and we compared the results with that of blank CR-39. The reading was performed manually using the track reading facility “PAVICOM” in the Lebedev Physics Institute, Russian Academy of Sciences, Moscow, Russia. The #7 detector was initially covered with 6 μm Mylar filter, protecting the CR-39 surface from mechanical stress and electrostatic (spark discharge) effects induced by the cathode wire during electrolysis. We carried out the #7 detector reading (and the blank detector reading) from its both sides, including the front face (that was attached to the cathode) and opposite face (that was located from the side opposite to the front side). The reading area of the foreground #7 detector was S=1.0 cm² of each side. In case of the blank detector (background) we obtained only a small piece of
CR-39 with readable area of $S = 0.25 \text{ cm}^2$. It was found that track density of the blank detector in the track diameter range of interest ($4.0 < d < 8.0 \mu\text{m}$, $t = 7 \text{ hr etch}$) contain in total 3 track/$0.5 \text{ cm}^2$ (from both sides). This number is typical for the blank Landauer RadTrack detectors ($N = 6 \pm 4 \text{ track/cm}^2$ as a result of more than 100 of our measurements), which is why we concluded that the blank detector has not been irradiated by neutrons from an airport security facility or some other unaccounted-for source. This observation allowed us to use our background data obtained with Landauer detectors, in order to increase background statistics used for comparison of foreground #7 detector’s results with the blank data.

The summary result of the two blank detectors readings ($S = 2 \text{ cm}^2$ of each side) is presented in Fig. 1. The result of 7 hr etch shows track density $N = 6 \text{ cm}^{-2}$ in the track diameter range of interest, consistent with the proton recoil track diameters. The track density of 14 etch, which is within the $4.5 - 12 \mu\text{m}$ diameter range consistent with Cf-252 14 hr etch proton recoil, is higher ($N = 26 \text{ cm}^{-2}$). This inconsistency between 7 and 14 hr backgrounds is caused by two factors: First, the increase of CR-39 efficiency with respect to fast neutrons (cosmic background) with removed depth in the range down to 20 $\mu\text{m}$ from the surface. Second, the presence of other “old” tracks that were stored in the blank CR-39 since the time they were manufactured.

**Figure 1.** Typical background spectra of Landauer CR-39 detector (RadTrack) etched for 7 and 14 hr, respectively ($S = 2 \text{ cm}^2$). The number of proton-like tracks resulting in background neutron irradiation is much smaller than that for SRI’s #7 detector: At a 7 hr etch, the mean number of tracks within the range of $4.5 - 8.0 \mu\text{m}$ (consistent with Cf-252 proton recoil distribution) is only $<N> = 6 \text{ cm}^{-2}$. At a 14 hr etch the number of tracks within the $4.5 - 12 \mu\text{m}$ diameter range (consistent with Cf-252 14 hr etch proton recoil) is $<N> \sim 26 \text{ cm}^{-2}$. The tracks with diameter $d \geq 8.0 \mu\text{m}$ (7 hr etch) and $d > 11 \mu\text{m}$ (14 hr etch) represent a build...
up of stored background alpha activity (mainly radon and triton series). Notice that the background distributions do not contain noticeable increase at 5.2 and/or 6.0 µm track diameter.

In contrast to the background, the Landauer CR-39 spectra representing neutron calibration with a Cf-252 neutron source (Fig. 2) contain high track density at its both sides. It was found that the number of tracks at the front CR-39 detector side (the front with respect to the neutron source) is about 20-30 % higher than that at the opposite one at any etching time (7-21 hr).

![Figure 2](image.png)

**Figure 2.** Cf-252 recoil proton spectra (Cf-252 neutron source with intensity $I_n = (120\pm20)$ n/s in $4\pi$-solid angle. Total neutron fluence through the CR-39 chip is $F_n \approx 7 \times 10^8$ n/cm$^2$. The Landauer CR-39 chip with 200 µm PE radiator has been used. After 7 hr etch in 6 N NaOH at $T = 70^\circ$C, the proton recoil spectrum is located between 4.5 and 9.0 µm track diameter with maximum near 5.2 µm. This maximum is consistent with the mean recoil proton energy in the range of 2.2-2.5 MeV (see Landauer’s CR-39 proton calibration curve obtained with a Van de Graaf accelerator, Fig. 3a). The recoil spectrum of 14 hr etched CR-39 a is broader than that for 7 hr etch and is located within the proton recoil track diameters ranged between 5.0 and 12.0 µm with the maximum near 6.0 µm. The shift in track diameters from 5.2 to 6.0 µm, compared to 7 hr etch, is consistent with 2.2-2.5 MeV proton track diameter gain at 14 hr etching compared to 7 hr etch (Fig. 3b). Notice that for both etchings at $t = 7$ and 14 hr about 30 % of all tracks have oblique incidence. The neutron detection self-efficiency of CR-39 at $t = 14$ hr ($\varepsilon_n \sim 1.2 \times 10^{-4}$) is about a factor of 1.3 higher than that at $t = 7$ hr ($\varepsilon_n \sim 0.9 \times 10^{-4}$) due to increase in proton recoil critical angles with the removed CR-39 depth.

The calibration curve allowing an estimate of proton energy (including also recoil protons) based on track diameters at etch time $t = 7$ hr is depicted in Fig. 3a. The
dependences of track diameter versus etching time 7 - 28 hr of normal incidence protons in the energy range of 1.0 - 2.5 MeV are shown in Fig. 3b.

**Figure 3a.** Van de Graaf accelerator calibration curve for the 0.65-3.0 MeV proton beam of normal incidence with respect to the detector surface. The targets are Landauer RadTrack and another Fukuvi-type CR-39 detector. Etching conditions: 6 N NaOH, T = 70°C, t = 7 hr.
Figure 3 b. Track diameter vs. etching time (removed CR-39 depth \( h = 9.2 - 46 \, \mu m \)) for protons of normal incidence in the energy range of 1.0 - 2.5 MeV. Note a good linear dependence for Landauer RadTrack detectors. Etching conditions: 6 N NaOH at \( T = 70^\circ C \). The bulk etch rate \( v_b \) is derived from empirical equation: \( v_b = 1.275 \exp[0.828 \, C + 0.049 \, T - 0.002 \, C \, T - 17.624] \), where \( T \) and \( C \) are temperature (in K) and NaOH molarity (mol/l), respectively (D. Nikezic, K.N. Yu, Mat Sci. Eng., R46, 51 (2004)).

In Fig. 4 examples of proton recoil tracks obtained in CR-39 calibration are shown. The proton recoil tracks are represented by bright pits of 5-8 \( \mu m \) in diameter on dark background.

Figure 4. Examples of proton recoil tracks of 5-8 \( \mu m \) diameter (bright pits only - all others are surface defects!) for Cf-252 neutron source (7 hr etch, removed depth is \( h = 9.2 \, \mu m \)). Total neutron fluence is \( F_n = 7 \times 10^8 \, n/cm^2 \); the size of each image is \( S = 120 \times 90 \, \mu m^2 \).
The reading of both sides of #7 foreground detector (the front and the opposite one) showed that it contains real nuclear (proton recoil) tracks of both normal and oblique incidence similar to that obtained with the calibration CR-39 detector irradiated with the Cf-252 neutron source. Three examples of such tracks are presented in Figs. 5a and 5b.

![Figure 5. Examples of proton recoil tracks (compare with Cf-252 bright pits) of 5-7 µm diameter from CR-39 foreground detector #7 (removed depth is h ≃ 8.6 µm), images size is S = 120 x 90 µm²: (a) - two tracks of normal incidence (1,2); (b) – track of oblique incidence (1), track of normal incidence (2).](image)

The total track diameter distribution for the #7 foreground detector is shown in Fig. 6.
Figure 6. Track number distribution vs. track diameter for F. Tanzella’s (SRI) #7 CR-39 detector from both front and back sides. Etching time is 7 hr. The spectra contain real nuclear tracks. From the front side: the total number of circular and elliptic tracks (normal and oblique incidence) is $N = 77 \text{ cm}^2$. About 30% of all tracks have elliptic shape. Similarly, from the back side: $N = 40 \text{ cm}^2$. Notice that the number of proton recoil tracks at the front CR-39 detector side is higher than the back side.

Figure 7. Comparison of CR-39 Cf-252 proton recoil spectrum corresponding to 7 hr etching with the sum of spectra obtained from both sides of #7 CR-39. In the track diameter range of 4.5-8.0 $\mu$m the #7 spectrum look similarly to Cf-252 recoil. Note, that the maximum of track diameter distribution for the #7 detector is localized near the 5.2 $\mu$m value.
In order to confirm our finding concerning the observation of proton-recoil tracks at the 7 hr etched CR-39 we continued in-depth etching adding 7 more hr in the same conditions. The track diameter distributions are shown in Figs 8 and 9.

Figure 8. Track number distribution vs. track diameter for Tanzella’s #7 CR-39 detector from both front and back sides. Etching time is 14 hr. The spectra contain real nuclear tracks. From the front side: the total number of circular and elliptic tracks (the normal and the oblique incidence) in the range of 4.5 - 11.0 µm is \( N = 101 \text{ cm}^{-2} \). About 20% of all tracks have elliptic shape. Similarly, at the back side: \( N = 65 \text{ cm}^{-2} \). Notice again that the number of proton recoil tracks at the front CR-39 detector side is higher than the back side.
Figure 9. Comparison of CR-39 Cf-252 proton recoil spectrum corresponding to 14 hr etching time with the sum of spectra obtained from both the front and back sides of #7 CR-39. In the track diameter range of 4.5-11.0 µm the #7 spectrum looks almost identical to the Cf-252 recoil. Note that the maximum in the #7 detector is localized near 6.0 µm track diameter, as it is for the Cf-252 recoil spectrum. The total number of proton-like tracks at 14 hr etch is about a factor of 1.4 higher than that for 7 hr etch.
To further confirm the neutron emission effect, we carried out one more etching of #7 detector (total etch time $t_{\text{etch}} = 21$ hr, corresponding to total removed depth $h = 27.2 \, \mu m$). The result of track diameter distribution for both the front and back sides of the #7 detector at $t_{\text{etch}} = 21$ hr is shown in Fig. 8.

**Figure 10.** Normal incidence track distribution vs. their diameter for Tanzella’s #7 CR-39 detector from both front and back sides. Etching time is 21 hr. The spectra contain real nuclear tracks. From the front side: the total track number (both normal and oblique incidence) in the range of 5-14.0 μm (the diameters consistent with Cf-252 spectrum at $t_{\text{etch}} = 21$ hr) is $N=91$ cm$^{-2}$, about 30% of all tracks have elliptic shape. At the back side: $N=67$ cm$^{-2}$. Notice again that the number of proton recoil tracks at the front CR-39 detector side is higher than the back side.
Figure 11. Comparison of CR-39 Cf-252 proton recoil spectrum corresponding to 21 hr etch time with the sum of spectra obtained from the both sides (front and back) of #7 CR-39. In the track diameter range of 5 - 14.0 µm the #7 spectrum looks similar to the Cf-252 recoil. Note that the maximum in the #7 detector is localized near 7.0 µm track diameter, as it is for Cf-252 recoil spectrum. This position is consistent with the track diameter for 2.5 MeV proton etched during $t_{et} = 21$ hr (Fig. 3b).

Thus, all three etchings of #7 detector at $t = 7, 14$ and $21$ hr show track distributions similar to that obtained by exposure of the calibration detector to a Cf-252 fast neutron source. The position of maximum for track diameter distribution follows to that of Cf-252 source and is consistent with the 2.2-2.5 MeV proton track diameter vs. etching time (Figs. 12a, b). In summary, presented experimental evidence can be considered as strong, unambiguous proof that the #7 detector was exposed to fast neutrons (2.5 MeV).
Figure 12a. Rough reconstruction of the protons recoil spectra for CR-39 Landauer detectors obtained during electrolysis run (detector #7) and during exposure with Cf-252 neutron source. Etch time is t = 14 hr. The reconstruction of the spectra was deduced from the track density vs. track diameter histograms, taking into account two functions: (a) track diameter vs. proton energies at t = 14 hr, and (b) the critical angle $\theta_c$ vs. proton energy.

Figure 12b. Same as Figure a, but at etch time t = 21 hr.
As seen in Fig. 12, the proton recoil spectra of #7 detector are narrower than that of Cf-252 at 14 and 21 hr etch. They contain almost no counts above 3.0 MeV and the peak near 2.5 MeV. In contrast, the Cf-252 spectra look broader due to the presence of high energy neutron/recoil component (up to 12 MeV) and also demonstrate a peak near 2.5 MeV.

These comparative results allow us to conclude that fast monoenergetic neutrons with energy close to $E = 2.5$ MeV were emitted during the electrolysis runs. For a more accurate numerical estimate of the recoil spectra, a Monte-Carlo calculation must be performed.

II. Calculation of the neutron emission rate

1. For etch time $t_{et} = 7$ hr (removed depth is the $h = 8.7 \mu$m)

   The total (normal and oblique incidence) foreground track density in the range of proton recoil diameters ($4.5 < d < 7.8 \mu$m) is: $N(fg)_1 = 77$ cm$^{-2}$ on the front side; and $N(fg)_2 = 40$ cm$^{-2}$ on the back side. Average track density is $<N(fg)> = 58.5$ cm$^{-2}$.

   The total background track density on both sides of blank detector ($S = 0.25$ cm$^2$ each) is the $<N(bg)> = 6.0$ cm$^{-2}$. This is consistent with the background usually observed in fresh Landauer chips. This consistency allowed us to use our background data (Fig. 1) representing the result of large area (S=2.0 cm$^2$) reading of two Landauer background detectors.

   Thus, the “effect” with the background subtracted is $<\Delta N> = <N(fg)> - <N(bg)> = 52.5 \pm 8.0$ track/cm$^2$.

   According to calibration measurements, the CR-39 self-efficiency ($t_{et} = 7$ hr) with regard to Cf-252 neutrons was found to be $\varepsilon_s = 9.0 \times 10^{-5}$. Assuming a “neutron source” was a cathode wire in a $2\pi$-geometry with respect to the CR-39 surface, the neutron count rate/intensity ($I_n$) would be derived as:

\[
I_n = 2 <\Delta N> / (t \times \varepsilon_s),
\]

where $t$ is the electrolysis (foreground) duration.

Assuming that the neutron emission effect occurred during the time when electrolysis current ($j > 0.5$ mA) was turned on ($t = 15$ days), the $I_n = 0.90 \pm 0.14$ n/s in $2\pi$ solid angle. This is the lowest rate estimate. If we assume that the neutron emission was observed only during the time interval $\Delta t = 4$ days when neutron dosimeter showed a count rate above the background, the $I_n = 3.38 \pm 0.53$ n/s in $2\pi$ solid angle — the highest rate estimate. So, the neutron emission rate in run #7 can be estimated in the range of 1.0 - 3.0 n/s.
2. For etch time \( t_{et} = 14 \) hr (removed depth is the \( h = 18 \) \( \mu \)m)

Similarly to (1), the total (normal and oblique incidence) foreground track density in the range of proton recoil diameters for 14 hr etch (4.5 \( < d < 11.0 \) \( \mu \)m) is: \( N(fg)_1 = 110 \) cm\(^{-2}\) on the front side; and \( N(fg)_2 = 66 \) cm\(^{-2}\) on the back side. Average track density is \( <N(fg)> = 88 \) cm\(^{-2}\).

The background track density on both sides of blank detector (S = 0.25 cm\(^2\) each) is the \( <N(bg)> = 26 \) cm\(^{-2}\) (data from Fig. 1)

The “effect” with the background subtracted is \( <\Delta N> = <N(fg)> - <N(bg)> = 62.0 \pm 10.7 \) track/cm\(^2\).

Accordingly to calibration measurements CR-39 at etch time \( t_{et} = 14 \) hr the self-efficiency was found to be \( \varepsilon_s = 1.17 \times 10^{-4} \).

For \( t = 15 \) days: \( I_n = 2<\Delta N>/\left(t \times \varepsilon_s\right) = 0.82 \pm 0.14 \) n/s in 2\( \pi \) solid angle and for \( \Delta t = 4 \) days \( I_n = 3.08 \pm 0.53 \) n/s. Thus, the result for the 14 hr etch gives approximately the same neutron emission intensity range, within a standard deviation, as that for a 7 hr.

The entire dataset for the #7 CR-39 detector — including track readings with three removed depths (8.7, 18 and 27 \( \mu \)m); the comparison of foreground #7 track densities and distributions of their diameters with similar parameters of background and neutron calibration detectors; as well as CR-39 efficiency estimate with respect to Cf-252 neutrons — presents strong, unambiguous evidence for fast neutron emission, with neutron energy in the range of \( E_n \sim 2.2 - 2.5 \) MeV, at the rate \( I_n \) of \( \sim 1 - 3 \) n/s during electrolysis run #7 performed at SRI.

III. Summary of the #5 detector results (SRI run #BE010-5)

- The #5 CR-39 detector used in SRI #BE010-5 PdDx deposition electrolysis experiment had a 60 \( \mu \)m polyethylene film adhered to both faces while immersed in the electrolyte and in contact with the cathode.
- This detector showed confusing results. The front face was found to be covered with high density pits (defects) making it almost impossible to distinguish real nuclear tracks from defects.
- The rear face of the #5 detector shows proton recoil tracks similar to those found on both faces of the #7 CR-39 (with a track density 50 - 70% of that of #7).
The pit density distributions versus pit diameters at the front side of the #5 detector at 7 and 14 hr etch are very similar to that of a defective CR-39 surface observed during the analysis of another CR-39 sample: the #2 detector from W. Williams. See our paper in these Proceedings. [4]

With etching in depth during an extra 7 hr, the real tracks, in particular tracks from the proton recoil caused by fast neutrons, started to appear on the front side of #5 detector, against the defect background (Fig. 15).
Figure 15. Proton recoil tracks at the front side of #5 detector well distinguished among the defects (so-called “ground beef”) background at t = 14 hr etch. After total etching of t = 21 hr, the defects at the front surface of #5 detector lose contrast and assume a non-circular shape, while nuclear tracks (alphas and protons) become sharply distinguished compared to this low contrast background.

Figure 16. Typical image of the front side of #5 detector after total 21 hr etch (real nuclear tracks in the background of the “ground beef”). The bright oval track at lower part of the figure was made by a proton with oblique incidence. The dark circle at the upper part of the figure was made by an α-particle.
The back side of the #5 detector does not contain defect areas (which are called “ground beef” in CR-39 jargon). The side shows proton recoil tracks similar to those found at the both faces of the #7 CR-39 detector analyzed above. The proton recoil distribution on the back side of #5 detector are presented in Figs. 17a, b and c.

![Proton recoil tracks](image)

Figure 17(a-c). Proton recoil tracks from the “clean” back side of #5 detector: (a) 7 hr etch; (b) 14 hr etch; (c) 21 hr etch.

A comparison of the nuclear tracks obtained both at the front and at the back side of the #5 detector (at t = 14 hr etch) show the remarkable similarity of their distributions versus
track diameter (Fig. 18). This suggests that the #5 detector has actually been exposed to a low intensity fast neutron flux.

![Figure 18](image.png)

**Figure 18.** Comparison of the front and the back sides of the proton recoil spectra of the #5 detector at $t = 14$ hr etch.

During in-depth etching at $t = 21$ hr (when most of defect pits already lose their contrast) it was found that the number of nuclear tracks at the front side of #5 detector far exceeded the number of proton recoil tracks on the clean back side of the detector. To obtain a clue about the nature of those excess tracks (besides proton recoil), we have subtracted the back side track distribution vs. their diameters from that of the front side of the same detector (Fig. 19).
As seen from Fig. 19, after subtracting the neutron proton recoil, the front side nuclear track spectrum still shows a two-band structure consisting of the 3 MeV DD-protons and high energy alphas [3]. One possible way these nuclear signatures may have originated could be the charged particle emissions from PdDx powder deposited on the PE protective sheet of the CR-39 in the area where cathode is in contact with the cathode. Indeed, a metallic coating on top of PE film covering the front side of the #5 detector has been found.

The rate of possible neutron emission that was detected by #5 CR-39 (after 7 and 14 hr etch) in electrolysis run # BE010-5 (for t =20 days) is presented below (εs – is the self-efficiency of the CR-39 with regards to Cf-252 neutrons):

**t ~ 7 hr etch**
- only on back side: \( N(fg) = 30.0 \pm 5.48 \text{ recoil protons/cm}^2 \)
- \( N(Bg) = 6 \pm 4 \text{ cm}^2 \)
- \( \Delta N = 24.0 \pm 6.8 \text{ p/cm}^2 \)
- \( <I_n> = 2<\Delta N>/t(\varepsilon_s) = 48/(1.73 \times 10^6 \times 9.2 \times 10^{-5}) = 0.30 \pm 0.08 \text{ n/s in } 2\pi \text{ solid angle} \)

**t = 14 hr etch**
- back: \( N(Fg) = 45 \text{ cm}^2 \), front \( N(Fg) = 63 \text{ cm}^2 \) \( <N(fg)> = 54.0 \pm 7.3 \text{ cm}^2 \)
- Background \( <N(bg)> = 26 \pm 5.1 \text{ cm}^2 \)
- \( \Delta N = 28.0 \pm 8.9 \text{ cm}^2 \)
- \( <I_n> = 2<\Delta N>/t(\varepsilon_s) = 56/(1.73 \times 10^6 \times 1.2 \times 10^{-4}) = 0.29 \pm 0.09 \text{ n/s in } 2\pi \text{ solid angle} \)
- If \( t = 1 \text{ day} \) \( I_n = 6.0 \pm 1.6 \text{ n/s in } 2\pi \text{ solid angle} \).
In Fig. 20 the results of neutron measurements carried out in SRI with the BF$_3$ sphere (a simple neutron dosimeter) during run #BE010-5 are presented.

Figure 20. Neutron protocols of the run #5 obtained in SRI with the BF$_3$ detector.

As seen in Fig. 20, the neutron count rate in this run according to the BF$_3$ measurements was above background for 20 days, and showed a maximum in the first day of electrolysis. The neutron count rate in the run #BE-013-7, when the CR-39 detector #7 was exposed, showed similar characteristics. The analysis of the SRI data and their comparison with the CR-39 results is below.

**Sensitivity to neutrons of SRI’s BF$_3$ sphere and the CR-39 neutron results**

- At self-efficiency to fast neutrons $\varepsilon_s = 7.6 \times 10^{-3}$ (R ~0 cm) and distance between the detector and the hypothetical neutron source (the cathode wire) R = 10 cm, the total efficiency of the BF$_3$ sphere with respect to fast neutrons would be $\varepsilon_t = 7.6 \times 10^{-5}$.
- The sensitivity of the detector to fast neutrons — reflecting the minimal neutron emission rate that can be distinguished from the background and equal to, at least, 3 standard deviations of the background count rate — can be expressed as: $S =$
3[<N_b>/(e_τ^2)]^{1/2}, where <N_b> is the averaged count rate in the background measurement and τ is the duration of neutron detection.

- In the case of experiment #7: <N_b> ≈ 6.0 cps, t = 15 days, resulting in S ≈ 150 n/s, (300 n/s, assuming neutron emission continued for 4 days) showing the figure that is a factor 100 higher than the fast neutron emission rate resulting in recoil protons detected by CR-39 detector during the #7 run.

- In the case of experiment #5: for 20 days of exposure, S ≈ 130 n/s (a factor of 400 higher than CR-39 showed). If we assume that neutrons were emitted only in the one day (according to n-count peak), then the sensitivity would be S ~600 n/s, which is also ~100 times higher then #5 CR-39 shows.

IV Conclusions

- The entire set of results from the analysis of two CR-39 detectors show that a weak but statistically significant emission of fast neutrons has been observed in SRI’s #7 and #5 runs replicating SPWAR Pd-deposition experiment.

- The #7 detector, which was protected by 6 μm Mylar film, shows “clean” front and back faces, containing only nuclear tracks (proton recoil + background radionuclides).

- The #5 detector, which was protected by 60 μm PE film, shows mixed zones of defects (“ground beef”) and nuclear tracks at its front side, and proton recoil density lower than #7 on the back side. The small diameter defect pits can be eliminated by in-depth etching (removed depth h > 18 μm) allowing us to distinguish real nuclear tracks of proton recoil, caused by neutrons as well as by energetic charged particles (protons and alphas) emitted from the PdDx powder being deposited on top of the detector during electrolysis.

- A comparison of proton recoil spectra (track number versus their diameter) of the analyzed detectors with that of the background runs and tracks of Cf-252 calibration gives preliminary evidence for fast neutron emission in the runs #7 and #5.

- A comparison of the neutron emission rates obtained from CR-39 analysis with that deduced from SRI’s proportional BF3 detector shows a huge discrepancy of results, suggesting orders of magnitude higher neutron emission was recorded by the SRI detector than we calculated from the noiseless CR-39 measurement data.

- Due to the low sensitivity to neutrons of the SRI detector, and the absence of pulse-height/pulse shape analysis, we assume that the signal of the BF3 sphere contains a significant electromagnetic noise fraction, induced by the electrolysis power supply.

- In order to provide confirmation of our CR-39 results on neutron emission in SRI experiments, additional high efficiency measurements with a more sophisticated type of neutron detector would be desirable.
Acknowledgements

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“Excess heat” in a Gas-Loading D/Pd System with Pumping inside palladium Tube

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ABSTRACT

New equipment was set up to confirm the “excess heat” correlated with the deuterium flux permeating the thin wall of the palladium tubes. The experiment was designed to increase the excess heat and avoid any confusion caused by the reduction of the thermal conductivity of deuterium gas. This set of experiments has been consistent with the selective resonant tunneling theory.

1. Introduction

Gas-loading experiments at Tsinghua University have been conducted since 1989[1-4], because we believed that only the charged particles were the necessary products of any nuclear reaction. Hence, we did not try to replicate the prevailing electrolysis experiments, and did not attempt to detect neutrons. Instead we detected charged particles. In order to detect charged particles, we had to avoid using electrolyte which might stop the charged particles before they were detected. Hence the gas-loading system was used instead of electrolysis. However, high pressure and low temperature were applied at that time because we believed that the high loading ratio was the necessary condition, and that high pressure and low temperature was favorable to an exothermic loading process. In 1993, a description of the “heat after death” phenomenon was published and it encouraged our gas-loading approach[5]. Moreover, Flanagan and Oates’ gas-loading paper[6] showed that gas-loading at low pressure and high temperature would have better reproducibility. In 1995 a gas-loading system at low pressure and high temperature was set up at Tsinghua University[7], which led to the discovery of the “pumping effect.” “Pumping effect” means that when we start to pump out the deuterium:

(1) The temperature of a deuterium-loaded long, thin palladium wire increased.

(2) The electrical resistance of the palladium also increased.[8]

This was unexpected, because we thought that de-gassing was an endothermic process, and the resistance of palladium wire was supposed to decrease with de-gassing when the loading ratio was less than 1 [9]. This pumping effect was robust and reproducible. In order to confirm the excess heat was released by the pumping effect, a precise calorimeter was applied to measure this excess heat. This calorimeter was based on the
Seebeck effect, and was independent of the temperature distribution along the palladium surface. The precise calorimeter confirmed not only the excess heat, but also revealed the correlation between deuterium flux and the excess heat[10]. Moreover, the excess heat appeared while the D/Pd system was cooling down as theory predicted[11]; and the peak of the excess heat appeared in the temperature range of 140°C to 150°C. Therefore a self-sustaining excess heat system was proposed[12]. When this pumping effect was repeated in different laboratories in different countries[13,14], a question about the thermal conductivity was raised in two studies. This paper presents the preliminary results from a technique intended to eliminate the effect of thermal conductivity from the pumping inside the palladium tube.

2. Apparatus

Based on our previous experiments [10], we designed the apparatus as an enlarged gas-loading D/Pd system. With our previous C-80D calorimeter, we recorded 2 mW excess heat in a palladium tube of 2.6 cm length. In this new apparatus, 5 palladium tubes were used with length of 20 cm each in order to enhance the effect of excess heat. These palladium tubes were blocked at one end, and were connected to a manifold for pumping or feeding the gas (see Figure 1). 5 Pt-100 thermistors (#1 to #5) were attached on the palladium tube to record the temperature distribution along the palladium tube. This bunch of palladium tubes were sealed in a stainless steel vessel. The electrical heater winding on the surface of the stainless steel vessel can heat the palladium tubes to about 200°C. 5 Pt-thermistors (#6 to #10) were attached to the surface of the stainless steel vessel to record its temperature distribution also. An AC power supply with precise heating power was applied on this electrical heater. Two pressure gauges were used to record the pressure inside the palladium tube and pressure outside the palladium tube. Because of the limit in range, the pressure gauge read 13 kPa when the pressure inside the palladium tube was higher than 1 atmosphere, and another pressure gauge read 300 Pa when the pressure outside the palladium tube was higher than 300 Pa. However, they showed the time correctly when we started pumping inside or outside the palladium tubes. The whole stainless steel vessel and heater were enclosed by thermal insulation to reduce heating power.

3. Experimental Results

The experiments were conducted to confirm the pumping effect, i.e. excess heat correlated with the deuterium flux. We knew that the pumping would reduce the thermal conductivity of the D₂ gas; however, we might control the effect of the thermal conductivity of the D₂ gas, and show clearly the excess heat correlated with the deuterium flux permeating the thin wall of the palladium tubes.
Figure 2 shows the results of one of our experiments. The air was pumped out first from the stainless steel vessel and from the palladium tubes. Then, D₂ gas was fed into the stainless steel vessel and the palladium tubes. The pressure inside the palladium tubes was about 80 kPa. The pressure outside the palladium tubes was higher than 300 Pa; hence, it was beyond the range of that gauge. When we started electrical heating power, the pressure inside the palladium tubes increased with the temperature and was quickly out of the range of the gauge (130 kPa) also. The heating power was kept at about 80 W. After 6 hours the temperatures of the system reached a steady state (138°C to 178°C for #1 to #5). Near 28000 seconds, we started pumping inside the palladium tubes. The pressure inside the palladium tubes dropped quickly down, and a pressure gradient across the thin wall of the palladium tubes was established. A deuterium flux permeating the thin wall of hot palladium tubes was generated by this gradient, and this deuterium flux was correlated with a temperature rising in all 5 thermistors on the palladium tube. The maximum temperature rise was about 6°C. This experiment has been repeated three times, and the excess heat correlated with deuterium flux was confirmed again in this scaled-up system.

