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Alternative Interpretation of Low-Energy Nuclear Reaction Processes with Deuterated Metals Based on The Bose-Einstein Condensation Mechanism

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Abstract

Recently, a generalization of the Bose-Einstein condensation (BEC) mechanism has been made to a ground-state mixture of two different species of positively charged bosons in harmonic traps. The theory has been used to describe (D + Li) reactions in the low energy nuclear reaction (LENR) processes in condensed matter and predicts that the (D + Li) reaction rates can be larger than (D + D) reaction rates by as much as a factor of ~50, implying that (D + Li) reactions may be occuring in addition to the (D + D) reactions. A survey of the existing data from LENR experiments is carried out to check the validity of the theoretical prediction. We conclude that there is compelling experimental evidence which support the theoretical prediction. New experimental tests of the theoretical prediction are suggested.

1. Introduction

Recently, the Bose-Einstein condensation (BEC) mechanism has been generalized to a ground-state mixture of two different positively charged bosons (such as deuterons and lithium-6 nuclei, or deuterons and palladium nuclei) in harmonic traps [1]. One of the main predictions of the BEC mechanism is that the Coulomb interaction between two charged bosons may be suppresssed for the case of a large number of particles and hence the conventional Gamow factor may be absent. The theory has been used to analyze low-energy nuclear reaction (LENR) experiments involving atomic clusters (Pd black powders) [2] and acoustic cavitation [3]. The generalization to the two species case allows us to propose an alternative theoretical interpretation of LENR processes in deuterated metals to include the two-species reactions with entrance channel (D + X) where X represents a Bose nucleus other than D, in addition to the conventional one-specie (D + D) reaction. Both (D + X) and (D + D) reactions may be occurring in LENR and transmutaion experiments.

For application of the BEC mechanism to LENR and transmutation (or cold nucleosynthesis) experiments involving metals, we assume that non-equilibrium fluctuations might make either vacancies or impurities sufficiently mobile so as to allow Bose nuclei to move collectively in localized regions. Another possibility is that these non-equilibrium fluctuations might enable the particles to tunnel so as to create localized BEC states. These mechanisms are expected to be more favaorable with micro- and nano-scale atomic clusters, dendrites, and cavities on metal surfaces, and are consistent with recently proposed "crud" scenario [4].

The proposed theoretical interpretation is discussed for the results (excess heat and nuclear emission) of LENR experiments with deuterated metals (heavy water electrolysis, deuterium gas, etc.) including triggering requirements such as laser stimulation [5], and deuteron beam experiments [6,7]. To assess the validity of this proposed theoretical interpretation for the LENR experiments, it is essential to carry out accurate probes of isotope abundance ratios in deuterated metals by neutron activation analysis (NAA), time of flight secondary ion mass spectroscopy (TOF-SIMS), and trace-element accelerator mass spectroscopy (TEAMS) [8,9].

2. Bose-Einstein Condensation (BEC) Mechanism

Recently, the previously developed theory [10-14] of the BEC mechanism for one-specie LENR such as (D+D) reactions has been generalized to two-species case and applied to $(\mathrm{D+Li})$ reactions [1]. In this section, we summarize the results and predictions of two-species BEC mechanism for LENR and transmutation processes [1].

2.1 Selection Rules

For the BEC mechanism for LENR and transmutation processes, there are two selection rules: (1) nuclear spin selection rule and (2) nuclear mass-charge selection rule. Selection rule (1) is exact while selection rule (2) is approximate.

(1) The Nuclear Spin Selection Rule:
The nuclear spins of both species must be integer. This rule is obvious for the BEC mechanism.

(2) The Nuclear Mass-Charge Selection Rule:
This approximate selection rule is given by the following relation

$$Z_1 / Z_2 \;=\; m_1 / m_2 \approx (Z_1 + \tilde{N}_1)/(Z_2 + \tilde{N}_2)$$

where $\tilde{N}_i$ is the number of neutrons in the Bose nucleus for the specie *i*. We note that the above relation is satisfied, for example, for two species with Z_i=$\tilde{N}_i$.