4. Discussion

There are some frequently asked questions related to the thermal conductivity of the deuterium gas:

(1) Some might wonder if the thermal conductivity of the deuterium gas was reduced by the pumping. If so, the palladium tubes were better insulated from the environment such that the temperature of the palladium tubes increased with the same heating power. However, if we look at the path of heat transfer (Fig. 3), we will understand this is not the case. Figure 3 shows the location of these thermistors and their temperatures before or after pumping. It is evident that the palladium tubes were enclosed by a hot deuterium gas and the radiation from the stainless steel vessel. The only path to transfer heat from the palladium tubes to the environment was the thermal conduction of the palladium tubes and the metal leads connected on the thermistors. In comparison with the conductivity of these metal parts, the thermal conduction of the deuterium gas inside the palladium tubes was negligible. Hence, when we started the pumping, the heat transfer from the palladium tubes to the environment did not change substantially. Indeed the heat transfer from the stainless steel wall to the palladium tubes might be reduced by pumping, because the thermal conduction of deuterium gas outside the palladium tubes was comparable with the net thermal radiation from the stainless steel wall to the tubes. Consequently, we were supposed to observe a temperature decrease when the pumping was started. In reality we observed the temperature rising instead of decreasing. The temperature rise of the
palladium tubes was good evidence of a heat source in the palladium tube.

(2) To support this argument, we might look at the temperature of the stainless steel vessel (thermistors #6 to #10). If heat transfer from the stainless steel wall to the palladium tubes reduced by pumping, then, the temperature of the stainless steel vessel should increase when the pumping was started. This is true (Fig. 2, second row).

(3) According to the thermal kinetics of molecules, the thermal conductivity of the gas does not change until the mean free path of the molecules is comparable with the scale of the temperature gradient. In the present case, the distance between the stainless steel wall and the palladium tubes is about 1.5 cm; hence, the thermal conductivity of the deuterium gas does not change until its pressure drops down to less than $10^2$ Pa. The third row in Fig. 2 (right ordinate, dotted line) shows that the pressure outside the palladium tubes dropped down only to about 150 Pa after pumping; hence, we do not expect a big change in thermal conductivity of deuterium gas. The temperature rise of thermistors #1 to #10 is mainly due to the excess heat from the palladium tubes which was related to the deuterium flux.
Figure 1. Schematic of the improved D/Pd system
Figure 2. Pumping inside the palladium tubes. Row 1: Temperature of palladium Tubes; Row 2: Temperature of stainless steel vessel; Row 3: Pressure inside the palladium tubes (left) and outside the palladium tubes (right); Row 4: Electrical heating power.
Figure 3. The locations of 5 thermistors on the palladium tube (#1–#5 arrows with single line) and 5 thermistors on the surface of stainless steel chamber (#6–#10 arrows with double line).

How much was the excess power during pumping inside the palladium tube? We are able to make a semi-quantitative estimate. The excess power should be of the same order of magnitude as that of other channels of heat transfer; otherwise the pumping should not cause any detectable change in temperature. In the previous section we discussed mainly the thermal conductivity between the stainless steel chamber and the palladium tubes. There are, of course, other heat loss paths including thermal radiation, thermal convection of deuterium gas, conduction of the palladium tube, conduction of the deuterium gas inside the palladium tube, and conduction of metal leads which connected the Pt-100 thermometers to the interface between vacuum and atmosphere. Estimates showed that the major channel for heat transfer was the 10 copper leads (this was several watts). The
second largest heat transfer channel was the thermal radiation between the stainless steel chamber and the palladium tube (also several watts). The heat transfer through the palladium tube was \( \sim 100 \text{ mW} \), because its thickness was only 30 \( \mu \text{m} \). The heat transfer through the deuterium gas inside the palladium tube is of the same order of magnitude. Consequently the excess power should be on the order of 100 mW. This is reasonable. When we used a precision calorimeter (C-80D) the excess power correlated with deuterium flux was 2 mW with a palladium tube 26 mm long (\( \phi \ 4 \text{ mm} \times 100 \mu \text{m} \))[10]. In the present experiment, we have 5 palladium tubes. Each tube is 20 cm long (\( \phi \ 3 \text{ mm} \times 30 \mu \text{m} \)). Hence, the scaling up by a factor of 50 is reasonable. A calibration heater will soon be installed in the palladium tube to confirm this estimate.

The selective resonant tunneling theory predicts that a deuterium flux is necessary to keep a steady state of resonant tunneling in order to generate detectable excess heat[16]. This set of experiments has been consistent with the selective resonant tunneling theory.

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References


Selective Resonant Tunneling through Coulomb Barrier by Confined Particles in Lattice Well

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ABSTRACT

A confined particle in a lattice potential well may tunnel through Coulomb barrier in terms of resonance. It will select the resonance which is of a specific life-time. In contrast to beam-target situation using an accelerator, the selected life-time of this resonance is \( \tau_{\text{eff}} \approx \theta \sqrt{\tau_N \tau_L} \) instead of \( \tau_{\text{eff}} \approx \theta^2 \tau_N \). Here \( \theta \) is a large number as the square root of the reciprocal of Gamow penetration factor \( [1] \). \( \tau_N \) is the flight-time of this particle inside the nuclear potential well; and \( \tau_L \) is the flight-time of this particle inside the crystal potential well. Introducing an imaginary part in the lattice potential well has been found very useful to describe the deuterium-loading effect which has not been used in previous literature of tunneling \([2]\).

1. Introduction—Imaginary Part of Potential Well

The selective resonant tunneling model has been successful in calculating three major fusion cross-sections (d+t, d+d, and d+\(^3\)He) in terms of an imaginary part in a nuclear potential well \([3,4]\). In this paper we introduce another imaginary part in the crystal potential well, in order to describe the deuterium-loading effect in experiments. It is found that this imaginary part in the crystal potential well facilitates the description of the current conservation, and the steady-state requirement of resonant tunneling.

“Excess heat” is a major anomalous phenomenon in deuterium-loaded metals. Various calorimeters have been used to detect this excess heat; however, all the calorimeters have a time constant which is on the order of 100 seconds or more. This means that if the excess heat is a result of resonant tunneling, we have to have steady-state resonant tunneling in order to detect the excess heat in a calorimeter. In the case of a beam-target, this steady-state is maintained by an injected beam. Any absorption of the injected wave in the nuclear potential well is balanced by the probability current of the plane wave which is coming from infinity. Now in the case of the confined particle in a lattice potential well, we have to supply the particle in the lattice potential well in order to compensate for the absorption in the nuclear potential well. In experiments, this supplement is maintained by deuterium-loading in terms of electrolysis or gas loading procedures. The simplest way to describe this deuterium-loading effect is to introduce an imaginary part in the crystal potential well. That is
Here, $U_{1i}$ and $U_{2i}$ are the imaginary part of the potential in the nuclear well and the crystal well, respectively; and $\phi(r)$ is the reduced radial wave function of the confined deuteron wave (Fig. 1). In order to solve the Schrodinger equation for $\phi(r)$ it is necessary to assume the potential well in the regions I, II, and III respectively (Fig. 1). We shall find that a pair of specific values for the imaginary part of the potential well, $U_{1i}$ and $U_{2i}$, will make the tunneling current maximized.

2. Model—Eigenequation

A deep square-well is assumed for the nuclear potential well in region I; and a down shifted Coulomb potential is assumed in region II in order to show the repulsion between two positively charged nuclei and the electron screening effect in metal. Beyond region II, the potential is assumed to be constant in order to confine the charged particle and show the effect of reflections in the lattice potential well.
To satisfy the boundary conditions at $r = 0$ and $r = \infty$, the reduced radial wave function in region I, II, and III should be in the following form:

\begin{align*}
\phi_I (r) & = A \sin(k_I r) \\
\phi_H (r) & = B [F_0 (r) + \tan(K) G_0 (r)] / k \\
\phi_{III} (r) & = D \exp(-\beta r); \quad \text{Re} (\beta) > 0
\end{align*}

Figure 1. A square nuclear well is surrounded by a Coulomb barrier. The Coulomb potential is shifted down by $U_{sc}$, the screening potential. It forms a lattice well on the right of the Coulomb barrier.
Here, the wave number in each region is defined by the potential $U_1$, $U_2$, and $U_3$ as:

$$k_i = \frac{2\mu}{\hbar^2} (E - U_i); \quad k = \frac{2\mu}{\hbar^2} (E - U_2); \quad \beta = \frac{2\mu}{\hbar^2} (U_3 - E),$$ (5)

$U_1 = U_{1r} + iU_{1i}; \quad U_2 = U_{2r} + iU_{2i} - U_{i}; \quad U_3 = U_{3r} + iU_{3i}$

For simplicity, we have assumed $U_{3r} = 0$, and $U_{3i} = U_{2i}$. $F_0(r)$, and $G_0(r)$ are the regular and the irregular Coulomb wave function, respectively [5]. For the low incident energy, only the lowest partial wave (S-wave) is considered here. The potentials are assumed to be isotropic. $K$ is the phase shift, and $\tan(K)$ is the coefficient of the linear combination for the wave function in region II. $A$, $B$, and $D$ are the normalization constants in each region, respectively. $\mu$ is the reduced mass of the two interacting charged particles, $\hbar$ is the Planck constant divided by $2\pi$. The continuity of the logarithmic derivative at $r = r_0$, and $r = r_1$, will give two equations for $\tan(K)$. They are:

$$k_1 \cot(k_1r_0) = \frac{F_0'(r) + \tan(K) G_0'(r)}{F_0(r) + \tan(K) G_0(r)} \bigg|_{r=r_0};$$ (6)

$$\beta = \frac{F_0'(r) + \tan(K) G_0'(r)}{F_0(r) + \tan(K) G_0(r)} \bigg|_{r=r_1}.$$ (7)

Here, $F_0'(r)$ denotes the derivative of $F_0(r)$ with respect to $r$. Equations (6) and (7) give two expression for $\tan(K)$:

$$\tan(K) = -\frac{F_0(r) \left[ F_0'(r) F_0(r) - k_1 \cot(k_1r) \right]}{G_0(r) \left[ G_0'(r) G_0(r) - k_1 \cot(k_1r) \right]} \bigg|_{r=r_0};$$

$$\tan(K) = -\frac{\left[ F_0'(r) + \beta F_0(r) \right]}{\left[ G_0'(r) + \beta G_0(r) \right]} \bigg|_{r=r_1}.$$ (8)

$\tan(K)$ represents the coefficient of the linear combination in wave function $\phi_{II}(r)$. It gives the eigen equation:

$$\left[ \frac{F_0'(r) F_0(r) - k_1 \cot(k_1r)}{G_0'(r) G_0(r) - k_1 \cot(k_1r)} \right]_{r=r_0} = \frac{G_0(r_c)}{F_0(r_c)} \left[ \frac{F_0'(r) + \beta F_0(r)}{G_0'(r) + \beta G_0(r)} \right]_{r=r_1};$$ (8)

It is noticed that $r_0$ is much smaller than $a_c$. $a_c = h^2 / (\mu z_1 z_2 e^2)$ is the Coulomb unit of length for the two charged particles with electrical charge of $z_1 e$ and $z_2 e$, i.e. the Coulomb potential is much greater than the kinetic energy of the relative motion between two particles. Hence, $F_0(r_0)$ is exponentially small, and $G_0(r_0)$ is exponentially large. We may write [6]

$$F_0(r) = C \rho \Phi(r);$$

$$\Phi(r) \equiv \frac{1}{\sqrt{y}} I_1(2\sqrt{y}) = 1 + \frac{y}{1!2!} + \frac{y^2}{2!3!} + \frac{y^3}{3!4!} + ...,$$ (9)
\[ G_o(r) = \frac{\Theta(r)}{C} ; \]
\[ \Theta(r) = 2\sqrt{y} K_1(2\sqrt{y}) = 1 + y[\ln(y) + 2\gamma - 1]\Phi - \sum_{s=0}^{\infty} \frac{y^{s+1}}{s!(s+1)!} \sum_{t=1}^{\infty} \left( \frac{1}{t} + \frac{1}{t+1} \right) ; \] (10)

Here, \( \rho = kr, \) \( y = 2r/a, \) \( \gamma = 0.577 \ldots \) (Euler’s constant). \( C^2 \) is an exponentially small number which is called as Gamow penetration factor:
\[ C = \sqrt{\frac{2\pi \eta}{\text{Exp}(2\pi \eta) - 1}} ; \] (11)
\[ \theta^2 = \frac{1}{C^2} = \frac{\text{Exp}(2\pi \eta) - 1}{2\pi \eta} \] (12)
\[ \eta = \frac{e^2}{\hbar v} ; \] (13)

Here, \( e \) is the absolute value of the electron charge; \( v \) is the speed of relative motion between two particles. Using Eqs.(9) and (10), the eigenequation (8) leads to a relation between two time scales \( \tau_{\text{life1}} \) and \( \tau_{\text{life2}} \) (See Appendix (A.6)):
\[ \tau_{\text{life1}} \tau_{\text{life2}} \approx \theta^2 \tau_N \tau_L \] (14)

Here, \( \tau_{\text{life1}} \) and \( \tau_{\text{life2}} \) represent the life-time of deuteron in the nuclear potential well and in the lattice potential well, respectively. They are defined as:
\[ \tau_{\text{life1}} = \frac{\int |U_{\text{nuclear}}| |\phi|^2 \, dr}{\int |U_{\text{nuclear}}| \frac{h}{\hbar} |\phi|^2 \, dr} \] (15)
\[ \tau_{\text{life2}} = \frac{\int |U_{\text{lattice}}| |\phi|^2 \, dr}{\int |U_{\text{lattice}}| \frac{h}{\hbar} |\phi|^2 \, dr} \] (16)

\( \tau_{\text{life1}} \) and \( \tau_{\text{life2}} \) measure the rate of nuclear reaction in the nuclear potential well, and the rate of deuteron-loading in the lattice potential region, respectively.

\( \tau_N \) and \( \tau_L \) represent the flight-time of deuteron bouncing back and forth in the nuclear potential well and in the lattice potential well, respectively. They are defined as
\[ \tau_N = \frac{r_o}{k_{1r} \hbar / \mu} ; \] (17)
\[ \tau_L = \frac{r_L}{k_{1r} \hbar / \mu} . \] (18)

\( k_{1r} \) and \( k_r \) are the real part of the wave number \( k_1 \) and \( k \), respectively.
3. Probability Current Conservation—Requirement of a Steady State

Tunneling current is the most important physical quantity in the case of resonant tunneling through Coulomb barrier by confined particles in lattice well. The normalized tunneling current is defined as

\[
j = \frac{\int |\phi(r)|^2 dr}{\int |\phi(r)|^2 dr + \int |\phi(r)|^2 dr}.
\]

(19)

Because of the probability current conservation for a steady state, it may be written as:

\[
j = \frac{1}{\tau_{\text{life}1} + \tau_{\text{life}2}};
\]

(20)

Use has been made of the equation:

\[
\int |\phi(r)|^2 dr = \int |\phi(r)|^2 dr.
\]

(21)

Consequently,

\[
j = \frac{\tau_{\text{life}1}}{\tau_{\text{life}1}^2 + \theta^2 \tau_N \tau_L}.
\]

(22)

This is the most important result in this paper which gives the normalized tunneling current in the case of resonance. It involves the selectivity of life-time also.

4. Selectivity in Resonant Tunneling—Matching Loading Rate with Life-Time

This normalized tunneling current shows clearly the selectivity in resonance: it has a peak

\[
j_{\text{max}} = \frac{1}{2\theta \sqrt{\tau_N \tau_L}}
\]

at

\[
\tau_{\text{life}1} = \theta \sqrt{\tau_N \tau_L}.
\]

(23)
When \( \tau_{\text{life1}} \) or \( \tau_{\text{life2}} \) is close to \( \theta \sqrt{\tau_N \tau_L} \), this normalized tunneling current \( j \) would approach to \( j \approx \frac{1}{\theta^2 \tau_N \tau_L} \). It would be much smaller than the peak value \( j_{\text{max}} \).

The resonance would increase the tunneling current by a factor of \( \theta \) at the specific lifetime, \( \tau_{\text{life1}} = \theta \sqrt{\tau_N \tau_L} \), with a narrow width. Figure 2 shows the peak-wise behavior for the case of \( \tau_N = 10^{-23} \text{ sec.} \), \( \tau_L = 10^{-13} \text{ sec.} \), and \( \theta = 10^{23} \). [7]

It is noticed that this long lifetime reaction rate is in the range of weak-interaction (\( \tau_{\text{life1}} \approx 10^4 \text{ sec.} \)). The electromagnetic interaction and the strong nuclear interaction are too rapid to have any detectable tunneling current (Fig. 2).

5. Discussion

Based only on the general Principle of Quantum Mechanics, we have proved that:

1. Resonant tunneling selects not only the right energy level, but also the reaction rate in the nuclear potential well. Only if the life-time in the nuclear potential well is on the order of
\[ \tau_{\text{lifetime}} = \theta \sqrt{T_N \tau_L} \]  

There will be a maximized tunneling current which will be greater than that of non-resonance case by a great factor of \( \theta \). \( \theta \) is on the order of \( 10^{23} \) or more. It is different from the beam-target case, where the resonant tunneling would select the life-time in the nuclear potential well on the order of

\[ \tau_{\text{lifetime}} \approx \theta^2 \tau_N. \]

(2) In the case of confined deuterons in the lattice potential well, the resonant tunneling selects the loading-time in the lattice potential well also in order to keep a steady state. This means that there is a matching loading rate which allows a resonant tunneling in a steady state. **This point is important in carrying out any experiment with detectable excess heat.**

(3) This selectivity in resonant tunneling implies a specific linear combination of wave functions. It is neither a pure molecular state in lattice potential well (i.e. not the pure \( F_0(r) \)), nor a pure excited nuclear state of \(^4\text{He}^*\) (i.e. not the pure \( G_0(r) \)). It is a mixture of both molecular state in lattice potential well and the pure excited nuclear state of \(^4\text{He}^*\) (i.e. the linear combination: \( F_0(r) + \tan(K) G_0(r) \)). This coefficient, \( \tan(K) \), cannot be zero; but it also cannot be too large. It should be on the order of \((1/\theta)\) in order to have a maximized resonant tunneling current. This long-life-time state has been confirmed in experiment by 3-deuteron fusion reactions. [8,9,10,11]

(4) The electron screening effect is dependent on the temperature of the deuterium-loaded metal [12,13]; hence, the \( \theta \) factor is a function of temperature as well. Hence, in the experiment we should control not only the loading rate but also the temperature in order to maintain the resonant tunneling state.

(5) In the early literature after 1989, the concept of fusion cross-section was used without any consideration of the difference between the beam-target case and the lattice confined case. In this paper we introduced an important physical quantity, tunneling current \( j \), to replace the concept of the fusion cross-section. In terms of maximization of this tunneling current, we obtain the matching condition for resonant tunneling. This matching condition includes both the energy level and the reaction rate.

6. Acknowledgements

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References

Appendix A. Eigenequation

The eigenequation of this potential well in Fig. 1 will lead to both the constraints of the energy level, E, and the constraints of the life-time of the nuclear state.

Let us first write the eigenequation in the form of

\[
\frac{F_o \left( r_{1} \right) / F_o \left( r_{0} \right) - k_1 \cot(k_1 r_{0})}{G_o \left( r_{0} \right) / G_o \left( r_{1} \right) - k_1 \cot(k_1 r_{1})} = \frac{G_o \left( r_{1} \right) / G_o \left( r_{0} \right) - k_3 \cot(k_3 r_{0})}{F_o \left( r_{0} \right) / F_o \left( r_{1} \right) + \beta G_o \left( r_{1} \right) + \beta G_o \left( r_{0} \right)}.
\]  

(A.1)

The advantage of this form is: (1) the left-hand-side is mainly a function of \( k_1 \) only, and the right-hand-side is a function of \( k \) and \( k_3 \) only; (2) it clearly shows the big factor,
\( \frac{G_o(r_o)}{F_o(r_o)} \approx \theta^2 \pm 1 \), which determines the constraints on the solution of this eigenequation. In order to satisfy this eigenequation, we have to have:

\[
\left\| \frac{G_o'(r_o)}{G_o(r_o)} - k \cot(k_i r_o) \right\| \left\| F_o'(r_i) + \beta F_o(r_i) \right\| \approx \frac{1}{\theta^2} \rightarrow 0. \quad (A.2)
\]

When we introduce the imaginary part of potential well in nuclear region and in crystal region, it can be expand as

\[
\left\| \frac{G_o'(r_o)}{G_o(r_o)} - k \cot(k_i r_o) \right\| + i \frac{\tau_N}{\tau_{\text{life}}} \frac{d}{d(k_i r_o)} \left[ \frac{G_o'(r_o)}{G_o(r_o)} - k \cot(k_i r_o) \right] \approx \frac{1}{\theta^2} \rightarrow 0. \quad (A.3)
\]

The suffix “o” after the square-brackets means the real part of the content in the square-brackets.

Now we may find the condition of resonance: i.e.

\[
\left\| \frac{G_o'(r_o)}{G_o(r_o)} - k \cot(k_i r_o) \right\| = 0, \\
\left\| F_o'(r_i) + \beta F_o(r_i) \right\| = 0. \quad (A.4)
\]

And the constraint on life-time:

\[
\frac{\tau_N \tau_L}{\tau_{\text{life}}} \approx \frac{1}{\theta^2}, \quad (A.5)
\]

or

\[
\tau_{\text{life}} \approx \theta^2 \tau_N \tau_L. \quad (A.6)
\]

If only one of the two factors in (A.4) equals zero; then, we have

\[
\tau_{\text{life}} \approx \theta^2 \tau_N \quad (A.7)
\]

or

\[
\tau_{\text{life}} \approx \theta^2 \tau_L. \quad (A.8)
\]

In both cases, we have

\[
j \approx \frac{1}{\theta^2} \pm \frac{1}{\theta}. \quad (A.9)
\]

Consequently, only if the energy level satisfies the resonant condition, (A.4), and the loading rate satisfies the matching condition,

\[
\tau_{\text{life}} = \tau_{\text{life}} = \theta \sqrt{\tau_N \tau_L}, \quad (A.10)
\]

We shall have the maximized tunneling current
\[ j_{\text{max}} = \frac{1}{2\theta \sqrt{\tau_N \tau_L}} \approx \frac{1}{\theta} . \]
Anomalous heat Generation by surface oxidized Pd wires in a hydrogen atmosphere

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ABSTRACT

Thin Pd wires (diameter 50 micrometers) surface oxidized through joule heating have been loaded in a hydrogen (H_2) atmosphere at pressures in the range 1 - 10 bar. The atomic ratio H/Pd reached in the experimental conditions has been evaluated through its relationship with the electrical resistivity of hydrogen-loaded Pd. It was found that the loading rate of the surface oxidized Pd wires is exceptionally higher than with the untreated ones (full loading in a few minutes as compared with several hours). It was also observed that surface treated wires with H/Pd ≥ 0.75 do not lose hydrogen even when joule heated at temperatures up to about 150°C in a Hydrogen atmosphere. When the wire temperature exceeds 150°C (applied power about 12.4 W) anomalous heat generation (about 3.5 W) was detected.

During an experimental test, the wire was powered with stepwise increased higher power for 500 - 600 seconds at each step, followed by a period of zero power. It was observed that when the power was cut off after powering at 14 W, the wire spontaneously heated for about 70 seconds releasing an estimated heat of 1650 ± 160 J, corresponding to 3940 ± 400 Kcal per mole of Pd. Peak power was ∼ 16 W. The wire resistance spontaneously reaches a value R/R_o = 2.40 and then slowly dropped to the original value of 1.80 at room temperature.

In a second experimental test with the same wire similar phenomena have been observed although of lower intensity but lasting over 3000 seconds. After 16 W powering for 500 seconds, the power was cut off. Again the wire heated spontaneously releasing an anomalous heat of 3600 ± 360 J, corresponding to some 13200 ± 130 Kcal per mole of Pd. The peak power was ∼ 3 W. The wire resistance increased spontaneously up to R/R_o = 2.01 and then slowly decreased down to 1.90.

Such experiments were performed in 2005 and presented briefly by F. Celani at ICCF12 (Yokohama, Japan 2005). The present paper is in-depth analysis of previous experimental data.

1. Introduction

In a recent paper (J. P. Biberian [1]) it is shown that consistent excess heat is produced when the side walls of a thin Pd tube are crossed by a D_2 flow. The heat generation only occurs if the tube has been previously oxidised in air (at 500°C).
Since 1990, INFN Frascati Labs (Celani et al.) developed an experimental procedure for the electrochemical loading of thin Pd tubes. [2] The surface oxidation of the Pd tube (by electrolysis), and later wires, with co-deposition of “proper impurities”, was just one of our innovative technologies previously developed and adopted, more recently, for gas loading tests. We found that proper surface oxidation treatments allowed for a surprisingly rapid loading rate, in experiments conducted in 1994 with “Takahashi-style” Pd plates loaded electrochemically (ICCF5, Montecarlo 1995).

More surprisingly, we observed in 2005 that thin Pd wires (diameter of only 50 μm), warmed up very quickly (<10ms) by Joule heating when in-situ under pressurized H$_2$ atmosphere. Temperatures rose to about 200°C. The loading ratio remained unchanged only if the surface was previously oxidised and stabilised. In comparison, without proper surface treatments, using DC current with a current density up to 50000 A/cm$^2$, Joule heating only caused the H$_2$ releases from the wire, which followed the usual Pressure-Temperature-Concentration curves.

Preliminary tests performed in a hydrogen atmosphere were called for because the price of this gas is about three orders of magnitude lower than the cost of deuterium. In general, by adopting proper experimental conditions, we were able to check whether comparable (or better) H/Pd loading ratios might be achieved via gas, compared to loading ratios previously obtained via electrolysis.

Because we knew that the tests performed in November 2005 in H$_2$ (instead of D$_2$) produced unimpressive loading ratios (H/Pd ≈ 0.75 by resistivity methods, not a volumetric Sievert method), we were sure that no emission of excess heat could be expected. When a spontaneous warming up of the wire at “zero applied power” was recorded, we conservatively (and perhaps too hurriedly) attributed the phenomenon to chemical heat generation (absorption), although the amount seemed too large in comparison to a conventional chemical reaction and/or lattice energy.

After the ICCF12 we planned to make more accurate experiments but adverse circumstances prevented that, including: repeated damage to the experimental set-up, budget cuts, man-power reduction, other experiments of higher priority.

On the basis of the work of Jean Paul Biberian [1] and the references therein (especially the experiments of X. Z. Li at Tsinghua University) our old gas loading tests [3] have been revised and deeply analysed: they are the main argument of the present paper.

2. Experimental Setup

Experiments were performed employing a 30 cm long Pd wire (thickness 50 μm, weight 7 mg) inserted in a pressure-tight steel vessel, with mirrored external surfaces. This minimizes heat exchange with the external environment, and it allows high pressure
experiments to be performed. Although pressurized hydrogen gas has excellent thermal conductivity, for the specific tests we performed, that effect is not very significant.

Figure 1. Experimental setup

The resistance of Pd metal is a function of its hydrogen content [4] and is, in principle, the easiest way of determining the state of the Pd electrode (loading ratio H/Pd) as the experiment proceeds.

During the experiment we warmed up the wire by means of a DC current (joule heating) so much that we were able to measure the Pd wire resistance by introducing an AC component, as shown in Fig. 2.

Figure 2. Electric circuit for the measurements of Pd resistance and for joule heating.
3. Results

The Pd wires (thickness 50 μm) selected for the gas loading tests were previously oxidised by joule heating in air, according to the following procedure:

**Basic Oxidation/Reduction cycles in air by JOULE HEATING**

\[
2\text{Pd} + \text{O}_2 \rightarrow 2\text{PdO} \rightarrow 2\text{Pd} + \text{O}_2
\]

500\text{°} - 700\text{°}C \quad 800\text{°}C
(oxidation) \quad (decomposition)

After the joule heating oxidation, the PdO layer, formed on the wire surface, was stabilised with a further heat treatment. The aim of this treatment, which is still under development, is to prevent (or at least minimise) the collapse due to coalescence and crystallization of the thin and defective Pd layer, ensuing from the H\(_2\) reduction of the previous PdO layer.

**In order to prevent coalescence, stabilizing surface treatments were effected.**

\[
\text{Pd} \rightarrow \text{PdO} \rightarrow \text{stabilized, defective} ^*\text{Pd}^*
\]

(Stabilizing Treatments 500° - 700° C (oxidation))

Fig. 3a shows a typical loading rate of a Pd wire in Hydrogen atmosphere (1 bar, fluxing). Thermodynamic equilibrium is reached in about 1Ms (H/Pd ratio = 0.75, at 20°C).

It is well known [4, 5] that such a value corresponds to the maximum of the R/Ro = f(H/Pd) curve, where R is the actual electrical resistance of the wire and Ro is the resistance of the virgin wire (H/Pd = 0). By comparison, Fig. 3.b shows the loading rate of a similar wire, oxidized in air, with no stabilizing treatment. The loading rate of the wire reaches (equilibrium reached in about 500 sec). Fig. 3.c shows the extremely fast loading rate for a Pd wire oxidized in air and surface-treated. The time to reach thermodynamic equilibrium is just 80 s.
Figure 3. Increase in loading rate with oxidation-stabilizing treatments.

1) Blank: gas loading in H2 atmosphere, 1bar flux, without any kind of surface treatment. This test is performed in a flat cell, with gas flux (1 bar), and with a 50μm diameter Pd wire. 

2) Gas loading in H2 atmosphere, 4bar, no flux, only with oxidation cycles, without surface treatment.

3) Gas loading in H2 atmosphere, 3.6 bar, no flux, with surface treatments and oxidation cycles.
In order to evaluate the degassing rate as a function of temperature, the wires were oxidised with the procedure described above and preloaded at H/Pd = 0.75, and kept constantly in contact with the H₂ atmosphere. They were then warmed up by joule heating with currents of increasing intensity. The results are presented in Fig. 4.