2.2 Fusion Rates

For the two species case, we approximate the short-range nuclear interaction by a Fermi pseudo-potential [10] and write it in a generalized form as

$$Im V_{ij}^{\,F}(\vec{r}) \;=\; -A_{ij}\hbar\,\delta(\vec{r})/2,$$

where the nuclear reaction rate constants A_{ij} are given by

$$A_{ij} \;=\; 2S_{ij}r_B^{(ij)}/(\pi\hbar),$$

with $r_B^{(ij)} = \hbar^2/(2\mu_{ij}Z_iZ_je^2)$ and $\mu_{ij} \;=\; m_im_j/(m_i+m_j)$. S_{ij} are the *S*-factors for nuclear

fusion between two nuclei from species *i* and *j*.

The nucleus-nucleus fusion rates are determined from the trapped ground state wave function Ψ as

$$R_{11} = -(2/\mathrm{h})\sum_{i<j}^{N_1} < \Psi \mid ImV_{11}{}^{F}(\vec{x}_i - \vec{x}_j) \mid \Psi > / < \Psi \mid \Psi >,$$

$$R_{12} = -(2/\mathrm{h})\sum_{i=1}^{N_1}\sum_{j=1}^{N_2} < \Psi \mid ImV_{12}{}^{F}(\vec{x}_i - \vec{y}_j) \mid \Psi > / < \Psi \mid \Psi >,$$

$$R_{22} = -(2/\mathrm{h})\sum_{i<j}^{N_2} < \Psi \mid ImV_{22}{}^{F}(\vec{y}_i - \vec{y}_j) \mid \Psi > / < \Psi \mid \Psi >,$$

and in the mean-field approximation, we have R_{11}=$A_{11}N_1{n_1}^B/2$, R_{12}=$A_{12}N_1{n_2}^B$, and R_{22}=$A_{22}N_2{n_2}^B/2$, where $n_i^B = N_i/((4/3)\pi R_i^3)$. N_i is the total number of specie *i*, and R_i is the radius of the trap for specie *i*.

If the probabilities of the mean-field ground state occupation [10], Ω_i, are taken into account, the trap fusion rates are given by ${R_{11}}^t = \Omega_1 R_{11}$, ${R_{22}}^t = \Omega_2 R_{22}$, and $R_{12}^t = \Omega_3 R_{12}$. We expect that $\Omega_3 \approx \sqrt{\Omega_1 \Omega_2}$.

2.3 Application to (D+Li) Reactions

For ${}^6Li(d,\alpha)^4He$ (Q=22.37 Mev) and ${}^7Li(d,n)2^4He$ (Q=15.12 Mev), the S-factors are 18.8 Mev-barn[15,16] and 30 Mev-barn [17], respectively, as shown in Table 1. Using these values we find that the corresponding nuclear reaction rate constants are $A_{d^6Li} \approx 5.8\times10^{-15} cm^3/sec$ and $A_{d^7Li} \approx 8.97\times10^{-15} cm^3/sec$ which are about 50 times larger than the d-d nuclear reaction rate constant $A_{dd} \approx 1.5\times10^{-16} cm^3/sec$.

We expect that nuclear reaction rate constants for reactions ${}^6Li({}^6Li,{}^5Li)^7Li$ (Q=1.86 Mev) and ${}^6Li({}^6Li,\alpha)2^4He$ (Q=20.897 Mev) are much smaller than A_{d^6Li}.

For the BEC mechanism, the $(d+{}^7Li)$ reaction rate is expected to be suppressed compared with the $(d+{}^6Li)$ reaction rate due to the selection rule A. This is consistent with the observation of depletion of ${}^6Li$ [18,19] as inferred from increased ${}^7Li/{}^6Li$ abundance ratio in Arata-Zhang's particulate Pd exposed to deuterium gas [20-22].

The excess heat and ${}^4He$ observed in electrolysis experiments [23] may be due to ${}^6Li(d,\alpha)^4He$ in addition to other reactions leading to the final states without ${}^4He$ (see Table 1 and 2). This would be an alternative scenario to the (d+d) reaction scenario which has been proposed by many.