![Figure 4](image)

**Figure 4.** The wire was warmed up with amperage of increasing intensity

In Fig. 4 the sudden change of resistance is shown (red line) due to the applied electrical power (blue line). The starting R/R₀ value of the wire (30 cm long and 50 μm thick) was 1.85 (H/Pd ≈ 0.75); the gas temperature was 35°C. It appears that, when the power is on, the equilibrium temperature of the wire, because of its small thermal capacity, is reached almost instantaneously (within the 10 second cycle of the data acquisition system). When the power is off the cooling down of the wire to the ambient temperature (35°C) is as rapid as the heating.

In Table 1, the tests shown in Fig. 4 has been labelled from 1 to 12. The table shows the R/R₀ values, the relative applied electrical power and the calculated wire temperatures.
Table 1. R/Ro values, applied electrical power and wire temperature for the 12 tests shown in Fig. 4.

<table>
<thead>
<tr>
<th>Tests</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/Ro</td>
<td>1.85</td>
<td>1.95</td>
<td>1.98</td>
<td>2.02</td>
<td>2.06</td>
<td>2.14</td>
<td>1.85</td>
<td>2.37</td>
<td>1.85</td>
<td>2.36</td>
<td>1.92</td>
<td>2.39→1.82</td>
</tr>
<tr>
<td>Watt</td>
<td>0</td>
<td>2.6</td>
<td>3.9</td>
<td>5.2</td>
<td>6.7</td>
<td>9.2</td>
<td>0</td>
<td>12.4</td>
<td>0</td>
<td>13.6</td>
<td>14.7</td>
<td>0</td>
</tr>
<tr>
<td>t wire (°C)</td>
<td>35</td>
<td>67</td>
<td>76</td>
<td>89</td>
<td>102</td>
<td>128</td>
<td>35</td>
<td>201</td>
<td>35</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

Tests 1 through 9 will be analysed and discussed first. Tests 10, 11 and 12, the most important ones, will be treated separately.

Both Fig. 4 and Table 1 show that no degassing occurs when the electric current is crossing the wire. In fact, when the power is switched off, in tests 7 and 9, the R/Ro value comes back immediately to its starting value (R/Ro = 1.85).

By increasing the applied power (Fig. 3), the R/Ro values (tests 1 through 6) increase linearly, according to the relationship:

\[
\frac{R}{Ro} = 0.03 \cdot W + 1.86
\]  

(1)

The linear correlation: R/Ro = f(W) directly demonstrates that, in spite of the increase in temperature of the wire due to the supplied power input, the loading ratio (H/Pd = 0.75) remains unchanged; (i.e: no degassing occurs). In fact, let us consider the following two expressions, which correlate the wire temperature with the wire resistance and the applied electrical power:

\[
\frac{R_{\text{f}}}{Ro} = Ro \cdot (1 + \alpha \cdot t_w)
\]  

(2)

\[
t_w = (W + h t_e)/h
\]  

(3)

Where: \( R_{\text{f}} \) = wire resistance at the wire temperature \( t_w \);
Ro = wire resistance at 20°C when H/Pd = 0 (virgin wire)
Ro* = wire resistance at 0°C when H/Pd = 0.75 (Ro* = f(H/Pd))
α = thermal resistivity coefficient (α = f(H/Pd))
tw = actual wire temperature
W = applied power input
h = thermal exchange coefficient
tg = gas temperature (considered constant and equal to 35°C)

By combining (2) and (3) we have:

\[
\frac{R_t}{Ro} = Ro* \left[ 1 + \alpha \cdot \frac{(W + h \cdot t_g)}{h} \right] \tag{4}
\]

Equation (4) is the explicit form of the experimentally demonstrated relationship (1). Taking into account that Ro* and α are both dependant on the H/Pd ratio, the linear dependence requires that, while the wire is being warmed up, the loading ratio H/Pd remains constant (as it does in tests 1 through 9).

After establishing that the wire does not degas, it is possible to calculate with the equation (2) the wire temperatures. It is known [5] that when H/Pd = 0.75 the value of the thermal resistance coefficient is:

\[
\alpha = 1.8 \times 10^{-3} \degree C^{-1}
\]

It is necessary first to calculate the Ro* value; as the starting temperature is 35°C, we have:

\[
Ro* = 1.85/(1 + 1.8 \times 10^{-3} \cdot 35) = 1.740 \tag{5}
\]

by inserting the Ro* value in equation (2) it is possible to obtain the wire temperature. The calculated values are reported in Table 1.

Looking at the Fig 4, it appears that the coordinates (R/Ro versus W) of Test 8 are placed much above the prolongation of the straight line (1). In order to justify such a displacement, according to equation (1), the applied power would have been 16.7 Watt, instead of 12.4 Watt actually supplied; that is: 4.3 Watt in excess. It should be noted that
because the mass of the wire is small ($\approx 7$ mg), the excess power amounts to 0.61 KW per gram of wire!

![Diagram showing R/Ro vs. W with linear fit equation $y = 1.8596 + 0.030748x$ and R² = 0.99762.]

It also appears that the observed excess heat requires a triggering temperature, which is somewhere between $128^\circ$C and $152^\circ$C. This temperature corresponds to the power of 12.4 W during a calibration when no excess heat is produced.

Obviously, Test 8 is the most interesting, and the test that most encourages additional research.

Test 12 shows that when power is switched off R/Ro increases up to 2.4. We know that the R/Ro can only go above 1.8 is when the wire is warming up. (Ro is not corrected for temperature.)

The R/Ro of the wire stays over 1.8 for about 100 seconds, before returning to 1.8. The integral of excess power yield is about 1 KJ, or 4 Mcal per gram-atom of Pd. So, it exceeds the limits of chemical heat production.
Figure 6. Evidence of excess heat at W=0.

4. Conclusions

Gas loading of thin Pd wire has been studied:

a) Blank loading → 1Ms to thermodynamic equilibrium
b) After surface oxidation → 500 s to thermodynamic equilibrium
c) After surface stabilising treatment → 80 s to thermodynamic equilibrium

Excess heat was found in a loading gas experiment:
a) No degassing observed
b) Excess power of 4 W was found when power applied was 12.4 W
c) Excess heat of 4 Mcal/mol was found when power applied was 0 W
d) Experiment was reproduced
References

Cluster Reactions in Low Energy Nuclear Reactions (LENRs)

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ABSTRACT

Cold fusion reactions can be divided into two broad classes: deuterium reactions producing excess heat and helium; and transmutations of host metal atoms, termed Low Energy Nuclear Reactions (LENRs). Here we review some unique facts about a special class of LENRs leading to an array of transmutation products in thin-film electrodes of palladium (Pd) or nickel (Ni) highly loaded with hydrogen (H) or deuterium (D). This phenomena is explained in terms of the formation of an intermediate compound nucleus, one of which is identified as the double magic number compound nucleus $^{306}X_{126}$. The formation of this nucleus requires a multi-body reaction between the D (or H) and the host metal. This is explained in terms of a proposed D (H) cluster formation. Such clusters can react collectively with palladium nuclei leading to a compound nucleus.

Introduction

Cold fusion was initially observed in electrochemical loading experiments when a very high concentration of deuterium was dissolved into the metal palladium lattice giving heat production that could be explained only by nuclear reactions [1]. Later a very convincing experiment was performed using deuterium gas loading with heat generation which continued for hours after the gas had been removed (“life after death”) where an energy release of ~ keV/Pd-atom, much above levels possible from chemical reactions, was confirmed [2]. It was assumed that cold D-D fusion reactions producing helium were responsible for the energy generation.

A later discovery was that the conditions could be created where highly loaded palladium and other hydrides produce nuclear transmutation reactions (termed “Low Energy Nuclear Reactions,” or “LENRs”) [3-5]. It was concluded that this type of reaction is quite different from the D-D type cold fusion since reactions with the metal lattice atoms are involved[6]. We will leave the question about the difference between these classes of cold fusion reactions open. Here we mainly concentrate on the issue of how LENR processes can produce heavy elements, suggesting multi-body reactions occur.
As pointed out earlier, the complete array of products observed in the University of Illinois thin film experiments appears to involve some direct nuclear reactions plus fission of three distinctive compound nuclei [3, 4]. Here we focus on some very distinctive properties of the portion of reaction products associated with the heaviest compound nucleus in order to give further definitive insight into this process. Important insight can be gained from the similarity between the measured distributions of nuclei [3, 7-10] generated by LENRs with the well known fission-fragment yield curve observed in the fission of uranium. We analyse these results to derive a new sequence for nuclei magic numbers which is consistent with fission of a double magic number nucleus $^{306}_{126}X$. Such reactions are explained by the reduction of Coulomb screening in the swimming electron layer, leading to formation of reactive deuterium clusters. Other evidence that such cluster can form comes from separate studies of superconductivity states created by programmed loading of Pd-hydride.

It is important to distinguish the deuterium cluster model proposed here from neutron clusters proposed earlier by some prior cold fusion researchers [11]. Screened deuterons react like neutrons up to a radius in the range of picometers, generating clusters that behave like neutron clusters. However an essential difference is that the very high density of deuteron clusters makes them very reactive compared to the smaller size of neutron clusters.

**Maruhn-Greiner Fission Model**

The distribution of the nuclei after fission of uranium or plutonium shows a minimum at a nucleon mass $A$ about one-half of the mass of the initial nuclei, e.g. at $A \sim 119$ in Fig. 1 [8]. This distribution with a broad absolute minimum, however, refers to fission of an unexcited (low temperature) initial nucleus. In the case that the originating nucleus is excited to higher temperature in the MeV range, as shown in Fig. 2, the distribution exhibits a sharp local maximum superimposed on the minimum of the curve for an unexcited nucleus. This behaviour has been explained by Maruhn and Greiner [9] using calculations based on collective mass parameters from the BSC formulation with the parameter $\lambda$ of the length in the Schrödinger equation for splitting of heavy nuclei [12] taken from the theory of fragmentation dynamics in nucleus-nucleus collisions.
Figure 1. Fission mass distribution curves as measured for $^{233}\text{U}$, $^{235}\text{U}$ and $^{239}\text{Pu}$ [8]

Figure 2 shows the resulting fission mass distribution for $^{236}\text{U}$ for the elongation $\lambda = 1.8$ at different excitation temperatures of the fissioning nucleus. It is significant that a local maximum occurs at $A \sim 118$ when the fissioning nucleus is excited to $> 1$ MeV temperature. This behaviour is a crucial point for the following discussion of product yield curves in LENR experiments.

Figure 2. Fission mass distribution curves for $^{236}\text{U}$ calculated assuming the nucleus at the time of fission is excited to temperatures of 0, 0.5, 1, and 7 MeV respectively (upward sequence in plots) for the length parameter $\lambda = 1.8$ in the Schrödinger equation [9].
LENR Results

A key experimental result on LENRs with deuterium loaded thin-film palladium electrodes [3, 4, 10] was the product distribution dependence on proton number $Z$ as shown in Fig. 3. The maxima of this distribution follows a Boltzmann probability distribution $N(Z)$ of the form [13]

$$N(Z) = N' \exp \left(-\frac{Z}{Z'}\right)$$

where $Z' = 10$ provides a good fit as shown in Fig. 3. Other near-by numbers for $Z'$ (9 or 11) do not fit well. This is especially important for the following consequence for the new kind of evaluation of magic numbers. A similar distribution occurs in the standard abundance distribution (SAD) of the elements in the Universe for elements above iron (see Fig. 10 of [14]). Below iron, the distribution is different due to the well-known exothermic fusion reactions. The endothermic synthesis of nuclei above iron is considered a crucial problem in astrophysics. It can be understood at the big bang theory with a Debye-layer model for the confinement of protons and neutrons in nuclei [15, 16].

![Image](image1.png)

Figure 3. Dependence of the measured production rate on nuclei proton number [3.4]. The line represents a Boltzmann distribution, cf. Eq. (1).

The ratios for the maxima of $N(Z)$ was sorted out earlier to obtain the magic numbers of nuclei as [13]:

$$R(n) = 3^n \ (n = 1,2,3,\ldots) .$$

This suggests saturated shells follow a three-multiplicity of a quark property in the nuclei. This earlier result, however, had to take into account that there was a jump between the
numbers 20 and 28 (see Table 1 of [13]), i.e., between the following two sequences of magic numbers:

\[ M_{an} \in 2, 8, 20, 40, 70, 112 \]  

\[ M_{bn} \in 2, 6, 14, 28, 50, 82, 126. \]

Earlier Bagge [17] produced these series from speculative numerical combinations consistent with the observation that the numbers of the electron shells in atoms follow a \(2n^2\)-law following the Schrödinger equation with the spin included (as derived by Dirac). The jump between the bold printed numbers in sequences (3) and (4) was explained by Jensen and Maria Goeppert-Mayer [18] by different properties of spin and spin-orbit combinations in the nuclei. In contrast to this explanation, the derivation of (2) explains the jump between the sequences (3) and (4) directly.

From this procedure [10,13], higher magic numbers can be derived with confidence. This results in:

\textit{new magic numbers: 180, 246, 324,} \hspace{1cm} (5)

consistent with the rather linear relation shown in Fig. 4.

Figure 4. Ratio \( R(n) \) from Eq. (2) for the sequence of the magic numbers \( n = 1,2,3 \ldots \) with the fitting value \( Z' = 10 \) for Eq. (2) given by the line, dots and circles. An exception is caused by the jump between the Bagge sequences (3) and (4)
Another important measurement of LENR is the detailed mass distribution of the resulting nuclei near the nucleon number $A = 153$ or 155 as seen from Fig. 5 [3, 4, 7]. This yield curve exhibits an absolute minimum similar to the fission of uranium, Fig. 1, along with a local maximum similar to the fission of excited uranium nuclei shown in Fig. 2. Later we use this remarkable observation along with the new higher magic numbers to identify the intermediate compound nucleus. (Other significant experimental phenomena observed in LENRs such as magnetic anomalies, charged particle and x-ray emission [19] may play a role but are not discussed here.)

![Figure 5](image_url)

Figure 5. Detailed nuclear mass spectrum of the LENR generation probability at the highest minimum of Fig. 3.

We next consider the potential role of “cluster reactions” in this process. By this we mean the formation of very high density states of H or D in highly localized regions in the electrode. LENRs are expected to occur due to these reactive states. However, as pointed out by Storms [20], the widely held belief is that “clusters of deuterium cannot form spontaneously” has inhibited the search for such clusters. Thus, before delving into a theoretical model, we will review experimental evidence that supports the possibility of cluster formation.

**Indirect Evidence for Cluster Formation**

A number of cold fusion researchers (Dash, Mizuno, Shoulders, Ohmori, etc.) have reported local “volcanic” like eruptions on electrodes that strongly suggest reactions occur in localized areas. (See, for example, the distinctive creator formation on an electrode in the cover photograph of the book by T. Mizuno, [21]). Also, early studies by
M. Srinivasan [22] showed a pattern of small glowing spots on a fluorescent plate placed over an electrode after operation. SPAWAR researchers have presented a movie from an IR camera view of an operating electrode showing a dynamic “dance” of small glowing hot spots. All of these observations are strongly suggestive of localized cluster-like reaction sites. However, the most definitive measurement that shows the existence of a high-density cluster-like phase in a loaded hydride comes from work on superconductivity states at the University of Illinois [23]. We briefly review that work next, then discuss a proposed theory for cluster reactions in LENR.

Earlier Heuser et al., [24] discovered, by using small-angle neutron scattering (SANS), that dislocation cores caused by hydrogen cycling in palladium films are sites of high hydrogen absorption and concentration. The concentration of hydrogen (x = atomic ratio H/Pd) inside the dislocations depends on the hydrogen distribution with respect to distance from the core or the hydrogen binding energy. After cycling a palladium single crystal film with deuterium gas, a large number of dislocations (N_d ~ 2-7×10^{11} cm^{-2}) were generated. Without annealing, the residual hydrogen left in the palladium sample was α-phase with a concentration of 5 to 6 deuterium atoms per Å of dislocation line. This high level of residual hydrogen was associated with a low hydrogen binding energy of \( \varepsilon_H = 0.2 \) eV. But a much lower amount of residual hydrogen (x ~ 10^4) was found to have a much higher binding energy \( \varepsilon_H \) of ~ 0.7 eV. In that case, all the absorbed hydrogen atoms are tightly bound inside the deep dislocation cores [25].

Obviously, the loading ratio in the deep dislocation cores is significantly larger than the stoichiometric H/Pd value that characterizes the palladium hydride β-phase in a regular lattice. Simple estimates show that a condensed deuterium phase in deep dislocation cores along a dislocation line in a PdH_x sample may have a concentration as high C_H ≥ 0.4 mol/cm^3. Such cores would be a sort of “nanotube” with an effective diameter of about two Pd Burgers vectors. Notice that the pressure inside such deep cores of the edge dislocation should be comparable to the local palladium bulk modulus, that is, up to 120 GPa. So, both of the conditions for hydrogen “precompression” and external pressure impelling would be fulfilled. A very conceptual picture of this compressed state is shown in Fig. 6 to illustrate the concept.
Based on these observations, it appears that deep dislocation cores satisfy the conditions that are necessary for the formation of a quasi-metallic metastable hydrogen phase at room temperature. Even if the criterion of metallization were not fulfilled inside of the dislocation nanotubes, the loading ratio would be well above that achieved in a regular lattice. Indeed, for a dislocation core radius comparable to the Burgers vector, \( r_d = b = 2.75 \text{ Å} \) (assuming \( 5.6 \text{ H atoms/Å} \) along the dislocation line [24]), the loading ratio \( x \) with respect to the atoms attached to the core, may be estimated to be as high as \( x = 3.5 \).

The electronic properties of this type of overloaded or “super-stoichiometric” hydride (with \( x > 1 \)) have never been studied before because these compounds are not stable at ambient conditions. But loading hydrogen directly into deep dislocation cores in a palladium lattice would enable the measurement of the electronic and magnetic properties of super-stoichiometric hydride. Then, its properties may be compared with the properties of pristine palladium and stable palladium hydrides. It should be noted that there is an intimate relation between a superconducting site and the location where LENRs are expected. Thus E. Storms states “if superconductivity were important, the NAE, ”Nuclear Active-Environment”) would be located where superconductivity occurs” [20].

Annealed Pd-metal does not demonstrate superconductivity, at least above 3.0 mK. However, palladium films with defects produced by alpha-bombardment at low temperature did exhibit superconductivity at \( T_c \sim 3.2 \text{ K} \) [26]. It was speculated that the quantum fluctuation of electron spins will not allow structurally perfect palladium metal to transit to the superconducting state, but specially introduced disorder serves to suppress those fluctuations. In contrast, palladium hydrides and palladium deuterides with a loading ratio \( x > 0.8 \) are superconductors with a relatively high \( T_c \sim 10 \text{ K} \). Though the superconducting effects in palladium hydrides, such as the reverse isotope effect, are still not fully explained, the arguments suggesting this superconductivity are based on a strong electron-phonon coupling to the optical modes and require a suppression of the spin fluctuation in the palladium lattice and sd-hybridization of hydrogen and palladium electrons. Anomalous transport properties over the temperature range below 300 K in highly loaded palladium hydrides [27-29] were detected earlier. In particular, in [29] it
was shown that palladium foil electrochemically cycled with hydrogen possessed metallic conductivity down to a temperature of 4.2 K even though it was severely deformed.

If the state of the condensed hydrogen phase inside the dislocation cores were a quasi-metallic one, then at a low enough temperature the diamagnetic behaviour of this phase would be expected, but corrected for the contribution of the palladium lattice and impurities. On the other hand, in the hydrogen dominant palladium clusters of the deep dislocation cores, the conditions required seem to be fulfilled: sufficient pressure, strong electron-phonon coupling and high local optical mode energy. This, at least, suggests the occurrence of a superconducting transition in the super-stoichiometric palladium hydride above the critical temperature of the normal hydride PdH\(_x\) (with x ~ 0.8). The observation of a diamagnetic signal from a hydrogen phase in the palladium matrix dislocations is possible when two necessary conditions are fulfilled:

- There is a sufficiently large number of dislocations in a palladium crystal that contain tightly bound compressed hydrogen, and
- The network of dislocations is organized in the form of closed loops that can carry a persistent current.

To verify this concept experimentally we have studied the structural and magnetic properties of PdH\(_x\) with a very low loading ratio x ~ 4.0×10\(^{-4}\) that was produced by cycling an annealing pure palladium single crystal in H\(_2\) atmosphere [19, 23]. Thermal desorption analysis (TDA) shows that hydrogen exists only as a condensed phase captured in the deep dislocation cores. Magnetic measurements were carried out with a sensitive 1T SQUID and recorded the appearance of a strong diamagnetic contribution of the condensed hydrogen phase [PdH\(_x\)-Pd] in the palladium matrix at T < 30 K (in a weak magnetic field, H ≤ 5.0 Oe), and of antiferromagnetic behavior in a higher magnetic field. The thermal desorption analysis and the SQUID measurements together suggest that the dislocation nanotubes in the hydrogen cycled palladium sample contains a diamagnetic phase of condensed hydrogen or superstoichiometric hydride at low temperature.

In summary, there is strong suggestive evidence that high density H(D) states and/or H(D)/Pd states can exist in properly loaded hydrides. If so, this would be consistent with observations from the University of Illinois LENR experiments and experiments by others suggesting localized reaction sites. Thus we explore a theoretical model for such LENRs in following sections.

**Swimming Electron Layer Effects**

The theory for nuclear reactions with high concentration deuterium in palladium or similar host metals needs to be viewed in light of a few key experimental facts [30] before more details may be explored, otherwise incorrect speculations may block the
steps towards the truth. We first must realize that the usual hot fusion reactions (D-T, He-3 up to p-B-11) are fundamentally different from the usual nuclear reactions.

The original discovery that the reactions of the very light nuclei occur at beam energies around and above 10 keV only was a significant discovery. This was in contrast to the usual beam energy of a MeV required in order to move the nuclei against the electrical Coulomb repulsion to distance of their diameter around femtometers (fm; $10^{-13}$ cm). One of the tools for these experiments were the multi-million-volt accelerators, e.g. that of Cockroft and Walton. Cockroft was sufficiently adventurous to use – against all the knowledge for applying many million volts – at what happens when only 100 to 200 kilovolts were used: there the light nuclei did react [31], e.g. protons with boron. It was then Oliphant’s gas discharge technique for 100 keV beams that provided the high currents necessary to obtain more precise results, e.g. the correct energy gain from the proton-boron reaction [32] as the prelude to the discovery of the fusion reactions[33, 34]. These reactions can be summarized as:
\[
\begin{aligned}
T + ^1H + 4.03 \text{ MeV (50\%)} \\
D + D = \begin{cases} 
\begin{aligned}
^3\text{He} + n + 3.27 \text{ MeV (50\%)} \\
D + ^3\text{He} = ^4\text{He} + ^1\text{H} + 18.3 \text{ MeV} \\
T + D = ^4\text{He} + n + 17.6 \text{ MeV}
\end{aligned}
\end{cases}
\end{aligned}
\]

(6a)  
(6b)  
(7a)  
(7b)

It has to be realized that these “hot fusion” reactions at 10 keV impact energy (corresponding to 100 million degrees temperatures) happen at distances about hundred times larger (!!) than the fm distances for all the usual nuclear reactions. This cannot be explained by a Gamow factor. The measurements of the involved fusion reaction cross sections are available now with very high accuracy. Nevertheless there has not been a theory for explaining them, apart from numerical fitting, e.g. with 5 parameters [35] or more. That does not represent physics but is only an empirical type solution. It was not before Li et al. [36] that a reasonable theory was developed using a Schrödinger potential with an imaginary part that the cross sections could be best reproduced using the input of two obvious parameters the resonance energy and the resonance width.

To understand cold fusion or LENR we assume that the deuterons (or hydrogen) in the palladium are behaving like a Maxwellian gas on the background of the degenerate electron gas between the ions. The Debye length for screening the deuterons is given

\[
\lambda_D = 743(T/n_d)^{1/2} \text{ cm},
\]

with the deuteron density \( n_d \) in #/cm\(^3\) and temperature in eV results in \(~3.8\) pm for room temperature and solid state density for deuterons taking into account their non-degenerate state. For the special case of a two-dimensional geometry of the metal surface, the Debye length is reduced by a factor \( 2^{-1/2} \) as known for surface plasmons against the usual plasmons. This means that the Coulomb field of the deuterons is neutralized at a radius of \(~2\) pm and the deuterons behave like neutral particles, e.g. like neutrons at such a distance.

Alternatively and independently to this fact, it was clarified [37] from very early cold fusion experiments [38] that this results in a Coulomb screening by a factor 14 – compared to a factor 5 which is well known in high temperature plasmas (see Ichimaru in Ref. [10]). Such screening results in a screening again in the range of 3 pm. From the measured reaction times and deuteron distances for hot fusion, from muon-catalysed fusion and the calculated fusion probability in a \( D_2 \) molecule, a reaction time in the range of kilo- to megaseconds for the 3 pm distance could be concluded to fit with reaction rates [38]. These times agree with the K-shell electron capture by nuclei for Bohr radii in
the pm range. The megasecond range then is a reasonable time scale for LENRs with palladium [3, 4].

With these facts in mind, we next consider a possible cluster generation mechanism in effort to explain the result of Fig. 6 in terms of a compound nucleus.

The screened deuterons are mutually repulsed by their Coulomb field at distances less than ~2 pm. However, due to their screening they move like neutral neutrons at larger distances. The attraction between the screened deuterons by the Casimir effect [39] is too small to significantly decrease this distance. But our calculation of the gravitational attraction for the deuteron masses at ~2 pm distance suggests compression to about ten times higher energy density than for thermal motion at room temperature. This is the reason that once a high initial deuteron concentration is achieved in the palladium, cluster formation occurs. Clusters of 100 deuterons have a size of ~10 pm and move within the electron clouds of the palladium around the palladium nuclei. Consequently few pm nuclear reactions between a cluster and a palladium nucleus can take place on the megasecond time scale. Under the assumption that the screened deuterons in the cluster form a Bose-Einstein state, the deuterons (as bosons) are non-distinguishable. Thus a reactive interaction, e.g. by the deuterons with palladium nuclei, becomes a collective process of the whole cluster. This then allows the formation of compound nuclei via a multi-body type reaction.

Since the clusters are tighter in two-dimensional geometry, they are expected to appear preferably near the surface of the swimming electron layers; i.e. at a few 100 pm thickness from the surface of palladium or at interfaces in multilayer systems (e.g. in layered Pd-Ni thin film electrodes) due to the difference of the electron Fermi-Dirac energy between the metals. The swimming electron layer is an extension of the Debye layer for a plasma-material surface generalized to apply to the degenerate electron cloud at a metal surface [40]. This immediately explains the work function for electron emission from metals and explains the quantum theory of the surface tension of metals in agreement with measured values (versus “synthetic” theories of surface tension which can lead to unrealistic negative work function values [40]).

The tighter deuteron clusters within the swimming electron layers would explain why the low energy nuclear reactions LENR in multi-layers occur at higher rates than in bulk palladium electrodes [3, 4, 10]. This is consistent with the observation [10] that power levels exceeding a kW/cm³ in thin film multi-layered electrodes can occur during LENR experiments.

**Compound Nucleus Reactions**

Compound nucleus formation was proposed earlier to explain how the reactions of deuterium in palladium produce an array of nuclei [41]. Section 7 of Ref. [10] presents
examples for how a reaction of $^{101}$Nb and $^{106}$Pd can form $^{207}$Fr as an intermediary excited state. $^{207}$Fr then splits into $^{117}$In and $^{90}$Sr exothermally with an energy gain of 1.65 MeV. The same can be shown with the $^{238}$Am compound nucleus where the energy gains can be calculated for the accurately known masses of the nuclei involved.

It is important to remember the fact that the fission of the compound nuclei will result in a local maxima within the absolute minimum of the mass distribution curves as shown earlier in Figs. 1 and 2 for uranium fission. The question then is what compound nucleus is predicted by the mass distribution measurement shown earlier in Fig. 5 for these LENRs. The atomic half mass for the compound nucleus in this case is seen to be $A = 153$. Using the new magic numbers of Eq. (5), we expect a relatively stable very heavy nucleus as one with double magic numbers (similar to $^{208}$Pb with 82 and 126). The sequence and data suggest this to be:

$$\text{Compound nucleus} = ^{306}X_{126}. \quad (9)$$

This identification is supported also by the fact that the search for stable (or relatively stable) trans-uranium elements predicts an element number 126 [42]. The main support for our LENR case is indeed the data of Fig. 6 where the local maximum at $A = 153$ is indeed very significant for the identification. There is no question but that, if the compound nucleus (9) is produced for a very short time (less than $10^{-20}$ sec), it will be a very excited nucleus, similar to MeV excited consistent with a temperature for the compound nucleus in the MeV range.

There was earlier speculation [10] about which reactions could lead to the compound nucleus in (9). This may be possible based on the heuristic conclusion of the preceding section assuming large deuteron clusters form under preferred conditions in the swimming electron layer. The action of a cluster with 156 deuterons reacting collectively could lead to the generation of the compound nucleus in (9) by the following reaction:

$$^{108}\text{Pd}_{46} + 156 \text{D} = ^{306}X_{126} + 38 \text{He}_2 + E \quad (10)$$

Expressing the mass per nucleon $m_X$ by proton masses in X, we arrive at:

$$m_X = 1.004946 \text{ minus the related part going to E.} \quad (11)$$

This mass is not unexpected to be large due to the very low value $m_{Fe}=0.9988376$ compared to the value of $m_{U} = 1.0001868$ when splitting into $^{121}\text{Sb}$ with $m_{\text{Sb}} = 0.99824$. Comparable values would be for the splitting of the compound nucleus X into $^{153}\text{Eu}$ with $m_{\text{Eu}} 0.9988375$. The energy per nucleon in $^{306}X_{126}$ is 5.73 MeV minus the contribution going into the reaction energy $E$. 
The splitting of the compound nucleus leading to the yield curve around $A = 153$ in Fig. 5 can be represented by the following equation with varying integers $x$ and $y$, and a number $N$ of neutrons $n$:

$$^{306}X_{126} = ^{153+x+N}A_{63+y} + ^{153-x}B_{63-y} + Nn + E_{xy}.$$  \hspace{1cm} (12)

This implies that few or no neutrons will be emitted, and indeed to date none have been observed in the LENR experiments using reasonably sensitive neutron diagnostics. However, further detailed searches for neutrons are warranted. Also more studies such as the preliminary ones in [43,44] to examine the correlation of the reaction products and excess heat, i.e. $E_{xy}$, would provide further confirmation of this concept.

**Concluding comments**

In summary we have shown that the detailed reaction product data obtained from a certain class of LENR experiments employing thin film electrodes suggest LENR reactions can proceed through a compound nucleus to produce a distinctive array of products. This striking observation of a sharp maximum in the product yield superimposed on a broad minimum indicates formation of a double magic nucleus $^{306}X_{126}$. Such a reaction would require the collective interaction of a large number of H(D) nuclei with the host palladium, suggesting involvement of H(D) clusters. Localized cluster reactions have been suspected previously based on the observations of local hot spots and crater formations on electrode surfaces. More direct measurements indicating the formation of a cluster state come from studies of superconducting behaviour in dislocation loops formed in loaded palladium.

While further studies are needed to definitively tie these observations together with LENRs, they do form a basis for hypothesizing the cluster reactions which have been described here. Further experiments are needed to fully verify this theory, but it provides a provocative “road map” for future exploration.

Assuming the cluster concept is correct, two immediate key questions arise: Are clusters of this type involved in other cold fusion reactions beyond the specific type of LENRs studied here (i.e. do they create the NAE sought by Storms [20])? Is it possible to design experiments to enhance this effect? We must leave the first question for future study after more relevant experimental data is accumulated. However, a preliminary response to the second question can be offered. The initiation of clusters was achieved in the superconductivity experiments cited here by repeatedly loading and de-loading to create a large density of dislocation loops. In the transmutation experiments cited, thin films, sometimes with multi-layers, were used to create the initiating swimming electron layer regions. And, it would seem that the same interfaces giving these layers must have had a high density of dislocation loops. Thus it is reasonable to assume that a
combination of swimming electron layers and dislocation loops need to be created in order to trigger cluster formation. Along these lines, Miley suggested earlier the use of a special nanopore structure for the electrode [45]. Basically this electrode uses a micro-mesh nickel layer sandwiched between sputtered palladium films. The mesh-film interface is intended to create the simulated swimming electron layer – dislocation loop type conditions needed for cluster formation. This concept is currently under investigation.

References


Microscopic characterization of palladium electrodes for cold fusion experiments

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ABSTRACT

Recent results [1] highlighted that material science is one of the more critical issues in condensed matter nuclear science. In the last years, the experimental results have given a clear indication that a relevant role within this task is played by the material properties of the cathodes.

In order to improve the characterization of the materials, an approach based on the atomic force microscopy is proposed in this paper.

The preliminary study is mainly oriented to identify, by means of the AFM results, parameters suitable for screening the materials.

Introduction

The interaction of hydrogen with metal involves primarily the metallic surface. Therefore it is reasonably to assume that the surface morphology of the cathodes play a role in the metal-hydride formation. In fact, the hydrogen (deuterium) diffusion/adsorption mechanisms at the metal/electrolyte interface are primarily controlled by the surface activation energy and the effective surface area, which, in turn, strongly depend on the surface morphology.

Accurate images of the surface features can nowadays be obtained by different microscopic techniques. Between these, atomic force microscopy (AFM) is able to reproduce the surface topography in all three spatial dimensions.

However, microscopic analysis is limited to a very small area of the surface, which cannot be representative of the whole sample, mainly because of the random character of surface profiles.

Statistical analysis is usually applied in surface science to process AFM profiles, in order to extract information about the random or periodic properties of the surface, not just isolated features.

In this work, a preliminary study of the morphology of palladium cathodes is performed by AFM, mainly oriented to identify parameters suitable for a screening of the materials.
Experimental

Atomic force microscopy [2] is the profiling technique with the highest lateral resolution. Similar to a stylus-based profiler, the atomic force microscope contacts the surface by means of a probe tip mounted on a cantilever. While the tip scans the surface, the cantilever deflects or changes its mechanical vibration characteristics due to interaction with the surface peaks and valleys. A laser beam measures this deflection and feedback mechanisms drives the piezo-electric scanners to keep the tip-surface force constant, thus reproducing the surface topography. The very high lateral resolution (down to 1 Å) of AFM depends on the fact that the probe/surface interaction forces are much smaller than in any other stylus-based profiler (down to $10^{-11}$ N) due to the extreme sharpness of the tip.

The AFM instrument used in this work (Assing S.p.A., Perception, installed at the ENEA Lab at the research center in Frascati) is shown in Fig. 1. The head was equipped with triangular SiN probes (MLCTAU by Veeco). A detail of the tip is shown in Fig. 2. The tip worked in contact mode. The piezo-electric scanners have a maximum scale of 40 μm (in the x and y coordinates) and 5.3 μm (along the z axis, normal to the sample surface). The analyzed samples consisted of palladium sheets of about 50 μm thickness.

Fig. 1. Measuring unit of the AFM microscope Perception (by Assing).

Fig. 2. SiN probe - side angle 35°, tip height 3μm.
The images were taken at different points in each sample, but within the same crystal grain, in order to get average statistical information without losing the information about the presence of different crystal orientations in the sample.

For each sample zone, several images (see Fig. 3) have been acquired at different magnifications, the length scale ranging from 30 μm to 500 nm.

**Results and Discussion**

Typical AFM image numerical processing methods have been employed to describe the observed morphologies in terms of statistical function (power spectral density) and parameters (surface roughness, correlation length, fractal grain dimension).

The power spectral density (PSD) provides a decomposition of the surface profile into its component spatial wavelengths. For a periodic surface, the PSD function consists of only fundamental peak and harmonics; for a random surface, the PSD function occupies a range of spatial frequencies. In analysing the frequency characteristics of surface profiles, care must be taken in considering the frequency limits dictated by the instrument setup and the measurement parameters. The more important factors affecting the AFM frequency limits are the sampling distance and the profile length, determining respectively the high and low frequency cut-offs. The tip geometry can also affect the high frequency limit, but, in our case, the tighter limit is that defined by the sampling distance. In order to extend the pass-band of the measurements, for each sample point, the PSD curves have been computed from images taken at different sampling distance and scale length values, and then they have been merged together.

In order to extract numerical parameters able to characterize the surface morphology, the PSD curves can be fitted by different models. Non-engineered surfaces are typically well modeled by random processes, whose squared fluctuations are correlated on length scale shorter than the transverse correlation length (Lc), and have a mean value whose square is defined as the “root mean squared roughness (RMS). Actually, the RMS and Lc are not intrinsic properties of the surface, as according to the random model described above, but they depend on the length scale of the measurement. Such a scaling (self-affine) behavior of non-engineered surfaces is typically described by fractal statistics, by using an inverse power law function to fit the PSD curve. The power exponent (n) and coefficient (Kn) are intrinsic parameters of the surface; they do not depend on the measurement details and they are connected with the self-affine behavior of the surface.
In Fig. 4 the PSD curves computed from the AFM images of our samples are shown as a function of the spatial wavelength. Note that the AFM images shown in Fig. 3 are only a limited set of those used to compute the PSD spectra, and the frequency limits are not linked to the length scales shown here.

The PSD curves numerically retrieved from the digitized AFM images have been divided into two frequency ranges. In the low frequency range, the PSD curves have been well fitted by Gaussian functions, and the root mean squared roughness and the correlation length have been retrieved as best fit parameters and they have been reported in the first section of Table I. In the high frequency range, the PSD curves have been fitted by a power law function, and the power exponent and the coefficient have been derived as best fit parameters (see the second section of Table I).
Table I. Best fitting parameters retrieved by the PSD spectra of sample L25b, L40 and L35.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>L25B</th>
<th>L40</th>
<th>L35 rough</th>
<th>L35 smooth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gaussian Statistics</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>roughness (nm)</td>
<td>45</td>
<td>55</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>correlation length (μm)</td>
<td>0.73</td>
<td>3.32</td>
<td>0.81</td>
<td>3.12</td>
</tr>
<tr>
<td><strong>Fractal Statistics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fractal index</td>
<td>2.99</td>
<td>2.6</td>
<td>2.2</td>
<td>2.3</td>
</tr>
<tr>
<td>fractal coefficient</td>
<td>0.016</td>
<td>1.072e-5</td>
<td>2.71e-8</td>
<td>1.52e-8</td>
</tr>
</tbody>
</table>

Fig. 5. Deuterium loading curves of the cathodes during electrolysis. The deuterium concentration is deduced by the resistivity ratio of the loaded to the unloaded sample.

In the case of sample L35, the surface analysis has been performed on two different crystal grains (indicated in Figs. 3 and 4. and in Table I as “rough” and “smooth”), which were found in about equal amounts on sample surface.

The results from Table I have been compared with the deuterium loading capability of the investigated samples. Fig. 5 shows the resistivity of the samples during deuterium loading with electrolysis. To monitor the deuterium concentration dissolved into the samples, the resistivity values were measured in situ with the 4-probe Van der Paul technique, and they have nrrn normalized to the initial value of the unloaded cathodes. As can be seen from the graph, the characteristic drop in the resistivity versus time curve, which corresponds to a D-to-Pd ratio higher than 0.9, occurs after a short time in the case
of sample L25b and L40, but much later in the case of sample L35. The comparison of these results with those of table I suggest that, between the investigated surface morphology parameters, the roughness and the fractal index could correlate with the deuterium loading behaviour. Of course, this observation must be considered tentative, because of the limited statistics. Work is in progress to extend the analysis to a larger ensemble of samples and to look for possible correlations of the surface parameters with the heat production experiments.

Conclusions

A preliminary study of the surface topography has been performed on palladium cathodes by AFM. The profiles have been analyzed by using both conventional and self-affine statistics, each of them described by a limited set of parameters.

The preliminary results are indicative of a correlation between the hydrogen loading capability and the surface roughness.

Acknowledgments

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References

Gamma Emission Evaluation in Tungsten Irradiated By Low Energy Deuterium Ions

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ABSTRACT

An analysis of tungsten and tantalum foils before, during and after deuterium discharge with the gamma/x-ray spectrometry is described. An increase in light isotopes in tungsten cathodes during and after deuterium discharge was identified using gamma/x-ray spectrometry. The comparison of thermal ionization mass-spectrometry (TIMS) data and a series of energy peaks in gamma-spectra is evidence that the series of peaks observed in gamma spectra belong to the following isotopes:

\[ ^{169}_{70}Yb; ^{170}_{72}Hf; ^{171m}_{70}Yb; ^{172}_{72}Hf; ^{178}_{70}Yb; ^{180}_{72}Yb; ^{180m}_{72}Hf \].

Correlation of TIMS and Gamma spectrometry data lead to the assumption that the appearance of light isotopes in the tungsten was the effect of the initiation of the low energy decay process with deuterium discharge.

1. Introduction

Weak gamma-emission, short-term neutron bursts, neutron and gamma energy-spectra were measured. This data were published in the previous papers [1-2]. Neutrons with energy up to 17 MeV are detected. The intensity ratio of neutron groups (2.45 MeV / 14 MeV) shown the anomalous type of nuclear reaction [1-2]. X-ray film placed in contact with Pd, Ti and Ag were found to be blackened after irradiation with deuterium discharge [3-6]. Blackening of x-ray films placed inside and outside of the discharge chamber with stainless steel wall was observed [6]. In agreement with the radiography, radioactive isotopes corresponding to different energy levels were detected on Pd cathode after deuterium discharge: both high-energy and low-energy components [3].

A change in the level of uranium radioactivity after deuterium and hydrogen discharge was found [7-9]. The observed alpha emission increased by a factor of four after deuterium discharge for 500 hours, on both the irradiated and unirradiated sides. The increase of beta and gamma emission intensity was less than the alpha increase. The comparison of the intensity of energy peaks in gamma spectra allow to see that the intensity ratio (cps) of thorium and uranium in energy peaks was changed [10].
The appearance of increased light isotopes in tungsten and tantalum after exposure to deuterium glow discharge (DGD), measured using x-ray/gamma spectrometry are presented in this article.

2. Methods

2.1 Experimental method

Deuterium discharge was the experimental method. The experimental setup is shown in Fig. 1.

The x-ray/gamma-ray emission was measured with CdTe XR 100T detector (Amp tec). The energy peaks in x-ray/gamma spectra of W and Ta before, during and after irradiation in deuterium discharge was estimated. X-ray/gamma emission intensity for the different deuterium discharge parameters was analyzed in counts per second (cps). Gamma spectra during deuterium discharge were measured through a double quartz tube. The average intensity of x-ray and gamma ray was estimated as the total counts per time of spectrum recording. Figure 1 shows the location of the CdTe detector (it is the instrument marked “1”) during deuterium discharge measurements.

Figure 1. The gas glow discharge apparatus with CdTe detector.
2.2. Analytical Method

X-ray/gamma spectrometry was used as the analytical method. The distance between the Be window of detector and W foil during deuterium discharge was ~50 mm (6 mm thickness of double quartz tube + 3 mm layer of water cooling + 40 mm deuterium gas at ~5 Torr of pressure).

The tungsten foil was located in contact with Beryllium window on the distance ~1 mm during gamma/x-ray spectrometry after deuterium discharge exposure.

The analyzed foils had the diameter ~20 mm, and the ion-irradiated zone had a ~12 mm diameter.

2.2.1. Characterization of CdTe detector for the x-ray and gamma ray spectrometry

The XR-100T-CdTe is capable of detecting energies from a few keV to several hundred keV. This system has a thermoelectric cooler with feedback.

![Figure 2a. X-ray and gamma ray detector CdTe XR 100T detector (Amptec)](image)

The PX4 is a component in the complete signal processing chain of the nuclear instrumentation system. It replaces many different components in a traditional instrumentation system: the shaping amplifier, the multichannel analyzer, logic devices, high voltage power supplies, and several auxiliary components. The PX4 digitizes the preamplifier output, applies real-time digital processing to the signal, detects the peak amplitude (digitally), and bins this value in its histogramming memory, generating an energy spectrum.

The MultiChannel Analyzer (MCA) gives the number of events with the corresponding peak value.

The CdTe detector of 1 mm thickness has 100% efficiency from 8 keV to 60 keV.
Fluctuations are observed as rise time variations of the voltage step at the output of the charge sensitive preamplifier. As a result, the acquired spectra suffer from increase background counts and degraded energy resolution. Cooling the FET reduces its leakage current and increases the transconductance, which in turn reduce the electronic noise of the system.

The model XR-100T-CdTe is a new high performance X-Ray and gamma ray detector, preamplifier, and cooler system using a $3 \times 3 \times 1$ mm$^3$ Cadmium Telluride (CdTe) diode detector mounted on a thermoelectric cooler. Also, the input FET and feedback components to the Amptek A250 charge sensitive preamp are mounted on the cooler. The internal components are kept at approximately -30°C, and can be monitored by a temperature sensitive integrated circuit.

The calibration CdTe detector of soft radiation (diameter 9 mm and thickness 1 mm) was made. The efficiency of the CdTe detector is shown below in Fig. 2(b and c) and Table 1. An estimation of efficiency was made with Monte-Carlo calculation for isotropic source for case of the foils in contact with Beryllium window of CdTe detector in Fig.2c and Table 1.

![Figure 2b. Efficiency of CdTe detector with 250 micrometers thick of Be window.](image)

<table>
<thead>
<tr>
<th>E, keV</th>
<th>75</th>
<th>100</th>
<th>125</th>
<th>150</th>
<th>175</th>
<th>200</th>
<th>250</th>
<th>300</th>
<th>350</th>
<th>400</th>
<th>450</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eff %</td>
<td>48.06</td>
<td>42.0</td>
<td>33.12</td>
<td>25.87</td>
<td>20.08</td>
<td>15.8</td>
<td>9.55</td>
<td>6.0</td>
<td>4.43</td>
<td>3.2</td>
<td>2.34</td>
<td>2.0</td>
</tr>
</tbody>
</table>
2.3. Estimation of Gamma/ X-ray intensity.

An estimation of Gamma/ X-ray intensity as the value of energy peaks was performed. The value is measured in counts per second (cps).

3. Experimental results.

Gamma emission before, during and after Deuterium Discharge (DGD) experiments with W and Ta was measured.

Five series of the gamma emission measurements using gamma/x ray CdTe XR 100T detector were carried out:

1- During DGD experiments outside of double quartz walls;
2- After DGD experiments outside of double quartz walls;
3- W foils after DGD experiments, placed in contact with Be window of gamma/x ray CdTe detector on ~1 mm distance;
4- W foils before experiments
5- Background

It was shown that the gamma/x-ray spectra were reproducible under the same experimental conditions for short time intervals. A comparison of energy peaks in gamma
spectra of tungsten and tantalum after GDG showed repeatability of energy peaks in spectra of foils of various experiments during and after GDG experiments. A series of the main energy peaks of isotopes were found with mass-spectrometry and gamma-spectrometry data (See “Transmutation in Tungsten Irradiated by Low Energy Deuterium Ions” in these proceedings.). The peak values were estimated with two methods: gamma spectrometry data; and the gamma energy listed in a table of isotope decay data [11].

The intensity of gamma emission for the different experiments depended of exposure dose, current density and other experimental parameters.

More intensive energy peaks, reproduced in different experiments, were identified according to the table of isotope decay data [11].

Gamma spectra after experiment allowed us to surmise that gamma/X-ray emission continues after stopping the experiment.

X-ray and gamma-ray spectra for W and Ta during and after irradiation in the deuterium discharge with using Gamma/X-ray CdTe detector is presented in Figures 4 - 6.
Figure 4. Gamma spectra of tungsten after glow discharge.

Figure 4 includes the x-ray/gamma-ray spectra of W foil (#1817) after deuterium discharge (a and b) and c – the energy in keV.

- a. 16000sec after Deuterium Discharge; average rate ~0.195 cps;
- b. 12000sec after Deuterium Discharge; average rate ~0.217 cps (background’s intensity is 0.09±0.05 cps).

Figure 4 (a and b) illustrates the reproducibility of the main energy peaks for the different periods (12000 seconds and 16000 seconds). The energy and intensity of the
peaks have good reproducibility. The energy peaks of more intensive isotopes in different experiments were reproduced using gamma/x-ray CdTe detector and identified with using an Internet Table of Radioactive Isotopes [11].

a) Tungsten during deuterium discharge, – red square-zone with peak energy 63.8 keV, 20 000 seconds time recording, 10000 counts, average rate of counts ~0.5 cps

b) Tungsten after deuterium discharge (red square-zone) in contact 8251 sec, 773 counts, rate= 0.12 cps; main energy peaks ~50, 63.8 and ~73.6 keV

c) Unirradiated tungsten in contact with detector; blue spectrum - background; time recording – 20 000 sec., 2093 counts, rate= ~0.1cps; region of maximum energy ~125-215 keV
Figure 5. The spectra of x-ray/gamma emission of tungsten #1820 during deuterium discharge (a), after deuterium glow discharge (b) and unirradiated tungsten.

Examples of W foil spectra during of Deuterium discharge.

a)  
Figure 6 a. Time recording =2200 sec., counts = 389, intensity = 0.17 cps (background intensity = 0.09±0.05 cps)

b)
Figure 6a shows the first stage of deuterium bombardment without significant effects in intensity gamma emission (red zone). Figure 6b illustrates the interval from 4 keV to 200 keV of energy with energy peaks reproduced for the different time duration of recording (yellow and green contour).

The gamma/X-ray intensity of emission for the different spectra was analyzed. The maximums with high intensity of gamma emission are presented on Fig. 7. Peak time is 4.77(7) h in intensity (Table 4) and the peak intensity is 3.5 cps for an experiment lasting ~5.5 hours.

The intensity of gamma emission depended on experimental time, dose, current and other parameters. Gamma/x-ray emission continued after stopping the experiment.

3. Correlation of TIMS and Gamma spectrometry data

3.1. Comparison of main isotopes was observed using two different methods (mass spectrometry and Gamma spectrometry). The definition of the probable isotopes according to energy peaks in gamma/x-ray spectra and comparison with isotope mass peaks intensity in mass-spectra was performed.

Isotopes of lighter elements during and after exposure in deuterium discharge were selected using the block of energy peaks for each isotope (Table of Radioactive isotopes) and mass spectrometry data.

Table 2. ENERGY PEAKS FROM TUNGSTEN AND TANTALUM AFTER DEUTERIUM GLOW DISCHARGE IN THE GAMMA SPECTRA USING X - ray /Gamma CdTe DETECTOR (for the first group of isotopes)

<table>
<thead>
<tr>
<th>W</th>
<th>W</th>
<th>W</th>
<th>Ta</th>
<th>Isotope</th>
<th>Eγ keV</th>
<th>Half -life</th>
<th>Decay mode</th>
<th>Iγ(%)</th>
<th>Mass*; TIMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1817</td>
<td>1820</td>
<td>1818</td>
<td>1824</td>
<td>109Yb70</td>
<td>20,75</td>
<td>32d</td>
<td>ε</td>
<td>0,19</td>
<td>169</td>
</tr>
<tr>
<td>42±1</td>
<td>43</td>
<td>42</td>
<td>42,18</td>
<td>109Yb70</td>
<td>42,76</td>
<td>32d</td>
<td>ε</td>
<td>0,25</td>
<td>169</td>
</tr>
<tr>
<td>50±1</td>
<td>51,2</td>
<td>50,44</td>
<td>51</td>
<td>109Yb70</td>
<td>51,1</td>
<td>32d</td>
<td>ε</td>
<td>0,018</td>
<td>169</td>
</tr>
<tr>
<td>63±1</td>
<td>63</td>
<td>62,83</td>
<td>63,5±0,5</td>
<td>109Yb70</td>
<td>63,12</td>
<td>32d</td>
<td>ε</td>
<td>44,2</td>
<td>169</td>
</tr>
<tr>
<td>Peak</td>
<td>Mass</td>
<td>Abundance</td>
<td>Half-Life</td>
<td>IT (%)</td>
<td>Mass (amu)</td>
<td>19,1</td>
<td>19,06</td>
<td>19,1</td>
<td>19,39</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>-----------</td>
<td>-----------</td>
<td>--------</td>
<td>------------</td>
<td>------</td>
<td>-------</td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>19±1</td>
<td>19.89</td>
<td>19.06</td>
<td>19.1</td>
<td>19.39</td>
<td>5.25</td>
<td>IT</td>
<td>14.8</td>
<td>171</td>
<td></td>
</tr>
<tr>
<td>22.5±1</td>
<td>23.19</td>
<td>23.19</td>
<td>23.2</td>
<td>172 Hf</td>
<td>23.4</td>
<td>1.87 Y</td>
<td>ε</td>
<td>172</td>
<td></td>
</tr>
<tr>
<td>24±1</td>
<td>24</td>
<td>24.02</td>
<td>24.84</td>
<td>172 Hf</td>
<td>23.93</td>
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<td>172</td>
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<tr>
<td>60±1</td>
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<td>60.35</td>
<td>60.5±0.5</td>
<td>172 Hf</td>
<td>60.65</td>
<td>1.87 Y</td>
<td>ε</td>
<td>1.1</td>
<td>172</td>
</tr>
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<td>67±1</td>
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<td>62.35</td>
<td>67.5</td>
<td>172 Hf</td>
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<td>91±1</td>
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<td>172 Hf</td>
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<td>ε</td>
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<td>1.87 Y</td>
<td>ε</td>
<td>2.6</td>
<td>172</td>
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<td>172 Hf</td>
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<td>1.87 Y</td>
<td>ε</td>
<td>0.034</td>
<td>172</td>
<td></td>
</tr>
<tr>
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<td>119.8</td>
<td>172 Hf</td>
<td>119</td>
<td>1.87 Y</td>
<td>ε</td>
<td>1.46</td>
<td>172</td>
</tr>
<tr>
<td>129,03</td>
<td>129</td>
<td>127.25</td>
<td>127.5</td>
<td>172 Hf</td>
<td>127.9</td>
<td>1.87 Y</td>
<td>ε</td>
<td>6.7</td>
<td>178</td>
</tr>
<tr>
<td>42±1</td>
<td>43</td>
<td>42</td>
<td>42.18</td>
<td>178 Yb</td>
<td>42.4</td>
<td>74m</td>
<td>β-</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>13±1</td>
<td>14.1</td>
<td>14.1</td>
<td>13.3</td>
<td>180 Yb</td>
<td>13.9</td>
<td>2.4m</td>
<td>β-</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>57±1</td>
<td>58.7</td>
<td>57.05</td>
<td>57.88</td>
<td>180 Hf</td>
<td>57.555</td>
<td>5.5h</td>
<td>IT</td>
<td>48.0</td>
<td>180m</td>
</tr>
</tbody>
</table>

*Mass, measured with TIMS.

- Nine peaks corresponding to 172 Hf .
- The isotope with IT 99.7%, β-0.3% and T1/2=5.47 h was suggested as 180m Hf72, taking into account results from Table 4.
Table 3. PEAK ENERGY FROM TUNGSTEN AND TANTALUM AFTER DEUTERIUM GLOW DISCHARGE IN THE GAMMA SPECTRA USING X-ray /Gamma CdTe DETECTOR (for the second group of isotopes)

<table>
<thead>
<tr>
<th>W 1817</th>
<th>W 1820</th>
<th>W 1818</th>
<th>Ta 1824</th>
<th>Isotope</th>
<th>Isotope’s Eγ, keV</th>
<th>Half-life</th>
<th>Decay mode</th>
<th>I γ(%)</th>
<th>Mass**, TIMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>45±1</td>
<td>45,10</td>
<td>44,46</td>
<td>46,46</td>
<td>44,52</td>
<td>16,01 h</td>
<td>ε+β⁺</td>
<td>0,32</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>55,4</td>
<td>55,5</td>
<td>55,4</td>
<td>55,4</td>
<td>55,2</td>
<td>16,01 h</td>
<td>ε+β⁺</td>
<td>1,1</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>99,9</td>
<td>99,0</td>
<td>100,8</td>
<td>100,8</td>
<td>99,93</td>
<td>16,01h</td>
<td>ε+β⁺</td>
<td>2</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>113,2</td>
<td>113,3</td>
<td>113,2</td>
<td>113,2</td>
<td>113,9</td>
<td>16,01h</td>
<td>ε+β⁺</td>
<td>0,18</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>115,6</td>
<td>115,0</td>
<td>115,7</td>
<td>115,6</td>
<td>115,5</td>
<td>16,01h</td>
<td>ε+β⁺</td>
<td>0,2</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>133,0</td>
<td>132,0</td>
<td>132,2</td>
<td>132,7</td>
<td>132,2</td>
<td>16,01h</td>
<td>ε+β⁺</td>
<td>0,044</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>138,81</td>
<td>138,5</td>
<td>138,0</td>
<td>138,8</td>
<td>139,2</td>
<td>16,01h</td>
<td>ε+β⁺</td>
<td>0,018</td>
<td>170</td>
<td></td>
</tr>
</tbody>
</table>

- These gamma energy peaks were observed for different W and Ta foils. In other words, the same isotopes are created under different conditions at deuterium discharge and after the experiment was stopped.
- Contact* - foil after exposure at deuterium discharge was located in contact with the detector’s Be window during gamma spectrometry.
- ** Column 10 includes the mass measured with TIMS.
- Seven peaks corresponded to \( ^{170}_{72} Hf \).

Based on a comparison of these data, we suppose the gamma spectra peaks observed belong to the following isotopes: \( ^{169}_{70} Yb; ^{170}_{72} Hf; ^{171m}_{72} Yb; ^{172}_{72} Hf; ^{178}_{70} Yb; ^{180}_{70} Yb; ^{180m}_{72} Hf \).

We can see the same isotopes in Table 2 and Table 3, formed in W and Ta under the different experimental conditions after deuterium discharge.

Correlation of TIMS and Gamma spectrometry data leads to the assumption that the heavy isotopes decay under low energy impact.

Main isotopes Hf and Yb in different experiments with W and Ta foils for various time intervals were observed.
3.2. Estimation of Gamma/ X-ray emission intensity (value of energy peaks) and mass spectrometry data were performed

The maximum emission intensity was 3.5 cps after an experiment lasting ~5.5 hours. The intensity, estimated as integral counts of full duration of spectrum recording per second, designated as average intensity, was 0.5 cps. It is five times more than background. Background = 0.09±0.005 cps.

**Figure 7. The intensity of gamma emission in CPS vs. experimental time during Deuterium glow discharge.**

The majority of the isotopes were identified by the main energy peaks for X-ray and gamma-ray relating to masses, which were found by the peaks of intensity measured in counts per second (cps) (Fig. 7) and by mass-spectrometry analyses. Some repeatable measurements of peak time are included in Table 4.
Table 4. INTENSITY PEAKS VS. PEAK TIME IN GAMMA SPECTROMETRY MEASUREMENT

<table>
<thead>
<tr>
<th>1817 Cps</th>
<th>Peak Time after, min</th>
<th>1818 Cps</th>
<th>Peak Time after, min</th>
<th>1819 Cps</th>
<th>Time Peak after, min</th>
<th>1820 Cps</th>
<th>Peak Time after, min</th>
<th>Average peak time, min</th>
<th>Suggested Isotope (half life)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>2*</td>
<td>3*</td>
<td>4*</td>
<td>5*</td>
<td>6*</td>
<td>7*</td>
<td>8*</td>
<td>9**</td>
<td>10**</td>
</tr>
<tr>
<td></td>
<td>0.16</td>
<td>13</td>
<td>0.48</td>
<td>14.3</td>
<td>2.54</td>
<td>14.7</td>
<td>14.5±0.2</td>
<td></td>
<td>Ir (15m)</td>
</tr>
<tr>
<td>8</td>
<td>24.5</td>
<td>0.5</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.28</td>
<td>28</td>
<td>0.44</td>
<td>28</td>
<td>0.91</td>
<td>30</td>
<td>0.37</td>
<td>27.6</td>
<td>27.6</td>
<td>29±1</td>
</tr>
<tr>
<td>31.4</td>
<td>43</td>
<td>0.5</td>
<td>35</td>
<td>0.96</td>
<td>34.16</td>
<td></td>
<td></td>
<td>1.12</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>0.21</td>
<td>51.7</td>
<td>0.82</td>
<td>52</td>
<td></td>
<td>0.56</td>
<td>50</td>
<td>51±1</td>
<td>Lu (51.5m)</td>
</tr>
</tbody>
</table>

- *Column 1-8 – the measurements of gamma emission after deuterium discharge in contact of foil with detector (a ~10 minute pause after GDG ended was taken into account).
- ** Column 9-10 - the measurements of gamma emission for contact of detector with double quartz tube. It means that CdTe detector was on the ~50 mm distance from discharge zone during Deuterium Discharge and measurements were made through double quartz tube.
- Background was 0.09 ± 0.006 cps for the most measurements.
- The counts and time at seconds in Table 4 were written down by hand. It means that the intensity in cps and peak time could not be measured very exactly.