2.4. LENR and Transmutation Processes in the Metal Surface Region

As pointed out recently by Storms) [4,24], there are many experimental observations [26-37] suggesting that LENR and transmutation processes in condensed matter maybe occuring in nuclear active environment (NAE) or nuclear active spot (NAS) created in the surface region of deuterated metals. If this active spot contains a high-density plasma (positive ions (nuclei) and electrons) trapped in a micro/nano scale cavity in the metal surface region, our theoretical model for the BEC mechanism is appliciable and could provide an appropriate theoretical description of LENR and trasmutation (cold nucleosysthesis) processes.

Table 1. Lithium reactions with positive Q-values and extrapolated S-factors at E=0

Reaction	**Q-value (MeV)**	**S(MeV-b)**
$^{6}L_{i}(d,\alpha)^{4}He$	22.37	18.8[15], 16.9[16], 18.7[16]
$^{6}L_{i}(d,t)^{5}Li$	0.59	
$^{6}Li(d,\alpha n)^{3}He$	1.80	
$^{6}Li(d,\alpha p)^{3}H$	2.56	
$^{6}Li(d,n)^{7}Be$	3.38	
$^{6}Li(d,p)^{7}Li$	5.03	
$^{6}Li(d,\gamma)^{8}Be$	22.27	
$^{6}Li(p,\alpha)^{3}He$	4.02	
$^{7}L_{i}(d,n)2^{4}He$	15.12	30±6[17]
$^{7}L_{i}(d,\alpha)^{5}He$	14.23	
$^{7}Li(d,n)^{8}Be$	15.03	
$^{7}Li(p,\alpha)^{4}He$	17.24	

3. Experimental Evidences for (D+Li) and Other Two-Species Reactions

A number of hints have been evident over the past 16 years that lithium and possibly other light elements such as beryllium and boron were the source of excess heat production by various possible nuclear reactions with deuterium. Many of these reactions produce heat without appreciable emission of neutrons or tritium, but are indeed capable of producing the small levels of these products that have been detected.

The most obvious hint was the almost complete absence of neutrons or tritium commensurate with the observed levels of excess heat. When finally detected, these products were not even in the same ratio with each other as expected from the D+D reaction. The ratio expected was 1:1 and the observed ratio was more like one million to one, favoring tritium. Even tritium was about one million times smaller than expected from D+D, if indeed that reaction had been the source of the excess heat observed. Since those early observations many

attempts have been made to explain how D+D reaction channels could be modified in a solid to favor ^{4}He reaction by ten million times over the expected value and the almost complete, and unequal, suppression of the channels leading to tritium or neutrons [38,39].

3. 1 Possible Roles of Impurities

Another early hint was the observation that there was a batch effect present among the palladium samples used as cathodes in the electrochemical cells producing excess heat. Some were noticeably more productive of excess heat episodes than others. These more productive cathodes were among the least pure palladium batches. Here was a hint that the impurities in palladium were playing a role in the heat production process. It was assumed at the time that such a role might be in the physical strengthening of the metal to prevent cracking during its 10% volumetric expansion upon being loaded with deuterium. The idea that these impurities might be direct participants in the nuclear reactions producing heat was not seriously considered in those early few years.

The impurities were measured and found to be not overwhelmingly different among the various batches of palladium, but one element stood out as a major consitituent among those present. This was boron, element number 5. Among the electrolytes used in the electrochemical cells, the impurity levels were not readily distinguished from each other, but all had beryllium and boron present at parts per billion levels in addition to the predominant lithium. It was noticed that small additions of aluminum and boric acid to the electrolyte were apparently beneficial to increasing the frequency of excess heat episodes in a given cell. Again, the trace impurities showed some sign of influencing the output of excess heat. Pursuit of the boric acid electrolyte addition was truncated at SRI International by McKubre after their observation of a disturbing change in the curve of electrical resistivity versus deuterium loading. The changed nature of that curve from one maximum at around 0.7 D/Pd to one with two-peaks was such as to make definite monitoring of deuterium loading ratios highly uncertain [40]. The loading ratio was believed at that time to be the primary variable determining the appearance of excess heat episodes, so that boric acid addition was stopped. Of course, boron at around 50 to 100 parts per million by weight, was still present in the various batches of palladium (actually 1000 PPM as atom fraction since boron atoms are one tenth the mass of palladium atoms).