The isotopes that presumably caused the most intensive gamma emission, corresponding to maximums of gamma intensity in Fig. 7, are listed in column 12 of Tables 4 and 5.

Some time peaks with maximal intensity are presented in Table 5 for experiments with W foils.
Table 5

<table>
<thead>
<tr>
<th>Cps</th>
<th>Peak Time in Experiments</th>
<th>Suggested Isotope(half life)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>6.66 m</td>
<td>$^{172}<em>{74}W$ (6.6m); $^{168}</em>{71}Lu$ (6.7 m); $^{166}_{72}Hf$ (6.77m)</td>
</tr>
<tr>
<td>1.1</td>
<td>10.8 m</td>
<td>$^{189}<em>{74}W$ (10.7 m); $^{165}</em>{71}Lu$ (10.74 m)</td>
</tr>
<tr>
<td>0.5</td>
<td>61.5 m</td>
<td>$^{182}_{72}Hf$ (61.5m)</td>
</tr>
<tr>
<td>1.0</td>
<td>74 m</td>
<td>$^{178}_{70}Yb$ (74m)</td>
</tr>
<tr>
<td>0.3</td>
<td>2 h</td>
<td>$^{177}_{70}Yb$ (1.9 h)</td>
</tr>
<tr>
<td>0.6</td>
<td>4.8 h</td>
<td>$^{192}_{80}Hg$ (4.85h)</td>
</tr>
<tr>
<td>1.5</td>
<td>5.5 h</td>
<td>$^{180}_{72}Hf$ (5.5h)</td>
</tr>
<tr>
<td>0.2</td>
<td>21.6 h</td>
<td>$^{180}_{72}Os$ (22.1 h)</td>
</tr>
</tbody>
</table>

Mass defect, spin and parity were included for the following formula:

$$^{182}_{74}W + ^2_1D \rightarrow ^{178}_{72}Hf + ^{178}_{70}Yb + ^{12}_{5}B \sim +1.22MeB$$

$$-48(0+) +13(1+) = -49.7(0+) +13.37(1+) \sim 1.22 \text{ MeV}$$

Tungsten is supposed to be used in the first wall of a thermonuclear plasma reactor. Therefore researchers responsible for stability of the first wall should be aware of the formation of new groups of radioactive isotopes under irradiation by low-energy deuterium ions.

Conclusion

1. X-ray/gamma emission occurs during deuterium discharge experiments under 1000 ± 200 Voltage and after stopping of these experiments from the foils irradiated by deuterium ions.
2. The same isotopes are found from experiments under different conditions, and both during and after deuterium discharge.
3. The several x-ray and gamma of peaks and radiation intensity (cps) have been chosen for each prospective isotope $^{169}_{70}\text{Yb}$; $^{170}_{72}\text{Hf}$; $^{171m}_{70}\text{Yb}$; $^{172}_{72}\text{Hf}$; $^{178}_{70}\text{Yb}$; $^{180}_{70}\text{Yb}$; $^{180m}_{72}\text{Hf}$.

4. The comparison of thermoionization mass-spectrometry and x-ray/gamma emission data allowed us to suppose that the peaks observed in gamma spectra belong to the following isotopes: $^{169}_{70}\text{Yb}$; $^{170}_{72}\text{Hf}$; $^{171m}_{70}\text{Yb}$; $^{172}_{72}\text{Hf}$; $^{178}_{70}\text{Yb}$; $^{180}_{70}\text{Yb}$; $^{180m}_{72}\text{Hf}$.

5. Correlation of TIMS and Gamma spectrometry data leads to the assumption that the appearance of light isotopes in the tungsten and tantalum was the result (effect) of the stimulation (initiation) by low energy deuterium discharge.

6. The formation of new groups of radioactive isotopes under irradiation by low-energy ions of deuterium must be taken into account in order to estimate of operational properties of the first wall of a thermonuclear reactor.

Acknowledgments

The authors thank Dr. V. A. Starostin for the estimation of CdTe detector efficiency.

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11. WWW Table of Radioactive Isotopes. http://nucleardata.nuclear.lu.se/NuclearData/toi/Gamma.asp...
Transmutation in Tungsten Irradiated By Low Energy Deuterium Ions

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Federal State Unitary Enterprise Research Institute “Luch”

ABSTRACT

Analysis of tungsten and tantalum foils after deuterium discharge with the Thermal Ionization Mass Spectrometry (TIMS) method is described. Tungsten isotopes transmutation in elements lighter than tungsten was observed. Higher intensity of mass numbers 169, 170, 171, 178 and 180 was found. The mass spectra peak magnitudes for isotopes lighter than W increased by factors ranging from 5 to 400. The increase was from 5-50 cps in the original foils, to 100-20000 cps after deuterium discharge. Possible explanations for the reactions are suggested.

1. Introduction

In our previous papers [1-5] we described changing element and isotope structure in palladium and titanium. Weak gamma-emission, brief neutron bursts [6-7], changes of surface structure and of the elemental and isotopic composition of palladium cathode were observed. The increase in impurities in palladium, which were not detected in the original material, ranged from 0.5% to 5% (an increase of 100-10000 times).

Partial, local blackening of x-ray films placed in contact with Pd, Ti and Ag foils after irradiation by deuterium discharge was observed [3, 7, 8]. Local blackening of x-ray films placed both inside and outside of the discharge chamber stainless steel wall was observed [3, 9]. Based on the results of radiography analysis, the various energies of radioactive isotopes on the Pd cathode after deuterium discharge included high-energy and low-energy components [3]. Observed effects were explained by a fusion-fission reaction on the cathode; an interaction of a palladium lattice with deuterium and by the subsequent decay of more light elements. The majority of the elements found after deuterium discharge were in local zones (hot spots) [1, 2, 3, 8].

Groups of elements such as Sc, Ti, V; Ag, Cd, In; P, Cl, Br, Ge, As, Kr, Sr, Y, Ru, Xe were found in the Pd after an irradiation by ions of all types (D, H, Ar, Ar + Xe), but within various content. After irradiation in Ar, the impurity elements in the Pd samples increased by a factor of 2 or 3 with H bombardment, and by a factor or 10 with D bombardment [9].

Considerable changes in the isotope ratios for $^{10}$B/$^{11}$B; $^{12}$C/$^{13}$C; $^{60}$Ni/$^{61}$Ni/$^{62}$Ni; $^{40}$Ca/$^{44}$Ca and $^{90}$Zr/$^{91}$Zr were observed with different mass-spectrometry methods. See Ref. 6. Changes in the isotope ratios of $^{109}$Ag/$^{107}$Ag from the ratio of 1/1 in initial Pd up to 3/1 and 9/1 after gas discharge exposure was described in Refs. 5 and 9.
Changes in uranium alpha, beta and gamma emission after deuterium and hydrogen discharge was found for both sides of the uranium (the irradiated and un-irradiated sides) [10, 11].

Two series of experiments were performed. The first set produces immediate results. A W foil was analyzed with Thermal Ionization Mass Spectrometry (TIMS) in 15-minute intervals after deuterium discharge. In the second set of experiments W foils were analyzed with TIMS 3, 4 and 5 months after deuterium discharge.

Increases by factors ranging from 5 to 400 in the peak magnitudes for different isotopes with masses lighter than W were observed.

2. Methods

2.1. Experimental Method

Deuterium discharge was the experimental method. The experimental setup is shown in Fig. 1.

The glow discharge apparatus was made with double quartz tubes (as the wall of the discharge chamber) with cooling water between these quartz tubes.

The sequence of operations before discharge experiments was as follows: vacuum degassing to $10^{-3}$ Torr, followed by deuterium loading to between 3 and 10 Torr.
Molybdenum was used as the anode. Tungsten foil was placed on the cathode. The foil ~100 microns thick and ~20 mm in diameter. The anode and cathode were cooled by flowing water.

2.2. Analytical Method.
Thermal Ionization Mass Spectrometry (TIMS) was used to estimate isotope (ions) intensity, which is measured in counts per second (CPS).

2.2.1. Characterization of TIMS Analysis
The analysis was performed using MAT-262 and a mass spectrometer (Thermo Scientific, Finnigan TRITON). The most detailed analyses were performed in the range of mass numbers 166-206. The temperature between Re ionizer and analyzed foils was ~1800°C. The analyzed tungsten strip had the width ~ 1 mm, the length ~ 20 mm and the thickness ~100 microns. The strip was cut off from the central part of W or Ta foils, irradiated by deuterons. The analyzed zone included the unirradiated part of W foil as well as irradiated parts, which led to a reduced contribution by more light isotopes. The spectra of minimal intensity (CPS) were removed from the table of TIMS data. The data regarding to mass numbers 185 and 187 corresponding to rhenium (Re) isotopes were removed from the table data as well, because Re was used as the cathode. The cathode had two W foils layers. The side of the foil irradiated with deuterium ions was analyzed.

Figure 2 illustrates the TIMS spectra calibration on Re mass. An example of a precise definition of isotope mass is shown in the left spectrum, where we can see that 186.95 mass is $^{187}\text{Re}$ estimated very exactly. Peaks of $^{185}\text{Re}$ and of $^{187}\text{Re}$ isotopes are presented in the spectrum on the right.
CALIBRATION OF TIMS SPECTRA ON RHENIUM CATHODE

TIMS spectra measurements have good reproducibility. It should be noted that calibration on Re was performed before each investigation of new foil. The good reproducibility remained for short time intervals between scanned spectra.

The significant difference in isotopes intensity was found for the different conditions of experiments: especially, for dose of exposure and time interval after the experiment stopped. The confirmation of spectra reproducibility is presented on the Fig. 3.
Figure 3. TIMS spectra of the same W foil with time interval between scans of about 3 minutes.

In Fig. 3, the time interval between the right and left Spectra was ~3 minutes. It is possible to estimate that the intensity of main isotopes is closed for the both spectra. The main isotopes and their intensity are proportional to each other.
3. Experiments

As noted above, two series of experiments were performed: 15 minutes after irradiation, and 3, 4 and 5 months after experiments, both using TIMS. Both W and Ta samples were irradiated.

Tables 1 and 2 compare mass spectra data from the original unused W and W after deuterium bombardment. The main isotopes changes in the different experiments with W and Ta foils for various time intervals were investigated in detail for the mass range 166-210. An increase in isotopes with masses lighter than tungsten by factors ranging from 5 to 400 was found. The analysis temperature was ~1800°C.

A mass spectrum of original W in the 170-200 mass range is shown in Fig. 4. It shows the intensity ranged from 10 to 30 cps.

Figure 4. Mass spectra of original W in the 170-200 range of masses (CPS).
A mass spectrum of the W after deuterium discharge for the mass range of 170-182 for the same foil with two minutes intervals is shown in Fig. 5. Mass 172 is ~700 cps on the left spectrum, and mass 178 is ~20000 cps on the right spectrum. The intensity of these isotopes was 10 - 50 cps before experiments for similar scanning parameters. The increase of masses 172 and 178 intensity in the same tungsten foil was from 12 to 400 times, respectively.

Figure 5. Mass spectra of W #1820 through ~ 4 months after Deuterium discharge stop.
Figure 6. Ta before (left) and after (right) the Deuterium Discharge.

Tantalum before (left) and after (right) deuterium discharge are compared in Fig. 6. The intensity of mass 171 was ~50 cps before the experiment, and after the experiment it reached 19500 cps, increasing by a factor of ~390.
4. RESULTS

Table 1

INTENSITY OF THE MORE LIGHT ISOTOPES IN TUNGSTEN FOILS, IRRADIATED BY DEUTERIUM AND ANALYZED WITH THERMO-IONIZATION MASS-SPECTROMETRY (IN COUNTS PER SECOND - CPS )

*** Set 1

<table>
<thead>
<tr>
<th>Time, min*</th>
<th>84*</th>
<th>101*</th>
<th>137*</th>
<th>1062*</th>
<th>1073*</th>
<th>1133*</th>
<th>1150*</th>
<th>**Original W</th>
</tr>
</thead>
<tbody>
<tr>
<td>168</td>
<td>40</td>
<td>30</td>
<td>60</td>
<td>2000</td>
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<td>170</td>
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<td>171</td>
<td>60</td>
<td>95</td>
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<td>100</td>
<td>70</td>
<td>5 ±5</td>
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<td></td>
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<tr>
<td>172</td>
<td>70</td>
<td>100</td>
<td>100</td>
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<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>173</td>
<td>80</td>
<td>75</td>
<td>70</td>
<td>300</td>
<td>100</td>
<td>15 ±15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>174</td>
<td>30</td>
<td>55</td>
<td>60</td>
<td>200</td>
<td>100</td>
<td>5 ±5</td>
<td></td>
<td></td>
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<tr>
<td>175</td>
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<td>55</td>
<td>70</td>
<td>40</td>
<td>85</td>
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<tr>
<td>176</td>
<td>40</td>
<td>55</td>
<td>40</td>
<td>95</td>
<td>75</td>
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<td>10</td>
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<td>100</td>
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</tr>
<tr>
<td>181</td>
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<td>50</td>
<td>5 ±5</td>
<td></td>
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<tr>
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<tr>
<td>194</td>
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<td>65</td>
<td>0</td>
<td>10</td>
<td>10 ±10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*First line shows the time in minutes after experiment.
**Last column is intensity of isotopes in the original W.
***Set 1- The first analysis was carried out in 45 minutes after experiment stop. Farther the each analysis was fulfilled every 15 minutes during ~3 hours and then analysis was made in ~10 hours every 15 minutes during few hours.

Table 1 shows data from the first set of the experiments with W, showing that transmutation of heavier isotopes into lighter ones continues after the experiment is stopped. Increases from ~20 to ~200 times for different isotopes were found.
An analysis of tungsten foils irradiated with different doses of deuterium discharge performed 3, 4 and 5 months after irradiation is presented in Table 2.

**Table 2**

**INTENSITY OF THE MORE LIGHT ISOTOPES IN TUNGSTEN FOILS, IRRADIATED WITH DEUTERIUM AND ANALYZED BY THERMO-IONIZATION MASS- SPECTROMETRY (IN COUNTS PER SECOND - CPS )*** Set 2

<table>
<thead>
<tr>
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<th>#1820</th>
<th>#1821</th>
<th>Original</th>
</tr>
</thead>
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<td>16.03.07</td>
<td>20.03.07</td>
<td>21.04.07</td>
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<td>5</td>
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<td>200</td>
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<td>169</td>
<td>25</td>
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<td>475</td>
<td>500</td>
</tr>
<tr>
<td>170</td>
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</tr>
<tr>
<td>181</td>
<td>0</td>
<td>120</td>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>

Columns 2-5, 11 – results of analysis after 3 months after experiments.
Columns 6-8 – results of analysis after 4 months after experiments.
Columns 9-10 – results of analysis after 5 months after experiments.
Columns 12****- average CPS of isotopes in the original spectra for 3-5 analyzed tungsten foils during all months.
5. DISCUSSION

Mass spectroscopy results include the following:

- Tungsten transmutation of heavy isotopes into lighter elements after exposure to deuterium discharge was confirmed.
- The group of lighter isotopes with mass numbers 169, 170, 171, 178, 180 had high intensity after deuterium discharge soon after the experiment, and also 3, 4 and 5 months later.
- Isotopes with lighter masses (compared to W isotopes) continued forming for at least 3-5 months after the exposure to the deuterium discharge. The observed increase of different light isotopes was into 5 - 400 times (from 5-50 cps in the original W up to 100-20000 cps after experiments).
- Experiment with tantalum was carried out to strengthen understanding of the possible reaction. Tantalum was selected because it has only one stable isotope, with mass number 181. As can be seen in Figs. 6 and 7, the increase in intensity of only of one isotope with mass number 171, and a decrease in the single stable isotope of Ta was found.
The intensity increasing of mass 9 in Ta after deuterium discharge.

Figure 7 shows mass 9 in Ta before (left) and after (right) of the deuterium discharge. Mass 9 increased from 20 to 9500 cps, a factor of ~475.

This observation suggests the possibility of the following reactions:

\[ ^2D + ^{181}_{73}Ta \rightarrow ^{171}_{72}Hf + ^{10}_{2}He^* + 2n; \]

(1+) + (7/2+) → (7/2+) + (0+) + 2(1/2+) - spin, parity;
(+13 MeV) +(-48.44 MeV) → (-55.4 MeV) + (+48.8 MeV) + (+16.14 MeV) + 84.90 MeV;

\[ ^{10}_{2}He^* \rightarrow n + ^{9}_{2}He^* \]

(0+) → (1/2+) + (1/2-)
(+48.8 MeV) → (+8.07 MeV) + (40.94 MeV) + 0.7 MeV

\[ ^{9}_{2}He^* \rightarrow ^{9}_{3}Li^* \rightarrow ^{178}_{8}ms; \beta^-- \rightarrow ^{4}_{1}Be^9 \]
This is only one variant of the possible reaction. Nevertheless, an alternative hypothesis might better reflect the details of this complex process. The polynucleon theory of transmutation, suggested by John Fisher [13], may be applicable. It is necessary to pay more attention to the electro-magnetic excitation for stimulation of this process. We noted this early [9], and Peter Hagelstein published it in one of his papers [14]. The cluster decay and the neutrino and dineutrons participation in this process may also take place [15].

More research is called for. However this will require additional funding for new applications and new, detailed knowledge. Even though our research has been fruitful, a lack of funding has meant that we cannot produce detailed data, which means we cannot get more funding – a vicious circle.

Conclusion

1. The isotopes with masses 169, 170, 171, 178, 180, 181 (less than W and Ta isotopes) after deuterium glow discharge were found in W and Ta by TIMS.
2. The isotopic changes continue to occur at least 3 - 5 months after glow discharge exposure. The separate isotopes with masses less than W and Ta isotopes increased by factors ranging from 5 to 1000 times.
3. The comparison of mass spectra with gamma spectra points to the existence of the following isotopes: $^{169}_{70}Yb$; $^{170}_{72}Hf$; $^{171m}_{70}Yb$; $^{172}_{72}Hf$; $^{178}_{70}Yb$; $^{180}_{70}Yb$; $^{180m}_{72}Hf$.

References


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A Review of Experimental studies about Hydrogen over-loading within Palladium wires (H/Pd ≥ 1)

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ABSTRACT

Many hundreds of systematic tests have been performed at Frascati National Laboratories in order to achieve very high concentration of hydrogen (overloading) in palladium wires.

The electrodes (cathode in central position: Pd wires 50 or 100 μm thick and anode: Pt wires 0.5 mm thick) were placed in a coaxial geometry into a small cylindrical electrolytic cell.

A special study has been performed in order to optimise the electrolytic solution based on H₂O (400 cm³) + HCl (50 ÷ 200 μM) and small amounts (tenth of μM) of salts (carbonate or sulphates) of one of these alkaline and alkaline-earth metals: Li, Na, K, Ca or Sr. Very small amounts (hundreds of nM) of HgCl₂ has been added to the solution. The addition of Hg ions has been crucial to achieve very high and stable H/Pd overloading.

To increase the reproducibility of the over-loading a special loading protocol based on high/low (or OFF/ON) cathodic current cycles has been tested successfully.

The H/Pd loading ratios have been estimated by the on-line measurement of the normalised wire resistance (R/Ro).

The loading results are quite satisfactory: H/Pd ≥ 0.97 (R/Ro ≤ 1.30; input electrolytic current/voltage: 7V, 5mA) are typically reached and sometimes H/Pd ≥ 1 (R/Ro ≤ 1.15; input current/voltage: 11V, 2.5 mA) has also been achieved. The reproducibility of the results is quite satisfactory.

1. Introduction

Over the past ten years, a great deal of effort has been made by the LNF Group to achieve very high H/Pd loading ratios (overloading) by using electrolysis with Pd wires as cathodes in acid solutions extremely diluted with light/heavy water. Loading procedures have been optimized and very high H/Pd loading values (H/Pd ≥ 1) are been reached, using a very small quantity of Ca or Sr added to electrolytic solution [1,2,3].
Recently a systematic study has been performed to test alkaline elements (such as Li, K, Na or Ca, Sr) in composed salts (carbonate or sulphate) in relation to H/Pd overloading in our loading procedures.

The role of Hg in increasing overloading and achieving stable and reproducible loading has been shown in our previous papers. In this study we have tested the addition of Hg ions to electrolytes containing alkaline and alkaline-earth salts, elements which have produced the best loading results.

In all these tests only light water has been used for the electrolyte. We have already shown that when heavy water is used, the loading procedures capable of insuring high D/Pd ratios are different and considerably more complicated. [4]

2. Apparatus

The electrolytic cell is a glass beaker filled with about 400 cm$^3$ of an acid solution containing 2 ml of HCl at 10 μM/ml. The electrodes are thin, long wires (20 cm length) placed parallel 2 cm apart. The cathode is Pd, 50 μm diameter; the anode is Pt, 0.5 mm diameters. The Pd wire is composed by 2 equal parts (top and bottom) connected to 3 pickups. The cell is located into a thermostatic water bath set at room temperature (22°C). The cell, bath and room temperatures are continuously recorded (Fig. 1).

To obtain a reference value of H/Pd loading we use the normalised Pd resistance versus hydrogen (or deuterium) molar fraction of Pd (Fig. 2). The peak value is: H/Pd=0.75, R/Ro=1.78 (with hydrogen) and D/Pd=0.75, R/Ro=2.0 (with deuterium). In the published literature, the highest loading ratio obtained by the electrolytic is H(D)/Pd=0.95 at R/Ro=1.4 (1.6) [5,6,7,8].
3. Loading results

Table 1 shows a summary of all electrolysis tests performed changing the alkaline elements (Na, Li, K, Sr, Ca) and compounds (carbonate and sulphate) in the electrolysis solution. We see that the best loading results occur when Sr is used particularly in sulphate compound ($R/R_o = 1.2$, $H/Pd \simeq 0.97$). We observed that the thickness of the layer of strontium sulphate deposited on the Pd cathode surface is more difficult to control during electrolysis compared to strontium carbonate.

We developed a special procedure during electrolysis operating with electrolytic current in low/high (L/H) regime and switching on/off the power supply [9]. This procedure plays an important role to increase the loading. This is clear, even though we do not yet have full comprehension of the phenomena occurring onto the Pd surface.
Table 1. Systematic tests performed using alkaline elements (I and II group of periodic table)

<table>
<thead>
<tr>
<th>Electrolyte (NO-Hg)</th>
<th>CO₃</th>
<th>SO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O + HCl (50 μmol)</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Loading at R/Ro-peak:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(R/Ro=1.75, H/Pd=0.67)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ Na</td>
<td>Concentration: 20 mg Procedure: L/H current Result: R/Ro=1.6, H/Pd=0.9</td>
<td>----</td>
</tr>
<tr>
<td>+ Li</td>
<td>Concentration: 200 μmol Procedure: Low current Result: R/Ro=1.52, H/Pd=0.92</td>
<td>Concentration: 30 μmol Procedure: L/H current Result: R/Ro=1.40, H/Pd=0.94</td>
</tr>
<tr>
<td>+ K</td>
<td>Concentration: 25 mg Procedure: Low current Result: R/Ro=1.50, H/Pd=0.92</td>
<td>Concentration: 10 mg Procedure: L/H/L Result: R/Ro=1.43, H/Pd=0.94</td>
</tr>
<tr>
<td>+ Sr</td>
<td>Concentration: powder (saturation) Procedure: L/H/L current Result: R/Ro=1.30, H/Pd=0.96</td>
<td>Concentration: powder (saturation) Procedure: L/H current Result: R/Ro=1.20, H/Pd=0.97</td>
</tr>
<tr>
<td>+ Ca (OLD TEST)</td>
<td>Concentration: 70 μmol Procedure: Middle current Result: R/Ro=1.30, H/Pd=0.96</td>
<td>----</td>
</tr>
</tbody>
</table>

In Fig. 3 and Fig. 4, R/Ro versus time is shown for the over-loadings using Sr in carbonate and sulphate compounds. The role played by L/H procedure to reach the overloading in the case of SrSO₄ should be noted (Fig. 4b).
Figure 3. Loading with SrCO₃, and L/H current procedure implementation.

The effectiveness of Hg ions in achieving stable and reproducible over-loading is shown in Fig. 5 (HgCl₂ + SrCO₃) and Fig. 6 (HgCl₂ + SrSO₄). In Fig. 5, Hg²⁺ is added in very low amounts, about of 3×10⁻⁷ Moles. In Fig. 6, relating to the sulphate, we added a little more HgCl₂ (5×10⁻⁷ Moles) and slightly higher over-loading was achieved. We have to take into account that the addition of larger amounts of Hg ions tends to produce a thicker deposit on the Pd surface, which has the effect of blocking the diffusion of hydrogen into the Pd bulk.
It is known that the solubility of the alkaline earth carbonates, because of the weakness of the carbonic acid, strongly increases by increasing the acidity of the solution. Whereas the solubility of the corresponding sulphates is only slightly dependent on the pH value.

During electrolysis, the region around the cathode is more alkaline than the rest of the solution.
For this reason, calcium or strontium carbonates, completely dissolved in the electrolyte, can precipitate in the form of a thin layer. This only happens on the cathode surface. In order to produce a proper thin layer on the cathode surface when calcium or strontium sulphate are used, it is necessary to add just enough of these salts to the electrolyte obtain an almost-saturated solution. Because of the increase of pH in the cathode region, it is possible to obtain the proper thickness of the salts layer on the cathode surface.

In case of inadequate thickness of the layer on the cathode surface it is possible to make the following corrections:

<table>
<thead>
<tr>
<th>Too high solubility (very thin deposit)</th>
<th>Too low solubility (very thick deposit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High current needed</td>
<td>Low current needed</td>
</tr>
<tr>
<td>Alkaline solution needed</td>
<td>Acid solution needed</td>
</tr>
</tbody>
</table>

Conclusions

In order to achieve overloading, very dilute electrolytes should be used. The addition to the electrolyte of very small amounts of carbonate and/or sulphates of Ca and Sr, together with extremely small amounts of Hg ions, is strongly effective. The thickness, structure and composition of the thin layer of precipitated salts on the cathode surface, which seems to be the main factor causing the overloading, has to be analysed in more detail.

Further studies are in progress to optimise the composition of the electrolyte, in particular when heavy water is used.

References

Radiation Produced By Glow Discharge in Deuterium
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KivaLabs, LLC

ABSTRACT

Radiation produced by low-voltage discharge in a gas containing deuterium was measured using a Geiger counter located within the apparatus. This radiation was found to consist of energetic particles that were produced only when the voltage was above a critical value. In addition, the emission was very sensitive to the presence of oxygen in the gas. In the presence of the required conditions, emission occurred reliably with reaction rates in excess of $10^8$ events/second.

I. INTRODUCTION

Evidence for the LENR effect was and still is based to a large extent on production of anomalous energy. Many of the observations imply nuclear reaction rates in excess of $10^{12}$ events/sec. In addition, the presence of detectable helium, tritium, and transmutation products show that nuclear products are, in fact, produced. Absence of expected conventional radiation, consisting of neutrons and gamma, has long since been acknowledged. Nevertheless, such a high reaction rate is expected to produce detectable X-ray emission even if the primary radiation cannot penetrate the surrounding wall. Failure in the past to detect any kind of radiation has led some theoreticians to propose a direct coupling of energy to the lattice, without need for emission of radiation or energetic particles of any kind.

With increasing frequency, as proper detectors are used, researchers are observing several types of radiation, as summarized in a recent book [1]. These emissions consist of X-ray, gamma ray, and various charged particles. Although the intensity of these emissions cannot explain the high levels of heat observed during some experiments, the mere existence of such energetic radiation raises important questions, such as the following.

1. Does the detected radiation result from one nuclear reaction or do several energetic processes occur at the same time?
2. Is any of the energy generated by these nuclear reactions coupled to the lattice? If so, why is the energy associated with the detected emissions not coupled?
3. Does the primary nuclear reaction produce the reported X-radiation or does it result when emitted energetic particles are absorbed by the surrounding material?
This study was initiated in an attempt to answer these questions using low-voltage gas discharge in low-pressure deuterium containing gas. A Geiger-Müller (GM) detector and a silicon barrier detector were located within the apparatus near the discharge. In the process, very energetic electron and particle emission were detected and characterized. These emissions occur at very high intensity and occur reliably within the appropriate voltage, current, pressure, and gas composition. This work is preliminary and is presented only to demonstrate that such radiation can be produced without making claims about its source or the mechanism of its production.

II. EXPERIMENTAL

The apparatus is shown in Fig 1. A turbomolecular pump is located below the table on which the apparatus is supported. This pump can produce a vacuum of less than $10^{-6}$ Torr in the discharge cell prior to adding deuterium-containing gas. Gas pressure within the cell during discharge is measured by Baratron gauges (0-10 and 0-100 Torr) located at the rear. To the left of the cell are connections for the GM detector, which has an end-window of mica (1.7-2.2 mg/cm², LND 712). To the right are connections to the water-cooled cathode, which is grounded to the apparatus. Connection to the anode is made out of sight at the rear of the cell. A residual gas analyzer (RGA) is provided to allow gas in the discharge chamber to be analyzed up to mass/charge of 50. Figure 2 shows the anode, which is a 2 mm diameter palladium wire and the cathode, which is surrounded by an insulating shroud. This arrangement allows the radiation detector, located at the left, a clear view of the cathode surface, as can be seen in the cathode-eye view in Fig. 3. The cathode is a thin metal disc directly cooled by flowing water, a design that allows the cathode surface to be easily examined. Details of cathode assembly are shown in Fig. 4. This design can dissipate power in excess of 300 watts, permitting a wide range of current and voltage to be used. A collection of absorbers of different thickness can be placed between the cathode and detector to allow the energy and type of the radiation to be determined. These are moved by magnets from outside the vacuum, as shown in Fig. 5.
FIGURE 1. Overall view of the apparatus.

FIGURE 2. View of anode (left) and cathode (right).

FIGURE 3. Cathode-eye view of the GM radiation detector. One of the copper absorbers is seen on the left. The anode is one of several designs using 2 mm wire covered by a glass insulator. The large tube from which it emerges is a glass-filled insulator.

FIGURE 4. Exploded view of the cathode showing the insulating shroud. The cathode disc can be removed and is sealed using a rubber O-ring.
Discharge is produced using a power supply rated at 1.5 A and 2000 V running under current control. Voltage is supplied to the anode through a forced-air cooled resistor of 300 ohm. The supplied current and the voltage at the anode are measured and stored approximately every 6 to 60 sec. Although calorimetry could be done using this apparatus, none was attempted during this study.

A Geiger counter alone or combined with a silicon barrier detector was used to measure radiation. During the first part of the study, the amount of radiation was proportional to a voltage produced by the GM counting circuit that averaged the count rate. A maximum count rate of approximately 5000 counts/sec on scale 10 was limited by the circuit becoming saturated. Later, the count rate was measured directly by counting individual pulses produced by the GM tube, which permitted much greater values to be determined. This design allowed particle production rates in excess of $10^6$/sec to be measured, a limit that was imposed only by unwanted electrical discharge to the body of the cell. The energy and type of radiation was determined by placing absorbers of varying thickness between the GM tube and the discharge. Later in the study, the output of the Si barrier detector, shown in Fig. 6, allowed the energy of radiation to be determined directly.

**FIGURE 5.** View of the mechanism used to move absorbers of varying thickness in front of the GM tube with magnets. Each assembly has two different thickness and an open position, which allows 8 combinations of thickness. The GM tube can be seen on the left.

**FIGURE 6.** Si barrier detector (Ortec TB-016-050-1000) and GM tube (2.2-2.6 mg/cm$^2$).
Energetic electrons and charged particles, having several energies, were detected. As yet, these charged particles have not been sorted into proton, triton, or alpha, although the energetic electrons have been clearly identified. Which of these emissions, if any, is produced depends critically on small impurities in the deuterium gas and the nature of the glow discharge including its voltage and current.

Before discussing the observed radiation, understanding the nature of a glow discharge is necessary. A discharge consists of three parts: the cathode bright zone, the dark zone, and the anode bright zone. The bright zones occur where sufficient energy is available to cause ionization as electrons move from the cathode to the anode. In this study, the cathode bright zone grows in thickness as applied voltage is increased until it engulfs the anode. Ions created in the bright zones bombard the cathode causing changes in the cathode surface. The resulting sputtering of cathode material causes growth of cones, shown in Fig. 7. As a result, thickness of the cathode increases while its weight decreases. Consequently, material is being lost from regions between the cones while it is deposited on their tops. In addition, any material sputtered from the shroud also deposits on the tops, as indicated by the dark regions seen in Fig. 7. Shroud materials consisting of Al$_2$O$_3$, BN, mica-based ceramic, or Teflon were used. All except Teflon worked well. Teflon caused the electron radiation to decay away over about 10 minutes during glow-discharge when it was used with a previously active cathode. When sufficient oxygen is present in the gas in any chemical form, detectable oxide also forms in these regions. The cones are proposed to be the radiation source.

During the first part of the study, only D$_2$ at a pressure of about 30 Torr was used in the cell to generate the radiation described below. Subsequent work suggested that the presence of a small amount of carbon-containing impurity in the gas was required for success. Too much hydrocarbon in the gas impedes the discharge as carbon is deposited on the cathode surface. On the other hand, a system that is too clean will not produce energetic electrons having an energy described here. Once the discharge become stable and uniform over the cathode surface, the relationship shown in Fig. 8 is obtained. Although variations in this behavior are seen, in all cases this radiation is sensitive to applied current but not to cell voltage. Little change in behavior was found when copper, copper plated with palladium, palladium, Sterling silver, or a Pd+Pt alloy are used as the cathode for producing this type of radiation. The anode is a 2 mm diameter palladium wire in all cases. A distance of 6 mm to 10 mm between the anode and cathode was used, all of which successfully produced the effect.
A combination of copper foils of varying thickness were placed between the GM tube and the glow discharge using a cathode made from an alloy of Pd + Pt, surrounded by a mica-based ceramic. The result is shown in Fig. 9. As absorber thickness is increased, the amount of radiation reaching the GM tube decreases. However, near the limit, the amount of radiation abruptly increases. This increase is caused by X-radiation, generated by the absorption process (Bremsstrahlung), adding to the remaining electron radiation. Above the limit, only X-radiation remains, which is slowly reduced as thickness is increased. This limit shows that the electrons have nearly a single energy of 0.8±0.1 MeV based on the equation given by Katz and Penfold.[2] Because these electrons are monoenergetic, they do not result from beta decay. Also, when cell current is stopped, the reaction stops abruptly without an apparent decay.

When oxygen containing gas, such as O₂, D₂O, or H₂O is added to the D₂, a different kind of emission is produced. This radiation is completely stopped by an absorber having 1.74 mg/cm² added to the absorption produced by the GM counter window of 2.0 mg/cm² for a total of ~3.74 mg/cm². The radiation could be protons with an energy of at least 0.7 MeV but less than about 1.2 MeV or alphas with an energy of at least 2.9 MeV but less than 4.7 MeV. The low value of this range is required for the particle to pass through the window of the GM tube and a particle having the upper value is stopped by the sum of
the window and absorber. Onset of this emission was very sensitive to applied voltage, with a critical voltage below which no radiation was detected. In addition, this behavior was altered by changing the D/O ratio in the gas. Least squares lines drawn through the data were used to obtain values for the slope and the critical voltage at which no radiation was detected. Examples of these effects are shown in Fig. 10 where various isotopes of oxygen are used as the source of oxygen. The effect is not sensitive to the isotopic composition of oxygen. When all measurements are compared, the maximum effect is found to occur when the D/O ratio in the gas is near 0.1, as shown in Fig. 11. In other words, once voltage is increased above the critical value, the voltage has a maximum effect on emission when about 10 atoms of O are present for each atom of D in the gas. When oxygen is added in the form of H$_2$O, the behavior is the same as when D$_2$O or O$_2$ are used. This effect only applies to relatively low emission rates. When the system was designed to measure higher rates and greater voltage was applied, the emission rate is found to increase in a nonlinear way, as shown in Fig. 12, but with the expected effect of increased oxygen.

**FIGURE 9.** Effect of copper absorbers on the amount of radiation reaching the GM tube from a Pd+Pt cathode.

**FIGURE 10.** Effect of voltage on emission at various D/O atom ratios and with various isotopic compositions of oxygen.
The GM tube is stated by the supplier to have a window with an area density of 1.5-2.0 mg/cm². Because this window limits the energy of detected radiation, its value must be known more accurately. For this measurement, a Po²¹⁰ alpha source was moved at various distances from the tube in air and the distance at which no counts were detected was determined. Counts stopped between 2.42 mg/cm² and 2.91 mg/cm², based on the density of laboratory air. The range of the 5.30 MeV alpha in air is 4.57 mg/cm². Consequently, the thickness of the GM window is equivalent to 1.7 mg/cm² to 2.2 mg/cm². A value of 2.0 mg/cm² was used to calculate the absorption characteristics of the GM counter using published values.[3]

IV. CONCLUSION

Energetic emissions are produced during gas discharge that cannot be detected outside of the apparatus. Nevertheless, their energy is so large that they can only result from nuclear reactions. If conditions are appropriate, the emissions are easily reproduced and imply a reaction rate at the cathode in excess of 10⁹ reactions/sec, limited only by the design of the apparatus. Consequently, these energetic emissions are completely anomalous, are produced at high rates that can be increased to the rates associated with anomalous heat production, and are not difficult to generate. The observations show that energetic electrons make up part of this emission and energetic particles that might be
protons and/or alpha particles add to the radiation, depending on the chemical composition of the cathode and gas. The type of radiation, its energy, and the rate are all sensitive to the presence of certain elements in the environment.

This work indicates that when nuclear reactions are generated at the cathode surface using glow discharge, the energy is not coupled to the lattice, but appears as very energetic charged particles. Because the particles cannot escape most apparatus and their presence can only be discovered when certain kinds of detectors are used, their presence has not been detected before at the rates generated in this study.

If these observations apply to LENR in general, the chemical composition of the environment in which the nuclear reactions are initiated would play a significant role in permitting nuclear reactions to take place and would determine the resulting nuclear products.

References

D-Cluster Dynamics and Fusion Rate by Langevin Equation

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ABSTRACT

Condensed matter nuclear effect, especially 4D-cluster fusion, in metal-deuterium complex systems, has been studied by applying Langevin equations.

One dimensional Langevin equations for solving time-dependent d-d distance $R_{dd}(t)$ for deuteron-clusters under the Platonic symmetry were formulated for D-atom, D$_2$ molecule, D$_2^+$ ion, D$_3^+$ ion, 4D/TSC and 6D/$^2$/OSC. Established values of ground state d-d distances $R_{gs}$ were reproduced by expectation-value equations, which were obtained by ensemble averaging with weight of quantum mechanical wave functions (Gaussian wave functions), for D-atom, D$_2$, D$_2^+$, and D$_3^+$ molecule.

In analogy to the above Langevin equations, the Langevin equation for 4D/TSC under the tetrahedral double Platonic symmetry was derived and numerically solved by the Verlet time-step method. It was shown that only 4D/TSC among 5 D-systems except D-atom could condense ultimately from $R_{dd}(t=0)=74$ pm to very small charge neutral entity with about 20 fm radius at TSC-min state after about 1.4 fs condensation time. The 6D/$^2$/OSC system converged at $R_{gs}=$about 40 pm, namely converged on the way of condensation from $R_{dd}(t=0)=74$ pm.

Time-dependent Coulomb barrier penetration probabilities (barrier factors) for condensing 4D/TSC were calculated by the Heavy Mass Electronic Quasi-Particle Expansion Method (HMEQPET). 4D fusion rate per TSC generation was obtained based on the Fermi’s first golden rule to result in almost 100% 4D fusion reaction per 4D/TSC generation. Fusion rates were compared with those of muonic dd molecule, D$_2$ molecule and dde*(2,2) Cooper pair molecule to meet good consistency. Major nuclear products of 4D fusion are two 23.8 MeV $\alpha$-particles. 4H/TSC should condense in the same way until when TSC-min state with classical electron radius (2.8 fm) comes, but no strong interaction exists among protons and will make 1p to 4p capture transmutations with host metal nuclei when 4H/TSC has sufficient drift (CMS) momentum.

Keywords: D-cluster fusion, dynamics, condensation, 4D/TSC, D-molecules, Langevin equation, barrier factors, 4D fusion, helium-4
1. Introduction

To explain apparent hard-radiation-less excess heat with helium-4 ash in CMNS (condensed matter nuclear science) experiments, especially in dynamic PdDx systems, we have done a long series of study for modeling D-cluster (or multi-body deuteron) fusion reaction mechanisms to reach at our latest theory based on Langevin equations\(^1\)\(^2\).

This paper describes the basics of formulation of Langevin equations for D-cluster dynamics, especially for D-atom, D\(_2\) molecule, D\(_2^+\) ion, D\(_3^+\) ion, 4D/TSC (tetrahedral symmetric condensate) and 6D\(^2\)/OSC (octahedral symmetric condensate).

First one-dimensional Langevin equations for D-clusters with the R\(_{dd}\) d-d distance are formulated under the Platonic symmetry\(^1\)\(^3\) of multi-particle D-cluster systems with deuterons and quantum-mechanical electron centers. Under the orthogonally coupled Platonic symmetry for a Platonic deuteron-system and a Platonic electron system, dynamic equations for so-many-body system of deuterons and electrons with metal atoms (more than 4 deuterons plus 4 1s electrons of deuterium atoms plus 40 4d-shell electrons of 4 Pd atoms in fcc lattice plus surrounding lattice atoms under D-phonon excited states should be considered in our modeling\(^7\)), a simple one-dimensional Langevin equation for the inter-nuclear d-d distance R\(_{dd}\) can be formulated, as we will show in this paper. By the ensemble averaging of one-dimensional Langevin equation with the weight of quantum mechanical wave-functions for electrons and deuterons, we can further derive a time dependent equation for expectation value \(<R_{dd}>\), which is nonlinear, but can be solved by the Verlet time step method\(^2\). We show in this paper that only 4D(orH)/TSC can condense ultimately to be finally very small charge neutral entity with about 10-20 fm radius. At the final stage of 4D/TSC condensation in about \(2 \times 10^{-20}\) s, 4D fusion with 2 \(^4\)He products takes place with almost 100% probability, according to our HMEQPET calculation for barrier factors and fusion rate formula by the Fermi’s first golden rule\(^2\).

In the next section, we show the derivation of Langevin equations for known systems as D-atom, D\(_2\) molecule, D\(_2^+\) ion, and D\(_3^+\) ion. This procedure gives the basics for formulating Langevin equations of complex D-cluster systems as 4D/TSC and 6D/OSC. In analogy, we apply the methodology and derive Langevin equations for 4D/TSC and 6D/OSC condensation motions in the following section.

2. Langevin Equations for Known D-Systems

2.1. Langevin equation in general

The Langevin equation is useful to treat dynamic motion of particles under friction (or constraint) and random fluctuation of force-field.
\[ m \frac{d^2 R}{dt^2} = -F_c - \zeta \frac{dR}{dt} + f'(t) \]  

(1)

Here \( m \) is the particle mass, \( R \) is particle position, \( F_c \) is the Coulombic force, \( \zeta \) is the coefficient for friction (or constraint) and \( f'(t) \) is the randomly fluctuated force term (white noise), for our deuterons plus electrons system.

2.2. Langevin equation for D-atom

In Fig. 1, simple quantum mechanical image of D-atom is drawn. In the view of Platonic symmetry, D-atom is the orthogonal coupling of central point (deuteron) and sphere (electron-wave). The Langevin equation is given as balance of the centripetal force of Coulombic attraction between plus-charged deuteron and minus-charged electron and the centrifugal force of electron rotation around central point (deuteron);

\[ m_e \frac{d^2 R_{de}}{dt^2} = -\frac{e^2}{[R_{de}]^2} + \frac{m_e v_e^2}{R_{de}} + f(t) \]  

(2)

Here, \( m_e \) is the electron mass, \( R_{de} \) is the d-e distance, \( e \) is the unit charge and \( v_e \) is

D-Atom: Point-Sphere Coupling

\[ \Psi_{100}(r) = \frac{1}{\sqrt{\pi a^3}} e^{-r/a} \]

\[ \int_0^\infty (\Psi_{100}(r))^2 4\pi r^2 dr = \int_0^\infty 4\pi (r\Psi(r))^2 dr = 1 \]

Peak at \( R_{de} = a = R_B \) (52.9 pm)

Electron Weight Peak Localizes at
\[ R_{de} = a = R_B = 52.9 \text{ pm} \]

Figure. 1. Quantum mechanical image of D-atom
the electron velocity. We have no friction in this case. By taking ensemble average of Eq. (2) with the weight of squared 1-s wave function $\Psi_{100}^2$, we obtain,

$$m_e \frac{d^2\langle R_{de}\rangle}{dt^2} = -\left(\frac{e^2}{R_{de}^2}\right) + \left(\frac{m_e v_e^2}{R_{de}}\right) = 0$$  \hspace{1cm} (3)$$

The right side becomes zero, because of the average kinetic energy

$$\langle E_{KE}\rangle = \frac{1}{2} m_e \langle v_e^2 \rangle = \frac{e^2}{2R_B} = 13.6 eV$$

and the average Coulomb energy

$$\langle E_C \rangle = -\frac{e^2}{R_B} = -27.2 eV$$

as well known for hydrogen (or deuterium) atom.

We can integrate Eq. (3) over time to get,

$$m_e \frac{d\langle R_{de}\rangle}{dt} = F(T) = \int_0^T f(t) dt = \langle f(t) \rangle$$  \hspace{1cm} (4)$$

The time-average (integral) of random fluctuation $f(t)$ is equal to the ensemble average $<f(t)>$ due to the ergodic process. We integrate Eq. (4) to obtain the well known result as,

$$\langle R_{de}\rangle(t) = R_0 = R_B = 52.9 pm$$  \hspace{1cm} (5)$$

Namely, expectation value $\langle R_{de}>$ of radial electron orbit is constant to be Bohr radius $R_B = 52.9 \text{ pm}$.

2.3. Quantum Mechanical Ensemble Average for D-Cluster

Since both positions of electrons and deuterons fluctuate quantum mechanically for D-cluster systems, we need to average with both weights of wave functions for electrons and deuterons. Applying the Born-Oppenheimer (adiabatic) approximation for total wave function, we can make step-wise averaging for electron-waves and then for deuteron-waves. The adiabatic wave function for D$_2$ molecule is;

$$\Psi(R_{dd}; r_{A1}, r_{A2}, r_{B1}, r_{B2}) = \Psi_{2D} \cdot X(R_{dd})$$  \hspace{1cm} (6)$$

The electron wave function of D$_2$ molecule is given$^4$ by,

$$\Psi_{2D} = \frac{1}{\sqrt{(2 + 2\Delta)}}[\Psi_{100}(r_{A1})\Psi_{100}(r_{B2}) + \Psi_{100}(r_{A2})\Psi_{100}(r_{B1})]X_\delta (S1, S2)$$  \hspace{1cm} (7)$$
And the wave function for a d-d pair is approximated by the Gaussian wave function as, rewriting X with $\Psi$ and putting $R_{dd} = R$,

$$
\Psi(R, R') = \frac{1}{\sqrt{2\pi\sigma^2}} \exp(-((R'-R)^2/(2\sigma^2)))
$$

(8)

Quantum-mechanical ensemble average of observable G is given by,

$$
\langle G \rangle_{\text{ensemble}} = \langle \Psi | G | \Psi \rangle
$$

(9)

2.4. Langevin equation for D$_2$ molecule

Electron localization (weight distribution) of D$_2$ molecule is roughly understood by the normalization equation of wave function,

$$
(4\pi)^4 \int_0^\infty \int_0^\infty \int_0^\infty \Psi_{2D}^2(r_{A1}, r_{A2}, r_{B1}, r_{B2})r_{A1}^2 r_{A2}^2 r_{B1}^2 r_{B2}^2 dr_{A1} dr_{A2} dr_{B1} dr_{B2} = 1
$$

(10)

$$
\int_0^\infty \int_0^\infty \int_0^\infty \rho(r_{A1}, r_{A2}, r_{B1}, r_{B2}) dr_{A1} dr_{A2} dr_{B1} dr_{B2} = 1
$$

(11)

$$
\rho(r_{A1}, r_{A2}, r_{B1}, r_{B2}) = \frac{(4\pi)^4}{2 + 2\Delta} \left\{ r_{A1}^2 \Psi_{100}^2(r_{A1}) r_{B1}^2 \Psi_{100}^2(r_{B1}) f_{A1}^2 f_{B1}^2 + 2 r_{A1}^2 \Psi_{100}^2(r_{A1}) r_{A2}^2 \Psi_{100}^2(r_{A2}) r_{B1}^2 \Psi_{100}^2(r_{B1}) r_{B2}^2 \Psi_{100}^2(r_{B2}) f_{A1}^2 f_{A2}^2 f_{B1}^2 f_{B2}^2 \right\}
$$

(12)

Since $|r\Psi|^2$ is the element of particle density localization function, localized peaks appear at $r_{A1} = r_{A2} = r_{B1} = r_{B2} = a = R_B$ (52.9 pm); namely the drawn sphere with Bohr radius is a good measure of electron localization.
D<sub>2</sub> Molecule Electron Localization: 2/2

At \( r_{A1} = r_{B1} \) and \( r_{A2} = r_{B2} \):

\[
\rho(r_{A1}, r_{A2}, r_{A1}, r_{A2}) = \frac{4(4\pi)^4}{2 + 2\Delta} \left[ r_{A1} \Psi_{100}(r_{A1}) \right]^2 \left[ r_{A2} \Psi_{100}(r_{A2}) \right]^2 r_{A1}^2 r_{A2}^2
\]

Platonic System:
“Di-Cone”
Dipole-Circle Coupling

At \( r_{A1} = r_{A2} = r_{B1} = r_{B2} = a \)

Maximum appears.

\[
\rho(a, a, a, a) = \frac{4(4\pi)^4}{2 + 2\Delta} a^4 |\phi\Psi_{100}(a)|^2
\]

\( R_B = a = 52.9 \) pm

\( R_{dd} = R_{AB} = 74.1 \) pm

Classical view:
Electrons rotate around \( R_{dd} \) axis.

Figure 2. Localization of electron wave and semi-classical image of D<sub>2</sub> molecule

In the view of Platonic symmetry, D<sub>2</sub> molecule is an orthogonal coupling of d-d line (dipole) and circle (torus of electron center) to form a dicone. Freedom of electron motion is constrained by the existence of counterpart deuteron and electron to form the torus of electron center, but averaged centrifugal force exists as the rotation of electrons around \( R_{dd} \) axis. See Fig. 2.

The Langevin equation for D<sub>2</sub> molecule becomes as,

\[
m_d \frac{d^2 R_{dd}}{dt^2} = -(4\sqrt{2} - 2) \frac{e^2}{R_{dd}^2} + \frac{2m_e v_e^2}{(R_{ee} / 2)} - \frac{\partial V_{\text{coul}}(R_{dd}; l, l)}{\partial R_{dd}} + f(t) \tag{13}
\]

Here the Coulomb force term under Platonic symmetry is derived by derivative (minus sign) of Coulomb energy,

\[
E_C = -4 \frac{e^2}{R_{de}} + \frac{e^2}{R_{dd}} + \frac{e^2}{R_{ee}} \tag{14}
\]
\[ E_C \approx -4\sqrt{2} \frac{e^2}{R_{dd}} + 2 \frac{e^2}{R_{dd}} \]  

(15)

By taking QM-ensemble average with weight of squared electron wave function,

\[ m_d \frac{d^2 \langle R_{dd} \rangle}{dt^2} = -\left( \frac{5.26}{R_{dd}^2} \right) + 4 \left( \frac{m_e v_e^2}{R_{ee}} \right) - \frac{\partial V_{s2}(R_{dd};1,1)}{\partial \langle R_{dd} \rangle} + \langle f(t) \rangle \]  

(16)

The first and second term of Eq. (16) right side cancels each other\(^4\), and we obtain,

\[ m_d \frac{d^2 \langle R_{dd} \rangle}{dt^2} = -\frac{\partial V_{s2}(R_{dd};1,1)}{\partial \langle R_{dd} \rangle} + \langle f(t) \rangle \]  

(17)

By taking ensemble average with the Gaussian wave function of d-d pair, the second term of Eq. (17) \( \langle f(t) \rangle \) becomes zero, since we have no distortion in d-d dipole line by QM fluctuation to deviate from the Platonic symmetry. Thus, Eq. (17) becomes well known Newtonian mechanical equation, with constraint by molecular trapping potential \( V_{s2} \) (\( R_{dd};1,1 \)). Mathematical formulas for trapping (shielded) potentials of D\(_2\) and D\(_2^+\) systems are given in our previous papers\(^2,5\). Figure of plotted data for two potentials are shown in Fig. 3.

![Figure 3. Trapping potential of d-d pair for D\(_2\) molecule and D\(_2^+\) ion](image-url)
As understood by potential shape for D₂ molecule given in Fig. 3, the Langevin equation for expectation value \( \langle R_{dd} \rangle \) gives always convergence to \( R_{gs} = 74 \) pm after time-dependent motion starting from arbitrary position \( R_{dd} (t=0) \). If \( R_{dd} > R_{gs} \), we have acceleration force. If \( R_{dd} < R_{gs} \), we have deceleration force.

2.5. Langevin Equation of D₂⁺ Ion

In analogy to the D₂ molecule, Langevin equation for D₂⁺ ion (stable in vacuum) is given by,

\[
m_d \frac{d^2 R_{dd}}{dt^2} = -2 \frac{e^2}{R_{de}^3} + \frac{e^2}{R_{dd}^2} + \frac{m_e v_e^2}{R_e} - \frac{\partial V_s (R_{dd}; l,l)}{\partial R_{dd}} + f(t)
\]

(18)

By taking QM-ensemble average,

\[
- e^2 \left\{ \frac{2}{R_{de}^2} \frac{1}{R_{dd}^2} \right\} + \left\langle \frac{m_e v_e^2}{R_e} \right\rangle = 0
\]

(19)

\[
m_d \frac{d^2 \langle R_{dd} \rangle}{dt^2} = - \frac{\partial V_s (R_{dd}; l,l)}{\partial \langle R_{dd} \rangle}
\]

(20)

Potential curve is shown in Fig. 3. In the view of Platonic symmetry, D₂⁺ ion molecule is an elongated dicone with \( R_{dd} = 130 \) pm, with rotating triangle of “d-e-d” type face around the \( R_{dd} \) axis. Dynamic motion of deuteron by Eq. (20) gives convergence to \( R_{dd} = R_{gs} = 130 \) pm.

In the following for complex D-cluster systems, Eq. (17) and Eq. (20) with those potentials will provide intrinsic components of friction (constraint) by QM electron waves with D-cluster condensation.

2.6. Langevin Equations of Expectation Values for Complex D-Clusters

In complex D-cluster systems under Platonic symmetry, averaged rotation motion over whole system is prohibited by constraints of many particle arrangements. This form of self-organization makes simpler treatment to derive one-dimensional Langevin equation possible. The term form is meta-physical concept.

The QM-ensemble average on electron wave function can be subdivided as multiple constraint function of “d-e-d” type or “d-e-d-e” type potential derivative as,

\[
\left\langle Constraint_{electron-wave} \right\rangle = -N_f \frac{\partial V_s (R_{dd}; l,l)}{\partial R_{dd}}
\]

(21)
Here \( N_f \) is the number of faces of Platonic polyhedron for a D-cluster, and \( i=1 \) for the “d-e-d” type (\( D_2^+ \) type) face and \( i=2 \) for the “d-e-d-e” type (\( D_2 \) type) face.

The Langevin equation for a D-cluster under Platonic symmetry with \( N_e \) number of d-d edges and \( N_f \) number of faces is written for \( N_e > 2 \),

\[
N_e m_d \frac{d^2 R}{dt^2} = -\frac{k}{R^2} - N_f \frac{\partial V_s}{\partial R} + f(t)
\]  

(22)

Here \( k \) is constant (11.8 for 4D/TSC).

The QM-ensemble average on d-d wave function (assuming Gaussian form) is given by

\[
N_e m_d \left\langle \frac{d^2 \Psi(R,R')}{dt^2} \right\rangle = -\left\langle \frac{k}{R^2} \Psi(R,R') \right\rangle - N_f \left\langle \frac{\partial V_s}{\partial R} \Psi(R,R') \right\rangle + \left\langle f(t) \right\rangle \left\langle \Psi(R,R') \right\rangle
\]

(23)

with a Gaussian wave function for d-d pair of D-cluster,

\[
\Psi(R,R') = \frac{1}{\sqrt{2\pi}\sigma^2} \exp\left(-\frac{(R'-R)^2}{2\sigma^2}\right)
\]

(24)

We drive a Langevin equation for expectation value \( \langle R_{dd} \rangle = \langle R \rangle \) as,

\[
N_e m_d \frac{d^2 \langle R \rangle}{dt^2} = -\frac{k}{R^2} - N_f \frac{\partial V_s}{\partial R} + \langle f(t) \rangle
\]

(25)

For complex D-cluster, \( \langle f(t) \rangle \) value does not always zero because of deviation of D-cluster system from ideal Platonic symmetry, due to the quantum mechanical fluctuation of d-positions which may distort the Platonic symmetry. The perturbed force component by this QM distortion is approximately given by the next formula, which is the change of system Coulomb energy derivative, as,
\[-\frac{\partial \Delta E_C}{\partial R} \approx -k \frac{1}{2} \left( \frac{1}{(R + \Delta R)^2} + \frac{1}{(R - \Delta R)^2} \right) + k \frac{1}{R^2} \]

\[\approx -\frac{k}{2R^2} \left( 1 - \frac{2\Delta R}{R} - \left( \frac{\Delta R}{R} \right)^2 \right) + 1 + \frac{2\Delta R}{R} - \left( \frac{\Delta R}{R} \right)^2 + k \frac{1}{R^2} \]

\[= \frac{k}{R^2} \left( \frac{\Delta R}{R} \right)^2 \quad (26)\]

By using a Gaussian squared wave function for d-d pair fluctuation, we write,

\[(\Delta R)^2 = (\sigma R)^2 \quad (27)\]

The change of Coulomb force by distortion is given by

\[<\text{Change of Coulombic Force}> = \frac{k \sigma^2}{(R_{dd})^2} \quad (28)\]

### 2.7. Langevin Equation of D$_3^+$ Ion Molecule

It is well known that tri-atomic hydrogen molecular ion D$_3^+$ (or H$_3^+$) is generated in ion source and glow discharged plasma and very stable in vacuum. However, quantum molecular physics for the system is of difficult problem to solve and studies are being continued in astrophysics needs.

The analogy of the present methodology for D (or H)-cluster under orthogonal coupling of Platonic symmetries for electrons and deuterons (or protons) can provide rather simple way of modeling its dynamics. Applying Eq. (25), we obtain,

\[3m_d \frac{d^2 \langle R_{dd} \rangle}{dt^2} = - \frac{6.13}{\langle R_{dd} \rangle^2} - 6 \frac{\partial V_s(R_{dd};1,1)}{\partial \langle R_{dd} \rangle} + \langle f(t) \rangle \]

\[\quad (29)\]

Here the force is given with unit of [keV/pm]. Image of D$_3^+$ ion is given in Fig. 4.
The system Coulomb energy and its derivative can be calculated by simple geometry exercise for the Platonic symmetry system of trigonal di-pyramid which is the orthogonal coupling of the 3d regular triangle and the $<-\mathbf{e}>\,-\SYM{<e>}$ line (dipole). Here two electron centers (or electron balls) appear in the system, and system-averaged rotation of electrons is prohibited (no averaged centrifugal force).