The fact that such minor additives of aluminum and boric acid to the electrolyte (~200 PPM each by weight) had such a large effect on the system shows that the cathode surface nature is a determining factor in excess heat appearance. It was surprising that the boric acid additive should so dramatically influence the bulk metal property of electrical resistivity by which the loading ratio D/Pd was measured. One could speculate that boron is loading into the bulk Pd along with the deuterium. However, we must not overlook the fact that the element boron appears to increase the appearance of excess heat episodes and that it is plausible that the boron atom can move within the bulk lattice of the palladium sufficiently to affect the electrical resistance, as already observed for deuterium atoms.

3. 2 Initiation Period and Surface Effect

Another factor widely observed in the electrochemical methods of producing excess heat was the 200-600 hour "initiation" period before any episodes of excess heat were observed. This fact suggests that some slow process must be completed to achieve the conditions

necessary for excess heat production. Speculation on such a slow process has included diffusion of some atom or ion to some required location at the cathode surface or within the bulk, such as at grain boundaries. Lithium ions in the lithium deuteroxide electrolyte along with the impurities always present in this electrolyte are the prime suspects for this process. Another slow process is the gradual buildup of a surface layer on the cathode from well known cathodic deposition of any positive ion in the electrolyte, whether initially present or dissolved from the cell anode (platinum in most cases) or from the glass or quartz or Teflon cell walls. Observation of a black layer of porous material on the cathodes of many cells that ran for long times is well established. The composition of this black layer has occasionally been analyzed. Platinum, palladium, and calcium, silicon, and boron are among the elements observed, but no systematic study of the layer is known to have been performed. Evidence from a study by Storms [41] using platinum cathodes suggests that this layer is the likely locale of the excess heat effect. The impurities as well as the metals present there in a finely divided form of high surface area may be the source of excess-heat episodes. A surface source is all the more plausible from the observation of helium of mass 4 in the gas phase of heat-producing electrochemical cells [42]. If helium had been formed initially within the palladium cathode lattice, it would not easily move to the gas phase of the closed cell. In fact helium in solids lies sequestered for many years if it is initially produced within the solid by nuclear processes driven by high energy particles in cosmic rays [25].

3. 3 Evidence for (D+Li) reactions

Lithium has two isotopes, ^{6}Li and ^{7}Li with a natural ratio of 12.5 favoring ^{7}Li. Both may plausibly react with deuterium or protium in a set of 12 exothermic reactions, nine of which produce helium of mass 4 as listed in Table 1. However, it is likely that the reaction rate for each of these isotopes may be different enough in various cold fusion type experiments to show a change in the ^{7}Li/^{6}Li ratio remaining after the excess heat episodes are sufficiently productive of excess heat to burn out one of the two more than the other. Therefore, several investigators measured the ^{7}Li/^{6}Li ratio in materials known or alledged to have produced a substantial quantity of excess heat [18,19,43]. The major problem in this effort is to avoid lithium that is depleted in ^{6}Li in the initial surface. The use of ^{6}Li for thermonuclear devices was intense enough to have left behind a legacy of lithium depleted in ^{6}Li below its natural level. The time of flight secondary ion mass spectrometry (TOF SIMS) method is particularly well suited to this measurement since there are no significant interferences at those two mass numbers and lithium is more readily ionized than most other elements by the input gallium-71 beam of the instrument. Also, if the active region of excess heat production is at the surface of the material, this surface analysis method is all the more appropriate. Tables 2 and 3 give the ^{7}Li/^{6}Li ratios measured in a number of palladium samples from experiments that reportedly produced substantial amounts of excess heat. Needless to say, a much more comprehensive effort on many more candidate samples is necessary to fully confirm these initial suggestive findings.

One might wonder how lithium might be the nuclear reation source of excess heat in experiments apparently lithium-free. The TOF-SIMS measurements of numerous solid samples convinced us that lithium, like sodium, is a surface contaminant on ALL surfaces explosed to handling in the earth's atmosphere. The amounts DID vary, but lithium always showed up. We believe it would take a determined effort to perform an experiment with a surface free of lithium.