By distortion of ideal Platonic symmetry with QM fluctuations of deuteron positions, we have positive $<f(t)>$ bias. As we have 3 d-d edges in the system, 3 times of Eq. (28) becomes the bias (about 30% of main Coulomb acceleration force). Therefore the total potential of the system becomes in expected value equation, as,

$$V_{3D+\text{main}}(\SYM{R_{dd}}) = -\frac{6.13}{\SYM{R_{dd}}} + 6V_s(\SYM{R_{dd}};1,1) + (<f(t)> \text{ component})$$

(30)

The calculated curve of this potential is shown in Fig. 5.
The tri-atomic hydrogen ion is thus stable and has its ground state at $R_{gs} = 80$ pm. As a reference, Helm et al (Freiburg University, 2003; google triatomic hydrogen ion and Helm) gave about $R_{gs} = 85$ pm which agrees considerably well with our result taking into account that appropriate sigma-value of wave function $^2$ is about 30% of $R_{dd}$. We can conclude that our approach with one-dimensional Langevin equations for D-cluster systems look successful.

3. Langevin Equation for 4D/TSC and Numerical Solution

3.1. Double Platonic Symmetry
In Fig. 6, we show feature of electron cloud for 4D/TSC (t=0), compared with those of D-atom and $D_2$ molecule.
b) D₂ molecule (stable): \( \Psi_{2D} = (2 + 2\Delta)^{-1/2} [\Psi_{100}(r_{A1}) \Psi_{100}(r_{B2}) + \Psi_{100}(r_{A2}) \Psi_{100}(r_{B1})] \chi_{S}(S_1,S_2) \)

Figure 6. Feature of QM electron clouds for 4D/TSC (t=0), compared with those of D-atom and D₂ molecule

The form of 4D/TSC (t=0) wave function is given as,

\[
\Psi_{4D} \sim a_1 [\Psi_{100}(r_{A1}) \Psi_{100}(r_{B2}) + \Psi_{100}(r_{A2}) \Psi_{100}(r_{B1})] \chi_4(S_1,S_2) \\
+ a_2 [\Psi_{100}(r_{A1}) \Psi_{100}(r_{D1}) + \Psi_{100}(r_{A4}) \Psi_{100}(r_{D1})] \chi_4(S_1,S_4) \\
+ a_3 [\Psi_{100}(r_{B2}) \Psi_{100}(r_{C4}) + \Psi_{100}(r_{A4}) \Psi_{100}(r_{C2})] \chi_4(S_2,S_4) \\
+ a_4 [\Psi_{100}(r_{B1}) \Psi_{100}(r_{D3}) + \Psi_{100}(r_{B3}) \Psi_{100}(r_{D1})] \chi_4(S_1,S_3) \\
+ a_5 [\Psi_{100}(r_{B2}) \Psi_{100}(r_{C3}) + \Psi_{100}(r_{B3}) \Psi_{100}(r_{C2})] \chi_4(S_2,S_3) \\
+ a_6 [\Psi_{100}(r_{C3}) \Psi_{100}(r_{D4}) + \Psi_{100}(r_{C4}) \Psi_{100}(r_{D3})] \chi_4(S_3,S_4)
\]

6-Bonds of “Bosonized” electron-pairs (e ↑ + e ↓), which forms Regular Tetrahedron (PA)
4-Electron-Centers at Vertexes of Regular Tetrahedron (PA)

\[ u_{1s}(r) = \Psi_{100}(r) = (1/\pi)^{1/2}(1/\alpha a)^{3/2}\exp(-r/\alpha a) \]

Top equation (31)

This TSC system has double symmetry of regular tetrahedrons for deuterons and electron-centers, namely the double Platonic symmetry which is the most ideal system in
3-dimensional condensation squeezing into the central focal point (Center-of-Mass; CMS).

3.2. Langevin Equation for 4D/TSC

The system Coulomb energy and its derivative are given in our previous work. We write here resulting final Langevin equation for Monte-Carlo calculation.

\[ 6m_d \frac{d^2 R_{dd}(t)}{dt^2} = - \frac{11.85}{[R_{dd}(t)]^2} - 6 \frac{\partial V_s (R_{dd}(t);1,1)}{\partial R_{dd}(t)} + \langle f(t) \rangle + f'(t) \]  

(32)

with

\[ f'(t) = f(t) - \langle f(t) \rangle \]  

(33)

\[ f(t) = \left[- \frac{\partial \Delta E_c (R_{dd})}{\partial R_{dd}} \right] \mathrm{mod}[X^2(R'_{dd};R_{dd}(t))] \]  

(34)

\[ X^2(R'_{dd};R_{dd}(t)) = \frac{1}{\sqrt{2\pi \sigma^2}} \exp\left[-(R'_{dd} - R_{dd}(t))^2 / (2\sigma^2)\right] \]  

(35)

For QM-ensemble averaged equation, we obtained.

\[ 6m_d \frac{d^2 \langle R_{dd} \rangle}{dt^2} = - \frac{11.85}{\langle R_{dd} \rangle^2} - 6 \frac{\partial V_s (\langle R_{dd} \rangle; m, Z)}{\partial \langle R_{dd} \rangle} + 6.6 \left(\frac{(R'_{dd} - R_{dd}(t))^2}{R_{dd}^4}\right) \]  

(36)

Time-dependent potential for this equation was given as,

\[ V_{sc} (R'; R_{dd}(t)) = - \frac{11.85}{R_{dd}(t)} + 6V_s (R_{dd}(t); m, Z) + 2.2 \frac{\left|R'_{dd} - R_{dd}(t)\right|^3}{[R_{dd}(t)]^4} \]  

(37)

Here we fixed m=2 and Z=2 for \( V_s \) (dde*(2,2) potential) for numerical calculation.

The third term of right side of Eq. (36) gives about 15% positive bias to main Coulomb force (first term), and was merged in the first term by multiplying factor 0.85 in the numerical calculation by the Verlet method.

In Fig. 7, we show the calculated trapping potential of 4D/TSC, compared with that of 6D²/OSC (shown later). 4D(or H)/TSC keeps in average the always accelerating force in its condensation motion, hence it can condense ultimately until when TSC-min state
(about 10-20 fm radius) comes, as illustrated in Fig. 8. On the contrary, $6\text{D}^{2-}/\text{OSC}$ converges to $R_{dd}=40$ pm on the way of condensation (we derive equation later). Within the presently studied 5 kinds of D-clusters, only 4D/TSC can condense ultimately to very small charge neutral entity.

![Main Trapping Potential of 4D/TSC and 6D/OSC](image)

Figure 7. Trapping potential of 4D(or H)/TSC, always attractive, compared with $6\text{D}^{2-}/\text{OSC}$ potential which has converging point (40 pm) at its ground state
Figure 8. Condensation of 4D/TSC and 4D-fusion to two $^4\text{He}$-particles break-up

Numerical solution of Eq. (36) was obtained by a computer code based on the Verlet time-step method$^2$, a standard result is shown in Fig. 9.

Figure 9. Numerical results of 4D/TSC condensation motion; time-variation of $<R_{dd}>$ and mean deuteron kinetic energy $<E_d>$
The condensation time of 4D/TSC is very fast as 1.4007 fs. As we show in the next section, 4D fusion reaction takes place with almost 100% probability in the final stage of condensation within the time interval of about $2 \times 10^{-20}$ s. For other details of time-dependent behavior of TSC dynamics with different conditions, see our previous paper\(^2\).

### 3.3. Estimation of Fusion Rates

The Gaussian wave function was quite useful for making QM-ensemble averaging of Langevin equation, but unfortunately the accuracy in its tails (for very small $R_{dd}$ values) is not high enough to apply for the estimation of barrier factor of d-d pair and 4d cluster, as we illustrate the relation between trapping (shielded) Coulomb potential, wave function and the very short (within $r_0 = \text{about 5 fm}$) range of nuclear strong interaction, in Fig. 10.

To obtain usable accuracy in barrier factor, we introduced the Heavy Mass Electronic Quasi-Particle Expansion Method (HMEQPET) to provide equivalent time-dependent potentials for the squeezing 4D/TSC system. Detail description is given in our previous paper\(^2\).

![Diagram](image)

**Figure 10.** Relation between d-d trapping (shielded) Coulomb potential, wave function and the very short (within about 5 fm) range of nuclear strong interaction. By calculating Gamow integral from $R_{gs}$ to $r_0$, we obtain barrier factor for fusion rate estimation.

Time-dependent or equivalently $R_{dd}$-dependent barrier factors were calculated as we copy from our previous paper\(^2\) as given in **Table 1.** TSC starts at $R_{dd} = 74$ pm and
condenses very rapidly to reach at the final TSC-min state with \( R_{dd} = 0.0206 \text{ pm} \) (20.6 fm) in this case. On the way of condensation, TSC passes the equivalent state with that of dd-muon molecule for which we have reference data\(^6\) to show good agreement with our calculation. Barrier factors for 2d and 4d fusion were calculated using the WKB approximation with Gamow integral\(^2\).

Fusion rates for steady molecules were then calculated based on the Fermi’s first golden rule\(^3\),

\[
\lambda_{nd} = \frac{2}{\hbar} \langle W \rangle P_{nd}(r_0) = 3.04 \times 10^{21} P_{nd}(r_0) \langle W \rangle
\]  \hspace{1cm} (38)

Here \( P_{nd} \) is barrier factor for \( n \)-D-cluster and \( \langle W \rangle \) is the averaged value of imaginary part of nuclear optical potential\(^7\). The extrapolation of \( \langle W \rangle \) value to 4d fusion was made\(^2\) by using the scaling law \( \langle W \rangle \propto (PEF)^{2/3} \) with PEF-value which is given in unit of derivative of one pion exchange potential (OPEP) (simple case of Hamada-Johnston potential\(^1\))

\[
\langle OnePEF \rangle = -\frac{\partial \langle V_{OPEP}(x) \rangle}{\partial r} = \frac{1}{1.43} \frac{\partial \langle V_{OPEP}(x) \rangle}{\partial x}
\]  \hspace{1cm} (39)

\[
V_{OPEP}(x) = v_0 \cdot (\vec{r}_1 \cdot \vec{r}_2) \left\{ \vec{\sigma}_1 \cdot \vec{\sigma}_2 + (1 + \frac{3}{x} + \frac{3}{x^2}) S_{12} \right\} \frac{\exp(-x)}{x}
\]  \hspace{1cm} (40)

Here \( x = \frac{m_x c}{\hbar} r = \frac{r}{1.43} [\text{fm}] \)

and \( S_{12} \) is the tensor operator \( S_{12} = 3 \frac{(\vec{\sigma}_1 \cdot \vec{r})(\vec{\sigma}_2 \cdot \vec{r})}{r^2} - \vec{\sigma}_1 \cdot \vec{\sigma}_2 \)

and \( v_0 = \frac{1}{3} \frac{f^2 m_x c^2}{\hbar c} = 3.65[\text{MeV}] \).

And \( \vec{r} \) is the isospin operator for n-p charged pion exchange and \( \vec{\sigma} \) is the spin operator for nucleon state. The table of \( \langle W \rangle \) values is given in our previous paper\(^2\).

Time-integrated fusion yield per TSC generation was given\(^2\) by the following formulas,

\[
\eta_{4d} = 1 - \exp(-\int_0^{t_f} \lambda_{4d}(t) dt)
\]  \hspace{1cm} (41)
\[ \lambda_{4d}(t) = 3.04 \times 10^{21} \langle W \rangle P_{4d}(r_0; R_{dd}(t)) = 1.88 \times 10^{23} P_{4d}(r_0; R_{dd}(t)) \]  
(42)

\[ \int_0^t \lambda_{4d}(t) dt = 1.88 \times 10^{23} \int_0^t P_{4d}(r_0; R_{dd}(t)) dt \]  
(43)

\[ \int_0^t P_{4d}(r_0; R_{dd}(t)) dt = 2.31 \times 10^{-22} \]  
(44)

\[ \eta_{4d} \cong 1.0 \]  
(45)

Macroscopic fusion rate is given by

\[ Y_{4d} = Q_{\text{tsc}} \eta_{4d} \]  
(46)

We have obtained that 4D fusion may take place with almost 100 \% yield per a TSC generation, so that macroscopic 4d fusion yield is given by simply with TSC generation rate \( Q_{\text{tsc}} \) in the experimental conditions of CMNS. However, when we consider that one deuteron has spin-parity 1+ and combination of 4d has total spin state 4, 3, 2, 1 and 0, the 4d fusion with out-going channel to two \(^4\text{He} \ (0+;\text{gs})\) particles is forbidden, by spin-parity conservation (for S-wave in/out channels), except for the 0+ spin-parity state (T=0) of 4d combination, to be explained detail analysis including P-wave and D-wave states with isospin elsewhere.
Table-1: barrier factors under 4D/TSC condensation

<table>
<thead>
<tr>
<th>$R_{dd} = R_{gs}$ (pm)</th>
<th>$P_{2d}$; 2D Barrier Factor</th>
<th>$P_{4d}$; 4D Barrier Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0206 (TSC-min)</td>
<td>4.44E-2</td>
<td>1.98E-3</td>
</tr>
<tr>
<td>0.0412</td>
<td>1.06E-2</td>
<td>1.12E-4</td>
</tr>
<tr>
<td>0.103</td>
<td>1.43E-3</td>
<td>2.05E-6</td>
</tr>
<tr>
<td>0.206</td>
<td>3.35E-5</td>
<td>1.12E-9</td>
</tr>
<tr>
<td>0.412</td>
<td>9.40E-7</td>
<td>2.16E-13</td>
</tr>
<tr>
<td>0.805 (μ dd)</td>
<td>1.00E-9</td>
<td>1.00E-18</td>
</tr>
<tr>
<td>1.03</td>
<td>9.69E-11</td>
<td>9.40E-21</td>
</tr>
<tr>
<td>2.06</td>
<td>6.89E-15</td>
<td>4.75E-29</td>
</tr>
<tr>
<td>4.12</td>
<td>9.38E-21</td>
<td>8.79E-41</td>
</tr>
<tr>
<td>10.3</td>
<td>2.16E-32</td>
<td>4.67E-64</td>
</tr>
<tr>
<td>21.8 (dde*(2,2))</td>
<td>1.30E-46</td>
<td>1.69E-92</td>
</tr>
<tr>
<td>74.1 (D2 molecule)</td>
<td>1.00E-85</td>
<td>1.00E-170</td>
</tr>
</tbody>
</table>

Table-2: Fusion rates by Fermi’s golden rule for steady molecules

<table>
<thead>
<tr>
<th>Molecule</th>
<th>$R_{dd} = R_{gs}$ (pm)</th>
<th>$P_{nd}$; B- Factor</th>
<th>$&lt;W&gt;$ (MeV)</th>
<th>$\lambda_{2d}$ (f/s)</th>
<th>$\lambda_{4d}$ (f/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D$_2$</td>
<td>74.1</td>
<td>1.0E-85</td>
<td>0.008</td>
<td>2.4E-66</td>
<td></td>
</tr>
<tr>
<td>dde*(2,2)</td>
<td>21.8</td>
<td>1.3E-46</td>
<td>0.008</td>
<td>3.16E-27</td>
<td></td>
</tr>
<tr>
<td>μ dd</td>
<td>0.805</td>
<td>1.0E-9</td>
<td>0.008</td>
<td>2.4E+10</td>
<td></td>
</tr>
<tr>
<td>4D/TSC-min</td>
<td>0.021</td>
<td>1.98E-3</td>
<td>62</td>
<td></td>
<td>3.7E+20</td>
</tr>
</tbody>
</table>

The ultimate condensation is possible only when the double Platonic symmetry of 4D/TSC is kept in its dynamic motion. The sufficient increase (super screening) of barrier factor is also only possible as far as the Platonic symmetric 4D/TSC system is kept. Therefore, there should be always 4 deuterons in barrier penetration and fusion process, so that 4d simultaneous fusion should take place predominantly. The portion of 2D (usual) fusion rate is considered to be negligible$^2)$. Major nuclear products of 4D fusion are two 23.8 MeV α-particles$^5,7)$. 4H/TSC should condense in the same way until when TSC-min state with classical electron radius (2.8 fm) comes, but no strong interaction exists among protons and will make 1p to 4p capture
transmutations with host metal nuclei when 4H/TSC has sufficient drift (CMS) momentum.

Figure 11. Illustration of 6D²/OSC system

4. Langevin Equation for 6D²/OSC

To fulfill the orthogonally coupled Platonic symmetry for 6D-cluster, 8 electron centers should appear on the center lines of 8 regular triangle faces of 6d octahedron; see Fig. 11. Therefore, the Platonic OSC should be with 2- negative ion state.

The Langevin equation for 6D²/OSC becomes as,

\[
12m_d \frac{d^2 R_{dd}(t)}{dt^2} = -\frac{29.3}{[R_{dd}(t)]^2} - 24 \frac{\partial V_s(R_{dd}(t);1,1)}{\partial R_{dd}(t)} + \langle f(t) \rangle + f'(t) \tag{47}
\]

The effective trapping potential of this system was already given in Fig. 7, which tells us that 6D²/OSC does not make ultimate condensation. However, in transient condensation process, we may have small probability that d-d distance would approach in
shorter d-d distances than 40 pm of its ground state and 6D fusion rate may be somehow enhanced. We need numerical study for this.

We need a different study on if there exists a condensing system of neutral 6D-cluster (face-centered dodecahedron\textsuperscript{11}) by coupling of two octahedrons (one of 6 deuterons and the other of 6 electron-centers).

**5. Conclusions**


2) Platonic symmetry appears in D-atom, D\textsubscript{2}, D\textsubscript{2}\textsuperscript{+},D\textsubscript{3}\textsuperscript{+} molecule, and 4D/TSC.

3) Platonic symmetry appears in CMNS of 4D/TSC for both of the Coulombic interaction and the strong interaction.

4) Dynamic Platonic symmetry is of key for super-screening of Coulomb repulsion and 4D Cluster Fusion.

5) We have obtained good solutions of molecular dynamics with Langevin Equations, for Platonic symmetric systems as, D, D\textsubscript{2}, D\textsubscript{3}\textsuperscript{+} and 4D(or H)/TSC.

6) It was shown that about 100\% 4D-fusion per TSC generation is possible, by the present work, in the condensed matter nuclear effects.

7) Only 4D (or H)/TSC can condense ultimately to a very small charge neutral entity with 10-20 fm radius size, as far as 5 kinds of D-clusters studied in this work.

8) Bosonized e(1/2)+e(-1/2) coupling for the “d-e-d-e” system makes D\textsubscript{2} type faces of 4D(or H)/TSC to help its ultimate condensation.

9) 6D\textsuperscript{2}/OSC converges its condensation at about R\textsubscript{dd}=40 pm, but closer d-d distance in transient may appear with small probability.

10) Single <e- >-center states for the “d-e-d” (D\textsubscript{2}\textsuperscript{+}) type faces of D\textsubscript{3}\textsuperscript{+} ion molecule and 6D\textsuperscript{2}/OSC enhance constraint (friction) for their condensation.
Acknowledgements

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Multiple Resonance Scattering

T. Toimela
Abstract

The previously proposed Multiple Resonance Scattering (MRS) theory is elaborated. In addition of predicting a radiationless fusion of two deuterium nuclei into a $^4\text{He}$-nucleus in its ground state, the MRS theory is also shown to be in agreement with the experimental results concerning the transmutations of heavier nuclei. A form for the nuclear active environment is suggested and new experiments are proposed to verify the MRS theory.

1. Introduction

Condensed matter nuclear science (CMNS) has been mostly overlooked by the main physics community for years. The main reason for that has been the gap between the known experimental facts of CMNS and the presently existing theoretical knowledge. The aim of this article is to provide a bridge over this gap proposing an idea, how the results of CMNS can be consistent with the accepted theories of modern physics. The theory proposed here is an elaborated version of the idea proposed earlier in ref. [1].

We consider here a nano-size cluster of Pd atoms (or other host metal atoms). Furthermore, we assume that the deuterons absorbed (or adsorbed) to the Pd cluster are confined into the cluster but can otherwise move quasi-freely. Alternatively we can consider other kind of deuterium traps, voids in metal or acoustic cavities in heavy water.

Normally the deuterons inside the metal lattice are assumed to situate rigidly in the interstitial sites. However, the free particle approximation, which will be used here as a calculation tool, can be defended by two arguments. Firstly, the mobility of deuterons inside palladium and their thermal movement make the free particle approximation as a reasonable starting point. Secondly, consider the enhancement of the cross sections for the normal $d + d$ fusion reactions found in the thick target experiments [2]. That enhancement can be understood by the screening caused by charged particles obeying classical Maxwell-Boltzmann distribution (leading to the Debye screening) as noted in ref. [2], where the electrons are assumed to have Maxwell-Boltzmann distribution although the known Fermi-Dirac distribution for the cold electron gas is noted. However, the enhancement can be understood by the screening caused by the background electron gas modulated by the moving quasi-free classical deuterons. The role of the mobility of deuterons in the enhancement of the fusion cross sections in thick target experiments have also been stressed in refs. [3,4]

In bulk palladium the maximum loading that can be attained is about $D/Pd \approx 1$. However, larger values, up to and even more than $D/Pd \approx 3$ are reported by pressure measurements, when nanoparticles of Pd is used [5]. Altogether, we assume rather high loading of quasi-free deuterons in the nano-clusters considered.
2. Transition rate for the deuterium fusion

Consider a reaction of N+1 deuterons confined in the Pd cluster such that two of them fuse together and the other deuterons share the released energy by consecutive elastic interactions. We regard here the deuterons as free particles confined in the finite volume \( V_0 \). The final state consists confined (or escaping) deuterons and the fusion product(s). There will be N particles in the final state for \(^4\)He -channel, and N+1 particles for tritium and \(^3\)He -channels. The transition rate (per unit time and per cluster) is given by the Fermi golden rule:

\[
\lambda = \frac{2\pi}{\hbar} \left| \langle \Psi_f | \hat{H} | \Psi_i \rangle \right|^2 \rho
\]

where \( \rho \) is the density of the states given by

\[
\rho = \delta(E_f - E_i) \left( \frac{V_0}{(2\pi)^3} \right)^N \prod_{j=1}^{N} d^3p_j
\]

Note that the conservation of momentum does not require here the existence of a photon in the final state in the \(^4\)He -channel, because the momentum conservation is fulfilled by the other deuterons in the final state. As the Hamiltonian that is responsible for the nuclear reaction, we use the Fermi pseudo-potential

\[
\hat{H} = -\frac{4\pi \hbar^2}{m} a \delta(\mathbf{r})
\]

where \( a \) is the nuclear scattering length, which will be of the order of the nuclear diameter. The scattering lengths for all the d+d fusion channels can be assumed to be roughly equal. Note that the relative branching ratio (of order \( 10^{-7} \)) for the \(^4\)He -channel in the vacuum reaction is mainly due to the electromagnetic coupling to the photon field, which is absent here.

For the elastic interaction between deuterons sharing the released energy we use a screened Coulomb potential such that, when the wave number of the transmitted momentum is larger than the Debye wave number, the potential is approximated by the pure Coulomb potential, and by a constant below that.
\[ \hat{H} = 4\pi\alpha\hbar c D(k) \quad , \quad (4) \]

where

\[
D(k) = \begin{cases} 
\frac{1}{k^2}, & k > k_D \\
\frac{1}{k_D^2}, & k \leq k_D 
\end{cases} \quad . \quad (5)
\]

The Debye wave number \( k_D \) is calculated in the first order approximation (RPA approximation) in ref. [1] and is for \( D/Pd \approx 1 \) of order \( 5 \cdot 10^{11} \text{1/m} \) and twice of that provided that the value \( D/Pd \approx 4 \) for Pd nanoparticles is adopted.

The process, where the energy is collectively distributed among all the deuterons in the trap, contains \( N-1 \) elastic interaction between the deuterons (in the tree-diagram level). Hence, the rate will be of form

\[
\lambda = \left( \frac{4\pi\hbar a}{m} \right)^2 \left| \psi_{rel}(0) \right|^2 \left( \frac{1}{V_0} \right)^N \int \frac{d^3N}{(2\pi)^{3N}} \prod_{i=1}^{N-1} G(\omega_i, q_i) \right|^2 .
\]

\[
(4\pi\alpha)^{2(N-1)} \left| \prod_{i=1}^{N-1} D(k_i) \right|^2 (2\pi)^4 \hbar \delta(E_i-E_f) \delta(p_f) \quad . \quad (6)
\]

In Eq. (6) the functions \( G(\omega_i, q_i) \) are the propagators corresponding to the virtual lines (the spin indices have been deleted for simplicity).

\[
G(\omega_i, q_i) = \frac{1}{\omega_i - \frac{\hbar q_i^2}{2m} - i\frac{\Gamma}{2\hbar}} \quad , \quad (7)
\]

where \( \omega_i \) and \( q_i \) are the frequency and the wave number vector of the virtual line (depending on the final state wave vectors \( p \) in such a way that the frequency and the momentum are conserved at all the verteces in the Feynman diagram). \( \Gamma \) is the line width corresponding the decay of the virtual deuteron to the lower energy states.

The dominant contribution to the transition matrix arises from the reaction, in which the energy released is distributed most effectively, so that the energies of the virtual particles split (roughly even) by consecutive interactions with the initial state deuterons. The corresponding diagram is shown in Fig. 1.
Now, consider a virtual deuteron that interacts with an initial state deuteron so that both of them become free particles at the final state. The conservation of the energy and the momentum determine that the propagator of the virtual particle, Eq. (7), has to be

\[
G(\omega_i, q_i) = \frac{1}{\frac{\hbar p^2}{2m} + \frac{\hbar q^2}{2m} - \frac{\hbar (p+q)^2}{2m} - \frac{i}{2} \frac{\Gamma}{\hbar}},
\]

where \( p \) and \( q \) are the wave number vectors of the two final state deuterons. From Eq. (8) we note that there will be a resonance, if the final state momenta are perpendicular to each other. Furthermore, there will be multiple resonances, if the final state momenta are such that after every vertex the momenta of the two (virtual or real) particles are perpendicular to each other. For this multiple resonance scattering to occur, N-3 components of the final state wave number vectors are restricted to be small. Moreover, the overall conservation of momentum gives three extra constraints. For the diagram shown in Fig. 1, the momenta of the internal and final state particles are shown in Fig. 2.
for this multiple resonance situation. Note that in Fig. 2 the two first momenta have to be opposite to each other due to the conservation of momentum.

Figure 2. The momenta of the virtual and final state particles in the multiple resonance scattering corresponding to the diagram in Fig.1.

We neglect the N-3 small components of the wave number vectors everywhere except in the propagators corresponding to the resonances. Then the integration over those N-3 wave number vectors can be performed yielding to

\[
\lambda = \left( \frac{4\pi \hbar a_{\text{nucl}}}{m} \right)^2 |\psi_{rel}(0)|^2 (\alpha c)^{2(N-1)}
\times \int \frac{d^{2N}p}{(2\pi)^{2N}} \frac{2\pi \hbar}{V_0^N} \delta(\sum_{i=1}^{2N} \frac{\hbar^2 p_i^2}{2m_i} - Q) \left| \prod_{l=1}^{N-1} D(k_l) \right|^2 \frac{\hbar^4}{Q^2 \Gamma^2} \prod_{j=1}^{N-3} m_j q_j \Gamma,
\]

where \(q_j\) are some combinations of the remaining 2N components of the final state wave number vectors. As a matter of fact, the line width \(\Gamma\) in Eqs. (7-9) is not a constant, but depends highly on the energy of the virtual line. However, for those internal lines, in which the energy is small, and which form the majority of the internal lines, the line width is small and essentially constant (arising from the decay to the bound deuteron pairs [1]). Consequently, considering the line width as a constant is not an essential error.
Noting that the final state wave vectors are of the order \( p_i \approx \sqrt{2mQ/N/h} \), the wave vectors \( q_j \) in Eq. (9) range from \( \sqrt{2mQ/N/h} \) to \( \sqrt{mQ/h} \). The product in Eq. (9) can then be approximated (assuming that the energy is of the virtual particles is split roughly even by consecutive interactions with the initial state deuterons):

\[
\prod_{j=1}^{N-3} \frac{1}{q_j} \approx C \left( \frac{\hbar^2 N}{4mQ} \right)^{N/2},
\]  

(10)

where \( C \) is some numerical constant of order unity. The product corresponding to the interaction propagators can be estimated respectively taking here into account Eq. (5), so that the number of unscreened elastic interactions is roughly \( Q/U_D \) while the number of screened interactions is \( N - Q/U_D \), where we have define the Debye energy

\[
U_D = \frac{\hbar^2 k_D^2}{2m}.
\]  

(11)

In the delta function of Eq. (9) all the masses \( m_i \) are deuteron mass except the one(s) corresponding to the fusion product(s). The same is true also for the last product in Eq. (9). However, at the large \( N \) limit we can replace those masses by the deuteron mass without making any essential difference. The delta function in Eq. (9) can then be approximated as

\[
\delta \left( \sum_{i=1}^{2N} \frac{\hbar^2}{2m_i} p_i^2 - Q \right) = \delta \left( \frac{\hbar^2}{2m} p^2 - Q \right) = \frac{m}{\hbar^2 p} \delta \left( p - \frac{\sqrt{2mQ}}{h} \right).
\]  

(12)

where \( p \) is the length of the 2N dimensional wave number vector in Eq. (9). It should be noted that Eq. (12) is actually an approximation and not rigorous, because the wave numbers \( p_i \) in the sum inside the delta function are not one to one the integration wave numbers of Eq. (9), but combinations of them. Finally, using the Stirling’s approximation

\[ I(x) \approx x^{-1/2} e^x \sqrt{2\pi} \]  

(13)

we can write the 2N dimensional integration volume element as
\[
\prod_{j=1}^{2N} dp_j = d^{2N} p = \frac{2 \pi^N}{\Gamma(N)} p^{2N-1} dp
\approx \frac{2N}{\sqrt{\pi}} \left( \frac{\pi}{N} \right)^N e^N p^{2N-1} dp.
\]

(Note that there is a misprint in the corresponding equation in ref. [1].) The transition rate given by Eq. (9) becomes now

\[
\lambda = A \cdot \frac{\hbar^3 a^2 |\psi(0)|^2}{m^2 Q N V_0} \left( B \cdot \frac{\alpha^2 mc^2}{\Gamma k_D^3 V_0} \sqrt{\frac{Q}{NU_D}} \right)^{N-1} 4^{-Q/V_D},
\]

where all the numerical factors (independent of N) have been embedded in the two constants A and B.

Eq. (15) greatly overestimates the transition rates for two reasons. Firstly, the deuterons are not free particles as assumed in the calculation, and consequently more sophisticated calculations are needed to obtain reliable quantitative results. However, the free particle approximation serves a reasonable starting point as discussed in the introduction. A more important thing is that the deuterons do not interact with all the other deuterons inside the trap, but only with their neighbours up to some distance, while the interaction with the deuterons far away is totally screened. It then means that the constant A in Eq. (15) will depend on the trap occupation N and the interaction distance r.

\[
A = A(N, r),
\]

in a way, which have to be studied in details in order to obtain quantitative predictions for the transition rates. Therefore, we can draw only qualitative conclusions from Eq. (15) at this stage.

The transition rate, Eq. (15), is extremely sensitive function of the trap occupation N and the energy released Q. This expression leads to measurable transition rates provided that N is large enough and that the factor

\[
\beta = B \cdot \frac{\alpha^2 mc^2}{\Gamma k_D^3 V_0} \sqrt{\frac{Q}{NU_D}}
\]

is greater than unity. This factor also explains, why the enhancement of the reaction rates by the multiple resonances has not been found in any other circumstances. What is
needed, is large number of heavy but (quasi-)free particles confined in a small volume. Electrons are too light, and lattice atoms cannot be considered as free particles in any reasonable approximation. Hence, the enhancement can appear only in the hydrogen loaded metals or other systems, where hydrogen atoms are confined in a small volume. Because the factor of Eq. (17) is proportional to the mass, the deuterium loading will give much higher transition rates compared to the hydrogen loading. It should, however, take into account that the difference between these two hydrogen isotopes is not as huge as could be assumed from Eq. (15). Protons, as lighter particles, can be approximated better as free particles than the heavier deuterons. Hence, their greater mobility compensates the mass difference up to some extent.

Furthermore, because of this mass dependence, the heaviest isotope, tritium would be the best catalyst for the low energy nuclear reactions. However, some mixture of tritium and deuterium should be used, because the deuterium is needed as fuel while tritons give the largest enhancement to the transition rate due to the larger phase space for the resonance. One should take into account that the metal lattices absorb hydrogen better than deuterium [6] and presumably similarly deuterium better than tritium. Hence, the tritium content in the electrolyte should be very large in order to essential improvement of the excess heat can be expected in the electrolysis experiment.

Moreover, the transition rate is a monotonic and rapidly increasing function of the released energy $Q$, provided the occupation $N$ is large enough. This shows that practically only the process having the largest possible releasing energy could take place. In the case of a fusion of two deuterons considered here, this is the $^4$He -channel, directly to the ground state.

As the dominant fusion process will be $d + d \rightarrow ^4$He (to the ground state and without any final state photon) there will be no radiation except possible soft secondary radiation caused by the free deuterons in the final state.

Proton-proton fusion in the light water experiments will not give detectable transition rates for two reasons. Firstly, (and more importantly) the released energy is too small. Moreover, the transition rate is smaller, because the protons are lighter and consequently the phase space of the resonances is smaller.

If we consider the fusion rate as a function of the trap volume $V_0$, we note that there will be a “window”, where the fusion can take place. If the trap volume is too small, the trap cannot maintain such a high deuteron occupation that the multiple resonances could overcome the Gamow factor and the factor $A(N,r)$ of Eq.(16) arising from the limited interaction distance. On the other hand, for too large volume the factor of Eq.(17) becomes less than unity for reasonable values of the trap occupation $N$ preventing the fusion to occur.
3. Transmutation processes

The MRS mechanism discussed here can also be applied to the transmutation reactions. The essential difference is that the overlapping of the deuteron wave functions in Eq. (15) has to be changed to the overlapping of the wave functions of the heavy nucleus and one or more interacting hydrogen nuclei. The transition rate will be much smaller than in the d + d fusion process due to the smaller Gamow factor corresponding to the overlapping of the wave functions. Again the transition rate depends very sensitively on the released energy. That explains the stabilising effect, because the higher released energies are obtained when the final state nucleus is as stable as possible.

Besides the released energy, also the electron structure of the heavy atom affects the transition rate through the screening of the positive charges, changing the overlapping of the wave functions. Similarly as in the case of the deuteron-deuteron fusion we can draw only qualitative conclusions on the transmutation processes at this stage.

Because the transition rate depends sensitively on the released energy, the outcome of transmutation processes will naturally show unnatural isotopic abundances.

As an example of the prediction of the mechanism proposed here, consider the gas permeation experiment by Iwamura et al [7], where they deposited barium on the Pd-CaO complex. The most abundant isotope of barium, $^{138}\text{Ba}$, was found to transmute to the isotope $^{150}\text{Sm}$ by absorbing six deuterons. If we consider all the stable isotopes of barium, the released energy are largest for similar processes for the isotopes $^{132}\text{Ba}$ and $^{134}\text{Ba}$. Because the structure of the core electrons are the same for all the isotopes of a given element and cannot then affect the relative transition rate, the released energy is the only factor that differs the isotopes. Hence, we can expect that the lighter isotopes will consume more rapidly compared to the heaviest isotope, $^{138}\text{Ba}$. Considering for example the isotope $^{134}\text{Ba}$, this does not mean that it will transmute by absorbing six deuterons:

$$6\, ^2\text{D} + ^{134}\text{Ba} \rightarrow ^{146}\text{Sm} + 71.6\, \text{MeV}$$

It can have also some other more probable transmutation channel, for example to neodymium

$$4\, ^2\text{D} + ^{134}\text{Ba} \rightarrow ^{142}\text{Nd} + 50.1\, \text{MeV}$$

or some fission channel. No matter, which one of these possible channels actually take place, it will have higher rate than the transmutation rate of the heaviest isotope $^{138}\text{Ba}$.

It should be noted that the MRS mechanism does not necessarily require any particle to penetrate the nucleus for a fission process to take place. That possibility has to be taken
into account, when interpreting the results of the transmutation experiments. In that kind of process the Gamow factor arises from the tunnelling of a charged particle out of the nucleus. One particular example of this kind of process is the enhancement of the decay rate of radionuclides. Consider for example the nuclei having mass number \( A \) greater than about 150. By the energy consideration all of them are unstable against alpha decay. However, the decay constant of those isotopes in vacuum is too low by several orders of magnitude in order to their decay could be measured in the cases, where the decay energy is smaller than about 3 MeV. In hydrogen, deuterium or tritium loaded metals the decay can, however, be enhanced by the MRS mechanism. For example, consider the tungsten isotopes. Among all the tungsten isotopes the two lightest isotopes \(^{180}W\) (0.12\%) and \(^{182}W\) (26.50\%) have the largest decay energies:

\[
^{180}W \rightarrow ^{176}Hf + ^4He + 2.51\text{ MeV}
\]

\[
\downarrow
\]

\[
^{172}Yb + ^4He + 2.26\text{ MeV}
\]

\[
^{182}W \rightarrow ^{178}Hf + ^4He + 1.77\text{ MeV}
\]

\[
\downarrow
\]

\[
^{174}Yb + ^4He + 2.08\text{ MeV}
\]

It could be possible that (at least part of) the hafnium and ytterbium signals found by Savvatimova [8] in the deuterium irradiation of tungsten are consequences of the enhanced alpha decay of these tungsten isotopes. If that is the case, it would represent the first measurement of the decay of these “stable” tungsten isotopes. However, further study would be needed to solve this issue.

4. Proposal for further experiments

The nuclear active environment (NAE), a term introduced by Edmund Storms, is by the prediction of the MRS mechanism a highly loaded correct size deuterium (or hydrogen or tritium) trap, for example a nano-cluster of the host metal atoms. Therefore, a detailed study of the size dependence of the Pd cluster to the excess heat and to the reproducibility would be very important.

As discussed in chapter 2, the highest transition rate will be obtained if the released energy is shared by tritons (and not by protons or deuterons). Therefore, a combination of deuterium and tritium will be the best choice in electrolysis experiment, because the deuterium is anyway needed as fuel. The optimum concentration of tritium should be investigated. Also a mixture of tritium and deuterium gas should be used in gas
permeation experiments for the same reason. One may expect that the optimum concentration of tritium would be less for the deuteron absorption processes involving four or six deuterons than for the deuteron-deuteron fusion.

Consider for a while the absorption processes – not involving deuterons – but tritons. For the heavy nuclei the binding energy per nucleon is typically 7.5-8.5 MeV. Consequently, the energy released per triton is about 14-17 MeV. That can be compared to the energy released per deuteron, which is about 13-15 MeV respectively. It is not clear, whether the larger energy (for the triton absorption processes) can compensate the smaller (mass dependent) Gamow factor. Although a definite prediction cannot be given here, possible transmutation involving several tritium nuclei should be explored.

As discussed in chapter 3, the rate of the similar transmutation processes of the different isotopes of the same element depend only on the energy released as far as the parity and spin conservation does not make a specific process less probable. Considering the transmutation of barium discussed there, we could propose here an experiment, where the abundances of the barium isotopes is measured as a function of time to see, whether the lightest isotopes consume more rapidly as predicted in chapter 3.

Furthermore, considering the enhancement of the decay rate of the radioactive nuclei, it would be interesting to study this by Iwamura type gas permeation experiment. Especially, one could deposit tungsten (which was discussed above) on the Pd complex to see whether the decay of the tungsten can be seen.

References

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Abstract

A joint effort performed by ENEA, SRI, Energetics Technologies, NRL and the University of Rome La Sapienza allowed to obtain a remarkable level of sheared reproducibility both in high loading of palladium with deuterium and in observing excess power production during calorimetric experiments. The excess heat was observed with a signal well above the measurement uncertainty, with up to 70% of reproducibility.

The wide-ranging scientific work carried out in optimizing the palladium electrodes and the accuracy of the calorimetry are the reasons for the success of this project.

Introduction

In 1989 M. Fleishmann and S. Pons [1] discovered excess power production during electrochemical deuterium loading in palladium but at that time the reproducibility of this effect was very low. McKubre (SRI) [2] and Kunimatsu (IMRA Japan) [3], in 1992, discovered that the excess power production was a threshold effect occurring only (but not always) when the average deuterium concentration in the palladium lattice exceeded the atomic fraction value D/Pd ~0.9. After these results were reported, research activity moved to concentrate on the aspects of material science concerning the mechanisms controlling the hydrogen isotope mass transfer into metal lattices. Material thermodynamics and transport processes have been investigated to optimize the palladium to be tested into calorimetric experiments during electrochemical loading of deuterium. The goal was to increase the reproducibility of the excess power production by increasing the hydrogen isotopes solubility into the metal lattice.

The dissolution of hydrogen isotopes into a metal lattice is not only a problem of thermodynamic equilibrium between the hydrogen inside the lattice and the hydrogen in
the external phase (gas or liquid) but is also a problem of non-equilibrium because of the occurrence of a transport process. The two aspects of the phenomenon are correlated since the equilibrium concentration of the solute is achieved when the chemical potentials of the hydrogen in both phases are equal and since the transport process inside the metal lattice is driven by the gradient of the chemical potential.

The migration of interstitials in a metal under an applied external bending is well known as Gorsky effect [4]. The deformation field produces the defects migration toward the expanded areas. Lewis and co-workers [5, 6, 7] showed that internal stresses are generated during insertion and diffusion of interstitial hydrogen and that the resulting strain production represents an opposing force to the flux produced by the concentration gradient.

The fields of force, like the stress field, modifying the free energy of the system, modify the chemical potential of the hydrogen in solid solution in a metal lattice.

Hydrogen isotopes dissolving into a metal (i.e. palladium) occupy interstitial positions and expand the lattice. This process generates a stress field when extreme concentration differences such as strong gradients are created [8]. Metallurgy and the status of the interface have been studied to design a material to increase control of the loading [9]. The control of the deuterium concentration threshold leads to an increase in both the reproducibility of the excess heat and in the amplitude of the signal.

A flow calorimetric system, designed on the basis of detailed and accurate modeling, was developed for this study.

**Materials**

A material having a metallurgical structure able to ensure homogeneous loading makes it possible to minimize the stress field by minimizing the concentration gradients. Some treatments, based on cold and annealing steps followed by thermal processing, optimize the metallurgical structure increasing the H(D) loading. The raw material was palladium foil 1 mm thick, which was able to reach a loading ratio of about 0.75 - 0.8 (hydrogen atomic ratio). The treatment was done in two steps:

1) Cold rolling of the raw material to produce a palladium foil 50 µm thick.
2) Annealing at temperatures around 900°C for one hour or more.

Figure 1 shows the effect of the treatment; that is, the metallurgical structure on the H (D) loading. H/Pd=0.97 has been obtained in the sample that was cold worked and annealed.

On the basis of the mechanisms considered above, a possible interpretation of such results is that in the sample the concentration profiles are maintained relatively flat.
because of the reduced size of the grains and because of proper boundary grain diffusion. Loading tests have shown satisfactory reproducibility.

![Pd cold worked and annealed.](image)

**Calorimetric system**

The experiment is carried out using flow calorimeters equipped with electrochemical cells in which pre-treated palladium cathodes have been electrochemically loaded by using LiOD 0.1 M electrolyte. Some experiments employ laser irradiation during the electrolysis. Figure 2 shows a schematic of the calorimeter.

The calorimetric cells have been modeled and designed to have the required sensitivity and measurement accuracy by using a three dimensional, time dependent, finite element approach.

Two methods have been adopted to cool the electrochemical cells. The first cell is working in a cooling water jacket, the second one employs a coolant pipe (steel covered by a thin Teflon layer) passing through the electrolyte and is equipped with two windows for the laser irradiation. Both are helium tight (He leakage < 1E-10 mbar l/s), and equipped with a catalyst that recombines the gas produced by the electrolysis. A pressure gauge is used to measure pressure in the cell during the experiment. The two cells have an electrolyte volume of 30 and 60 ml respectively.
The cells are enclosed in an insulator and operated in a thermostatically controlled constant temperature box (±0.05°C). The coolant coming from a thermostatic bath (Haake ±0.05°C), passes through a high precision flow meter and controller (Bronkhorst, 0.3 - 0.1 cc/s) and the input and output temperatures of the coolant are measured with PT-100 thermometers read by a temperature monitor (Lake Shore, model 218). Electrolyte temperature is also measured with PT-100 thermometers.

Cell power is supplied with a galvanostat modulated (AMEL, 555c), and sometimes equipped with a wave function generator (HP, 33120). Galvanostatic operation allows direct current power to be computed as a scalar product of current and voltage. Current and voltage are measured by means of two HP34401A 6.5 digit multimeters. Typically the cells operate with voltage and current ranging between 2.5 and 12 V and 5 - 300 mA. The constant temperature box, bath and ambient temperatures as well as the cell pressure are read by an HP34970A. The data acquisition system uses GPIB connections and LabView.

Output power is measured by means of the mass flow rate and coolant temperatures. R/Ro four-wire loading measurement is done by means of an HP-4284.

Several experiments have been done using light water (LiOH 0.1 M electrolyte) obtaining calorimeter heat recovery efficiency of 97.5% (output=0.975 input, with 0.025 unaccounted for heat losses).

---

Fig. 2. Flow calorimeter system with electrochemical cell.
The cathode is a palladium foil (20 × 10 mm × 50 μm) between two platinum foils (symmetric 45 × 15 mm), the anode-cathode distance is 6 mm.

Figure 3 show the temperature field in the cells under typical operating conditions.

![Temperature field](image)

**Fig. 3. Calculated 3-D Temperature distribution in the cell shown in Fig. 2.**

**Experimental activity**

Several cells have been run with light water with two goals: to determine the efficiency of the calorimeters and to study if anomalous thermal behaviour occurs with palladium loaded with hydrogen.

No excess power production has been observed using H₂O despite the fact that very high loading (H/Pd=0.97) was always achieved.

The sensitivity of the calorimeter was estimated to be 50 mW ± 20 mW.

Excess power production has been observed only during electrochemical loading of deuterium in palladium, both with laser irradiation and without irradiation.

Although only a small number of tests with laser triggering have been done, preliminary results indicate that the laser has a stabilizing effect on excess power production.
This experimental campaign shows very high reproducibility (close to 100%) in loading above the threshold, and significant reproducibility in triggering excess heat. Excess heat appeared in around 60% of the tests at ENEA and up to 75% of the tests at SRI. It is clear that the loading above the threshold, to an average value estimated to be around D/Pd = 0.9, is a necessary condition to obtain the production of excess power.

The strategy leading to this improvement in results was extended research into material science. Metallurgy was integrated with a study of surface materials, the processes occurring at the interface, and with the electrochemical experimental conditions. This project was jointly performed by ENEA, SRI, NRL, the University of Rome and Energetics Technologies. A study oriented to correlate the surface morphology with the loading is presented by some of the authors in another paper [10].

Here are some of the experimental results obtained at ENEA:

Sample L14 was etched with and nitric acid for 60 sec and with 100% aqua regia for 60 s before electrolysis. During the experiment the current and voltage ranged between 10 to 15 mA and 2.4 to 3.5 V respectively. This sample showed good loading, up to D/Pd = 0.95. The maximum was achieved at very low current (13 mA on 6 cm² of cathode surface).

Excess power occurred as shown in Fig. 3, where the measure of uncertainty is taken into account. Both heat bursts are very well correlated with the electrolyte temperature, as may be seen from Fig. 5. The temperature of the electrolyte was monitored with a PT100 thermometer as was the inlet and outlet coolant temperature. Notice that the electrolyte temperature was read with a different temperature reader, so that a malfunction of

Fig. 4. Excess power (sample L14)  Fig. 5. Electrolyte temperature (sample L14)
temperature reader can be excluded. The amplitude of the excess peaked at 80% of the input power.

Larger excess was obtained with sample L17. The input and output power are shown in Fig. 6. The second burst is long enough for the calorimeter to achieve a steady state. We can see in Fig. 6 that during the excess power event, the input power declines. This is due to the power supply operating in galvanostatic mode. The strong excess heat, up to 620 mW, produced a temperature increase of the electrolyte (Fig. 7) that reduced the electrolyte resistivity and the interface impedance, so that less voltage was required to maintain the set current, thus reducing input power.

In conclusion, input was 125 mW and output was 620 mW, so that the output gain was 500%. Specimen L17 was etched like L14. The current ranged from 10 to 65 mA and voltage ranged from 2.6 to 4.5 V. Figure 7 shows that the electrolyte temperature increase during excess power production in experiment L17 reproduced the behaviour observed during experiment L14.
Figure 8 shows the excess power during experiment L30, and Fig. 9 shows the corresponding increase in the electrolyte temperature. In this case a steady state in the calorimeter was not achieved. Output power increased up to 800 mW with input power of 100 mW. But a calculation accounting for the transient temperature rise of the calorimeter shows that 7 W of additional power output occurred during the 600-second transient event. This result is quite astonishing since it indicates output power that is 7000% of input. The model accurately describes the evolution of the electrolyte temperature. The modeling tool developed to design calorimeters was used to estimate the excess in transient conditions.

Figure 8. Temperature and Output Power decreasing after changing electric polarity. 
Pin=constant

Fig. 8. Excess power during experiment L30.

Fig. 9. Electrolyte temperature increasing and voltage evolution during excess power in experiment L30.

Fig. 9. Electrolyte temperature increasing and voltage evolution during excess power in experiment L30.
A very stable effect seems to be obtained with sample L35, under laser irradiation. Figure 8 shows the cell temperature and output power decreasing due to electric current polarity switching during sample L35 electrolysis. The two consistent effects prove the presence of an excess heat, switched off by a sharp de-loading produced by current inversion.

Conclusions

Research activity at ENEA in the field of Condensed Matter Nuclear Science has been oriented to material science in order to increase the reproducibility of excess power production during loading of palladium with deuterium.

A finite element model has been developed to simulate the calorimeter’s thermal response. This simulation allowed us to obtain real heat recovery efficiency of 97.5%. The sensitivity of the calorimeter was estimated to be 50 mW ± 20 mW.

The palladium metallurgy was optimized to improve the loading of deuterium.

A preliminary study has been done to identify a correlation between the loading and the surface structure.

Even though the extended material science approach is still in progress, an improvement at experimental level was obtained leading to increased of the reproducibility at ENEA, SRI and Energetics Technologies to a level of 60% in ENEA, and up to 70% at SRI.

Some examples of the observed excesses power are presented. Sample L14 showed good loading up to D/Pd = 0.95, and amplitude of the excess power is 80% of the of the input at the peak.

Sample L17 gave a large excess gain of 500%.

Sample L30 gave the strongest excess power observed up to now in the ENEA Frascati Laboratory using electrochemical loading of palladium with deuterium.

Laser triggering seems to act as a stabilizer of the phenomenon: excess power usually does not show burst behaviour, but is quite stable over time, and of low amplitude. The low level of excess heat could be ascribed to the small spot size of the laser beam.

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Element Analysis of the Surface Layer on the Pd and Pd-Y Alloy after Deuterium Permeation

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Abstract

ToF-SIMS analysis showed that new elements appeared on the surface layer of a palladium sample and on a palladium-yttrium alloy sample after permeation of deuterium through the surface. It agrees with the similar experimental results at the Advanced Technology Research Center, Mitsubishi Heavy Industries, Ltd. Our experiment showed that this phenomenon may appear at higher temperatures even when there is no multiple layer coating on the sample surface.

Keywords Condensed Matter Nuclear Science, Pd, Pd-Y, ToF-SIMS, deuterium permeation

Introduction

In contrast with early experiments using a palladium cathode in electrolytic cell, we have been using the gas loading method to study abnormal phenomena in palladium deuterides since 1989. We observed that when deuterium gas was pumped out from a palladium wire there was an abnormal heat flow. When a high-precision calorimeter was used to detect the heat flow, we found that there was a correlation between the abnormal deuterium flux and the heat flow in the D/Pd system[¹]. Y. Iwamura et al. have observed nuclear transmutations with a deuterium gas flux[²]. They confirmed their result by delivering their samples to France for ToF-SIMS analysis, while at their own laboratory they used on-line XRF (X-Ray Fluorescence spectrometry). Fortunately, in our National Key Laboratory for Surface Physics and Chemistry there is a gas purifying and gas-solid reaction system equipped with a ToF-SIMS for on-line analysis. It provided an opportunity to examine the Iwamura effect in situ. In a distinct difference from Iwamura’s method, we simply loaded the deuterium flux to the surface of Pd without multiple layer coating. Despite this difference we still observed new elements on the surface layer of Pd or Pd-Y alloy. Moreover, our system is able to heat the samples to much higher temperatures than Iwamura can achieve, but even at high temperatures we still observed anomalous nuclear phenomena after deuterium permeation.
Apparatus and Experiment

The gas purifying and gas-solid reaction system (Fig. 1) was used to perform deuterium permeation experiments and analysis on line. The reaction chamber vacuum can reach $10^{-8}$ Pa, and the heating platform offered program-controlled heating from room temperature to 1200°C. In the analysis chamber, a time of flight mass spectrograph was used for on-line analysis. The samples were first degassed in the vacuum and then they absorbed deuterium gas at room temperature. After that, they were heated to 400°C and cooled to room temperature in the D$_2$ atmosphere. When heated, they released the deuterium; and when cooled, they absorbed deuterium again$^{[3]}$. The D$_2$ gas was finally pumped out before the SIMS analysis. In this whole process, the samples absorbed and released deuterium twice; hence, we achieved the required deuterium permeation flux twice, in two directions.

Two kinds of samples were used: Pd samples (No. 1 and 2) supplied by Research Institute of Aeronautical Materials (99.98% purity); and Pd-Y samples (Nos. 3, 4 and 5) supplied by the Key Laboratory. Sample No. 3 and 4 contain Y 8.27 at. %, and No. 5 contains Y 7.64 at. %. The size of the samples is about 1 cm$^2$ with thickness of 0.1 mm.

The samples were glued to stainless steel blocks and polished with #2000 sandpaper in pure water. Then they were finely polished with a Metallographic Polishing Machine (model GPV-2) at a speed of 940 r/min. The samples were separated from the blocks by dipping them into acetone for about 2 hours, and then carefully cleaned with acetone. A small piece was cut from each sample for background analysis.

On the first day, before the deuterium loading, the vacuum in the sampling chamber was $5.5 \times 10^{-6}$ Pa, while in the reaction chamber it was $6.0 \times 10^{-7}$ Pa. Each of the samples was placed on a stainless steel plate. Sample No. 1 was put into the reaction chamber, while others remained in the sampling chamber. Sluice valve B closed, and the reaction
chamber was continuously pumped, while the sampling chamber was pumped for only 24 hours. On the fifth day, the sampling chamber was at 3.9 Pa and the reaction chamber was at $3.4 \times 10^{-7}$ Pa. After this, the sampling chamber was pumped again for about 12 hours, down to a vacuum of $8.6 \times 10^{-6}$ Pa. During all of these processes, the vacuum of the reaction chamber and the analysis chamber remained almost unchanged.

From 21:50 pm on the fifth day to 5:13 am on the sixth day, sluice valve B was kept open, and the samples were shifted between the sampling chamber and the reaction chamber one after another to undergo the process of absorbing and releasing deuterium gas. The deuterium gas absorbent (uranium) bed was heated to 420°C for 30 minutes to release the deuterium. The deuterium gas was purified through a Pd membrane filter first; then, it entered the reaction chamber and sampling chamber. After the samples were saturated with $D_2$, the vacuum reached $3.0 \times 10^{-4}$ Pa.

The main parameters of the heating program are listed in table 1.

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The experiment steps were under program control. The heating platform reached 400°C in 45 minutes and was kept at 400°C during the following processes. Sample No. 1 was fetched back to the sampling chamber after 30 minutes where it cooled down naturally. Then, samples No. 2 through 5 samples was shifted into the heating platform to be heated for 30 minutes and returned back to the sampling chamber one by one. Finally, sample No. 5 stayed on the platform after being heated, and the heater was shut off. Then it was cooled down to 50°C in 80 minutes. The cooling speed of sample No. 5 should be the slower in comparison with that of the other 4 samples that cooled in the sampling chamber. The deuterium gas was then pumped out by the uranium absorbent bed. The sampling chamber and reaction chamber were pumped to high vacuum again. Then the samples were shifted into the analysis chamber for analysis using the ToF-SIMS.

The primary ion of SIMS is Ar⁺, the intensity of which is adjustable from 300 nA to 20 mA. The mass resolution of the ToF-SIMS is 5000 FWHM; the ion beam footprint on the sample is 0.01 mm²; the sensitivity is $1 \times 10^8$/cc for aluminum or $2.4 \times 10^{12}$/cc for copper.
Results

1. Thallium (Tl) observed in Pd-Y alloy after deuterium permeation

The elemental analysis of sample No. 5 (Pd-Y) showed two peaks at m/z=203, 205 (Fig. 2).

The “counts” in the figure denotes the intensity of the secondary ions. In the background mass spectrograph, the compound ion Pd+Y, the m/z of which was 193,194,195,197,199, respectively were found in addition to Pd and Y, but there was no peak near m/z=203,205. Some other elements, such as Na, Si, K, Ar, Fe, and Zn were found, but they could not form any compound ion whose m/z=203,205. The natural abundance of Tl is Tl-203 29.52%, Tl-205 70.48%, which is different from the distribution in mass spectrograph shown here.

Some points on the surface layer of sample No. 5 were analyzed to study element variation by depth. These points were bombarded continuously (primary ion intensity: 10 mA), and the secondary ion intensity was measured at every minute. The mass spectrograph is shown in Fig. 3.
Fig. 3. Element variation at different depths

Curve 1 shows the SIMS analysis for the layer at the first minute on the surface; Curve 5 shows the SIMS analysis for the layer at the 9th minute. The time interval between neighboring curves is 2 minutes. Each curve is shifted upwards by 60 counts in order to show them clearly. In the initial 5 minutes, there was no Tl but there was Pd+Y; while in the following 5 minutes, there was no Pd+Y but there was Tl.

Just after this point was bombarded, another point in the nearby region was bombarded (Fig. 4, showing curves plotted like those in Fig. 3).

Fig. 4. Element variation at different depths at a nearby point.

In this case, Tl was detected during the initial 5 minutes, but no Tl was found over the next 5 minutes. After 10 minutes Tl appeared again. Probably there was no Tl in the
original surface layers at this location, but the Tl sputtered from the previous nearby location. There was almost no Pd or Y where the Tl appeared. The causation should be studied further in our next experiments.

Tl did not appear at the every point on the surface of the sample. We attempted to use SEM (Scanning Electron Microscope, WSD mode) to confirm this trace of Tl after the samples were taken out from this apparatus; however, SEM analysis (WDS mode) did not show any Tl on the surface. A possible explanation for this is that the Tl appeared only on some points and in the layer under the surface (as confirmed by Fig. 3 and Fig. 4). Tl was not observed in samples No. 3 or 4, so the slow cooling down of sample No. 5 may be essential. The negative results with samples No. 3 and 4 exclude the possibility of contamination in this apparatus.

2. Gadolinium (Gd), Terbium (Tb), Niobium (Nd) observed in Pd after deuterium permeation

The element analysis of No. 1 and 2 samples (Pd) shows peaks from m/z=155 to 160 after deuterium permeation. In Fig. 5, the upper two curves show the SIMS analysis of the background, the lower two curves show the SIMS analysis after deuterium permeation.

There are no peaks in this range of mass numbers in the background analysis. It was determined that the elements in these peaks are Gd (m/z=155, 156, 157, 158, 160) and Tb (m/z=159). There is also peaks of Nd (m/z=142, 143, 144, 145, 146, 148, 150). We observed the Tb in earlier experiments[4] as well.

![Fig. 5. Gd,Tb,Nd observed in Pd after deuterium permeation](image-url)
Conclusion and Discussion

Based on this experimental observation we conclude that: Gd, Tb, Nd are observed in Pd after deuterium permeation; and Tl is observed in Pd-Y alloy, and this Tl did not exist on the surface layers of Pd or Pd-Y before deuterium permeation. Contamination and compound ions have been excluded, so the new elements are presumably produced by nuclear reactions. This conclusion should be bolstered in our next set of experiments. We will increase the number of times deuterium permeation is performed, which we believe to be a critical parameter.

This experiment showed that deuterium flux permeating through the palladium surface might introduce not only the heat flow\cite{1}, but also the nuclear transmutation\cite{2,4}. This experiment showed also that the multiple layer coating on the surface might be not necessary, and the operation temperature can be higher than that in Mitsubishi’s experiment\cite{2}.

Acknowledgement

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References

List of Participants

8th International Workshop on Anomalies in Hydrogen / Deuterium Loaded Metals
13-18 October 2007

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