3. 4 Possible Roles of Boron Impurity

Beryllium with only one stable isotope, ^{9}Be, is not susceptible to this sort of experimental test. However, boron with the two isotopes ^{10}B and ^{11}B is subject to a similar test. Just as with ^{6}Li and ^{7}Li, both boron isotopes produce excess heat and ^{4}He without neutrons or tritium, but in any situation, reactions with one will most likely favor one over the other hence leading to a difference from the natural ratio of 4.0 favoring ^{11}B. No appreciable data on ^{10}B/^{11}B ratios are yet available. However, depletion of ^{10}B has been reported in several cathodes that reportedly produced substantial excess heat. These measurements were performed by prompt gamma neutron activation analysis (PGNAA)[44], but the method is not sensitive to ^{11}B.

Table 2. ^{7}Li/^{6}Li ratios in palladium exposed to gaseous hydrogen and deuterium from TOF SIMS analyses

Sample Designation	^{7}Li/^{6}Li Ratio	Uncertainty	One Sigma Range
Pd –D from Arata (Virgin)	13.6	1.0	12.6 - 14.6
Pd-A from Arata (Active)	14.5	0.3	14.2 - 14.8
Pd-B from Arata (Active)	22.0	1.4	20.6 - 23.4
Pd-C from Arata (Active)	16.2	0.1	16.1 - 16.3
SRI-H2O (Arata Exper.)	14.5	1.7	12.8 - 16.2
SRI-D2O (Arata Exper.)	13.8	0.1	13.7 - 13.9
Arata S-8 Powder	14.6	3.4	11.2 - 18.0
Arata S-5 Powder	13.5	1.8	11.7 - 15.3
Arata S-2 Powder	12.3	0.8	11.5 - 13.1
Arata S-1 Powder	13.1	0.5	12.6 - 13.6
Li Tsinghua Sample E	23.3	1.8	21.5 – 25.1
Li Tsinghua Sample D	13.1	1.1	12.0 - 14.2
Li Tsinghua Sample B (Virgin)	12.9	0.8	12.1 -13.7
SC-1 Unused Catalyst (Case [46])	16.7	1.4	15.3 - 18.1
SC-2 (SC-1)(prod 11 ppm He)	17.5	3.3	14.2 - 20.8
SC-19(SC-20)(prod 9 ppm He)	12.6	0.7	11.9 – 13.3
SC-20 (Prod. No He)	10.2	0.8	9.4 - 11.0
Terrestrial Lithium (Handbook)	12.48		

3. 5 Summary of Section 3

The case favoring non D+D reactions as the source of excess heat in cold fusion type experiments has been given here. The light elements have been favored because they are almost universally present at low levels in all the materials used in such studies and all three of them have known reactions producing excess heat and ^{4}He without predominantly neutrons or tritium, even though such reactions are known. Some hints of other nuclear reactions such as the fission of palladium isotopes to elements in the region around iron (element 26) exist [18] but are not considered sufficiently robust to treat in detail here. Such reactions may indeed be present and would produce excess heat without commensurate neutrons or tritium (with positive exothermic energies per reaction of 20-30 Mev). However, ^{4}He would not be produced in such reactions.

The evidence does point to a reaction on large surface area materials of a catalytic nature[20-23,45] and seems to indicate the possibility of a gaseous interface with the catalyst as being the key. For example, even in liquid electrolyte experiments, the high deuterium loading criteria may be signaling the need for a high rate of hydrogen bubble formation at the cathode surface, maximizing the time spent as a gaseous interface of bubble and surface. The long time required before observation of excess heat may signal the need to build a high surface area deposited film to contact that continual series of gaseous deuterium bubbles after loading is complete to a high level. In the case of Arata-Zhang [20-22], the production of excess heat seems to favor palladium particle sizes under 40 nanometers exposed to high pressure deuterium gas inside their hollow cylindrical cathode.

TABLE 3. Ratios of ^{7}Li to ^{6}Li in active samples relative to the virgin materials or materials from the same batch giving no excess heat or ^{4}He

Samples Ratioed	Ratio	Uncertainty
Pd-A/Pd D	1.066	0.082
Pd-B/Pd-D**	1.618	0.159
Pd-C/Pd-D	1.191	0.088
SRI-D2O/SRI-H2O	0.952	0.114
SRI-D2O/Pd-D	1.015	0.075
SRI-H2O/Pd-D	1.066	0.148
Arata S-8/Pd-D	1.074	0.268
Arata S-5/Pd-D	0.993	0.151
Arata S-2/Pd-D	0.904	0.090
Arata S-1/Pd-D	0.963	0.081
Li Tsinghua E/B**	1.806	0.181
Li Tsinghua D/B	1.016	0.107
SC-2/SC-1	1.053	0.221
SC-19/SC-20*	1.232	0.120

*High by ~2 sigma; **High by 3-5 sigma

4. Proposed Experimental Tests

In order to test the possibility that (D+Li) reactions are involved in the LENR processes in condensed matter and also to test the predictions of the BEC mechanism as described in section 2, we propose to use ^{6}Li and ^{7}Li separately and also to use microporous or nanopourous materials in the following types of experiments:

(1) electrolysis experiments of Fleischmann-Pons type[46-54].
(2) gas experiments[2,20-22,45,55], and
(3) nuclear emission experiments [56,57].

The microporous or nanoporous materials include: vycor glasses[58], aerogels[59], nanogels[60], ordered nanoporous thin films[61], carbon arerogels[62], and pocofoams[63]. The use of microporous or nanoporous materials in these experiments recently proposed by Kim et al.[64] is expected to enhance the observed effects by many orders of magnitude if the observed processes are surface phenomena, since active surface is substantially larger for these materials compared with the surface area of a bulk metal.

5. Summary and Conclusions

There are now a substantial number of LENR experimental data indicating that (D+Li) reactions are involved in LENR processes in condensed matters. In addition, there are many indications that the LENR processes in condensed matters are surface phenomena. The BEC mechanism may provide a suitable theoretical description for the surface phenomena involving high-density plasma (D, Li, e^-) formed in micro/nano scale cavities. The possibility of (D+Li) reactions and the predictions of the BEC mechanism for LENR processes can be tested by carrying out (1) electrolysis experiments of Fleischmann-Pons type, (2) gas experiments and (3) nuclear emission experiments, using ^{6}Li and ^{7}Li separately and also using porous materials instead of bulk metals, as recently proposed by Kim et al. [64].

References

[1] Y. E. Kim and A. L. Zubarev, "Mixtures of Charged Bosons of Confined in Harmonic Traps and Bose-Einstein Condensation Mechanism for Low-Energy Nuclear Reaction and Transmutation Processes in Condensed Matters", submitted to ICCF-11, 2004, Marseilles, France, and references therein.

[2] Y.E. Kim, D.S. Koltick, R. Pringer, J. Meyers, and R. Koltick, Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[3] Y.E. Kim, D.S. Koltick, and A.L. Zubarev, Proceedings of ICCF-10, Cambridge, Massachusetts

[4] E. Storms, "What Conditions Are Required to Initiate the LENR Effect ?", Proceedings of ICCF-10, 2003, Cambridge, Massachussetts.

[5] D. Letts and D. Cravens, Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[6] J. Kasagi, Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[7] J. Kasagi, Proceedings of ICCF-11, 2004, Marseilles, France.

[8] G. K. Hubler et al., Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[9] T. O. Passell, Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[10] Y.E. Kim and A.L. Zubarev, Fusion Technology **37**, 151 (2000).

[11] Y.E. Kim and A.L. Zubarev, Italian Physical Society Proceedings **70**, 375 (2000) for ICCF-8, 2000, Lerici (La Spezia), Italy.

[12] Y.E. Kim and A.L. Zubarev, Phys. Rev. A**64**, 013603 (2001).

[13] Y.E. Kim and A.L. Zubarev, J. Phys. B: At. Mol. Opt. Phys. **33**, 55 (2000).

[14] Y.E. Kim, Progr. Theor. Phys. Suppl. **154**, 379 (2004).

[15] S. Engstler et al., Z. Phys. A**342**, 471 (1992).

[16] A. Musumara et al., Phys. Rev. C**64**, 068801 (2001).

[17] J. Yan et al., Nucl. Phys. A**621**, 127c (1997).

[18] T.O. Passell, "Evidence for Litium-6 Depletion in Pd Exposed to Gaseous Deuterium and Hydrogen", Proceedings of the Ninth International Conference on Cold Fusion, pp. 299-304, May 19-24, 2002, Beijing.

[19] T.O. Passell, "Pd-110/Pd-108 Ratios and Trace Element Changes in Particulate Palladium Exposed to Deuterium Gas", Proceedings of the Tenth International Conference on Cold Fusion, 2003, Cambridge, Massachusetts.

[20] Y. Arata and Y.C. Zhang, Italian Physical Society Proceedings **70**, 11 (2000) for ICCF-8, 2000, Lerici (La Spezia), Italy.

[21] Y. Arata and Y.C. Zhang, Japanese J. Appl. Phys. **37**, L1274 (1998).

[22] Y. Arata and Y.C. Zhang, Japanese J. Appl. Phys. **38**, L774 (1999).

[23] M. McKubre et al., Italian Physical Society Proceedings **70**, 3 (2000) for ICCF-8, 2000, Lerici (La Spezia), Italy, and references therein.

[24] E. Storms, The APS conference, March 3-7, 2003, Austin, Texas.

[25] W.J. Camp, "Helium Detrapping and release from Metal Tritides", J. Vac. Sci. Technol. **14**, 514 (1977).

[26] E. Storms and C. Talcott-Storms, "The effect of hydriding on the physical structure of palladium and on the release of contained tritium", Fusion Technol. **20,** 246 (1991).

[27] P.A. Mosier-Boss and S. Szpak, "The Pd/(n)H system: transport processes and development of thermal instabilities", Nuovo Cimento A **112,** 577 (1999).

[28] S. Szpak, P.A. Mosier-Boss, and M.H. Miles, "Calorimetry of the Pd+D codeposition", Fusion Technol. **36,** 234 (1999).

[29] J. Dash and S. Miguet, "Microanalysis of Pd Cathodes after Electrolysis in Aqueous Acids", J. New Energy **1**(1), 23 (1996).

[30] G.H. Miley, et al. "Quantitative observations of transmutation products occuring in thin-film coated microspheres during electrolysis", in Sixth International Conference on Cold Fusion, Progress in New Hydrogen Energy. 1996. Lake toya, Hokkaido, Japan, New Energy and Industrial Technology Development Organization, Tokyo Institute of Technology, Tokyo, Japan.

[31] Y. Iwamura, et al. "Detection of Anomalous Elements, X-ray and Excess heat Induced by Continuous Diffusion of Deuterium Through Multi-layer Cathode (Pd/CaO/Pd)", in The Seventh International Conference on Cold Fusion. 1998. Vancouver, Canada: ENECO, Inc., Salt Lake City, UT.

[32] J.O.M. Bockris and Z. Minevski, "Two zones of 'Impurities' observed after prolonged electrolysis of deuterium on palladium", Infinite Energy **1**, 67 (1996).

[33] T. Ohmori, et al., "Transmutation in the electrolysis of lightwater – excess energy and iron production in a gold electrode", Fusion Technol. **31**, 210 (1997).

[34] D.S. Silver, J. Dash, and P.S. Keefe, "Surface topography of a palladium cathode after electrolysis in heavy water", Fusion Technol. **24**, 423 (1993).

[35] G.H. Miley, et al., "Multilayer Thin Film Electrodes for Cold Fusion", in Third International Conference on Cold Fusion, "Frontiers of Cold Fusion". 1992. Nagoya Japan: Universal Academy Press, Inc., Tokyo, Japan.

[36] E. Storms, "A critical evaluation of the Pons-Fleischmann effect: Part 2", Infinite Energy **6**(32), 52 (2000).

[37] R. T. Bush and R. D. Eagleton. "A Calorimetric study of the Excess Heat Effect in Thin Films of Palladium", in the Second Annual Conference on Cold Fusion, "The Science of Cold Fusion", 1991, Como, Italy: Societa Italiana di Fisica, Bologna, Italy.

[38] P.L. Hagelstein, Proceedings of ICCF-8, 2000, Lerici (La Spezia), Italy; Proceedings of ICCF-10, 2003, Cambridge, Massachusetts, and references therin.

[39] S.R. Chubb and T.A. Chubb, Proceedings of ICCF-8, 2000, Lerici (La Spezia), Italy; Proceedings of ICCF-10, 2003, Cambridge, Massachusetts, and references therin.

[40] M. McKubre et al., SRI EPRI Report TR-104195 (August 1994), pp. 3A-1 to 3A-22.

[41] E. Storms, Proceedings of ICCF-8, 2000, Lerici (La Spezia), Italy, pp. 55-61.

[42] M. McKubre et al., SRI EPRI Report TR-107843 volume 1 (June 1998), pp. 3-226 to 3-235.

[43] D. Thompson, Proceedings of ICCF-1, 1990, Salt Lake City, Utah.

[44] T. O. Passell, "Search for Nuclear Reaction Products in Heat-Producing Palladium", Proceedings of ICCF-6, 1996, Hokkaido, Japan.

[45] L.C. Case, "Fusion Technology", **20**, 478 (1991); Proceedings of ICCF-6, 1998, Vancouver, Canada; see also [23].

[46] P.L. Hagelstein, M.C. Mckubre, D.J. Nagel, T.A. Chubb, and R.J. Hekman, "New Physical Effects in Metal Deuterides", submitted to DOE for a review, July 2004, and references therein.This report was posted December 1, 2004 at the DOE website:http://www.sc.doe.gov

[47] See experimental papers in the Proceedings of the 10th International conference on Cold Fusion (ICCF-10), 2003, Cambridge, Massachusets.

[48 E. Storms, "Why Cold Fusion Has Been So Hard to Explain and Duplicate", The APS Conference, March 3-7, 2003, Austin, Texas.

[49] D. Letts and D. Cravens, "Laser Stimulation of Deuterated Palladium: Past and Present," Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[50] S. Szpak, P.A. Mosier-Boss, J. Dea, and F. Gordon, "Polarized D^+/Pd-D_2O System: Hot Spots and 'Mini-Explosions'", the Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[51] S. Szpak, P.A. Mosier-Boss, M.H. Miles, and M. Fleischmann, "Thermal Behavior of Polarized Pd/D electrodes prepared by co-deposition", Thermochimica Acta **410**, 101 (2004).

[52] M. McKubre et al., Italian Physical Society Proceedings **70**, 3 (2000) for ICCF-8, 2000, Lerici (La Spezia), Italy.

[53] G. H. Miley, et al. "Quanitative observations of transmutation products occuring in thin-film coated microspheres during electrolysis", in Sixth International Conference on Cold Fusion, Progress in New Hydrogen Energy. 1996. Lake Toya, Hokkaido, Japan: new Energy and Industrial Technology Development Organization, Tokyo Institute of Technology, Tokyo, Japan; Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[54] D.S. Silver, J. Dash, and P.S. Keefe, "Surface topology of a palladium cathode after electroylsis in heavy water", Fusion Technol. **24**, 423 (1993).

[55] Y. Iwamura et al., Japan Journal of Applied Physics, **41**, 4642 (2002); Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[56] S.E. Jones, et al., "Charged-particle Emissions from Metal Deuterides", Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[57] S.E. Jones, et al., "Neutron Emissions from Metal Deuterides", Proceedings of ICCF-10, 2003, Cambridge, Massachusetts.

[58] P. Levitz, G. Ehret, S.K. Sinha, and J.M. Drake, J. Chem. Phys. 95, 6151(1991).

[59] J. Fricke and A. Emmerling, J. of Sol-Gel Science and Technolgy 13, 299(1998).

[60] http:// www.cabot-corp.com

[61] Laika Menon, "Nanoarrays Synthesized from Porous Alumina," Dekker Encyclopedia of Nanoscience and Nanotechnology, pp. 2221-2238 (2004), Marcel Dekker, Inc., New York, NY.

[62] R.W. Pekala, et al., in "Sol Gel Science and Applications", edited by Y.A. Attia (Plenum Press, New York, 1994), p. 369.

[63] MRS Bulletin, December 2000, p. 10; http://www.pocofoam.com

[64] Y.E. Kim et al., "Proposal for New Experimental Tests of the Bose-Einstein Condensation Mechanism for Low Energy Nuclear Reaction and Transmutation Processes in Deuterium Loaded Micro- and Nano-Scale Cavities", Proceedings of ICCF-11, 2004, Marseilles, France.