Chemical Aspects of LENR

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Abstract – *The chemistry connected with low energy nuclear reactions is considered, starting with the Fleischmann and Pons work. Further innovations in electrochemical experiments following upon Fleischmann and Pons are examined. The chemical and structural nature of metal hydrides is discussed. Attention is paid to the variety of mixed metal hydrides that might potentially be exploited in LENR. Finally, the issues connected with LENR reactor design are touched upon.*

Key words: *LENR, Electrolysis, Hydrides, Palladium, Boron, Perspective*

I. INTRODUCTION

The study of low-energy nuclear reactions (LENR) has recently been experiencing a remarkable resurgence after spending many years in exile.[1] Therefore, a perspective view on where the field has been and where it is going seems in order. My view is that of an outsider, having followed LENR since it first burst on the scene as "cold fusion" in 1989, and then was promptly dismissed as nonsense. In this short perspective paper, I will address chemical aspects of the original cold fusion claims, some of the fine work that has been done during twenty-plus years in scientific exile, and a few thoughts moving forward as LENR stands on the verge of re-emerging as a contender in the global competition to identify viable new sources of energy.

II. WHY LENR?

The potential benefits of LENR seem too good to be true. And for all we know they might be. Nevertheless, it is important to discuss the enormous benefits that could be realized from successful implementation of LENR. These benefits are associated with a low-cost energy source using only small amounts of commonly available materials. Although palladium is fairly expensive, only small amounts would be required. And current trends suggest that nickel might be used instead. LENR-generated energy would be nearly carbon-neutral, fossil fuel use being associated only secondary matters, such as unit construction and transportation. Furthermore, it is reasonable to hope that LENR devices would be simple in design, compact, and low-maintenance.

It is to be hoped that LENR devices will be safe to operate; however, there are very real concerns to be addressed. These are associated with the radiological hazards of particle radiation and possible run-away reactions, with the chemical hazards of handling hydrogen, and with the physical hazards of pressurized gases and high temperatures. If these worries can be satisfactorily addressed, LENR might be used to address power needs connected with electricity generation, heating/air conditioning, water desalination, vehicles, aeronautics, and space applications.

A major advantage of putative LENR devices would be related to their independent, off-grid operation. There are a host of easily-imagined benefits to third world nations connected with off-grid use. Just as the wide acceptance of cell phones means that hard-wired infrastructure is becoming unnecessary in the developing world, so too might LENR make the construction of a full-fledged power grid similarly unnecessary. LENR devices could be used to power agricultural, water purification, irrigation, medical, transportation, environmental, and a plethora of other applications in advancing nations.

III. FLEISCHMANN AND PONS WORK

In 1989 cold fusion emerged from one of the pre-eminent electrochemistry laboratories in the world: that of Stanley Pons and Martin Fleischmann at the University of Utah. As a graduate student working partly in electrochemistry, I regarded the announcement of a new, potentially unlimited source of energy from a simple electrolysis experiment as remarkable and as a great coup for the oft-overlooked field of electrochemistry. Let's look

at the claims of these researchers.[2] They used a cell much like the one shown in Figure 1.3.[3] Using this apparatus, Fleischmann and Pons carried out the electrolysis of deuterium oxide/lithium deuteroxide (D_2O/LiOD) solutions over long periods of time using Pd cathodes. Electrochemical reduction of the D_2O produces D and OD^-, according to reaction 1 (See Figure 2A/B).
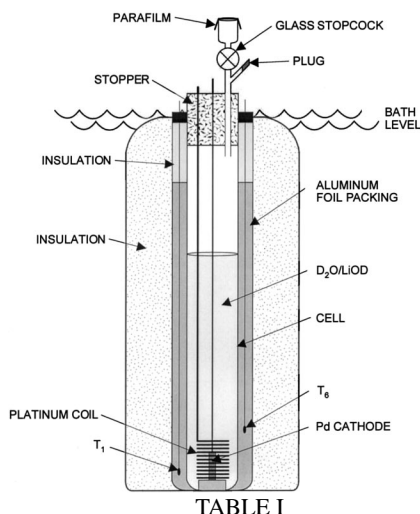
$$D_2O + e^- \rightarrow D + OD^- \qquad (1)$$

TABLE I

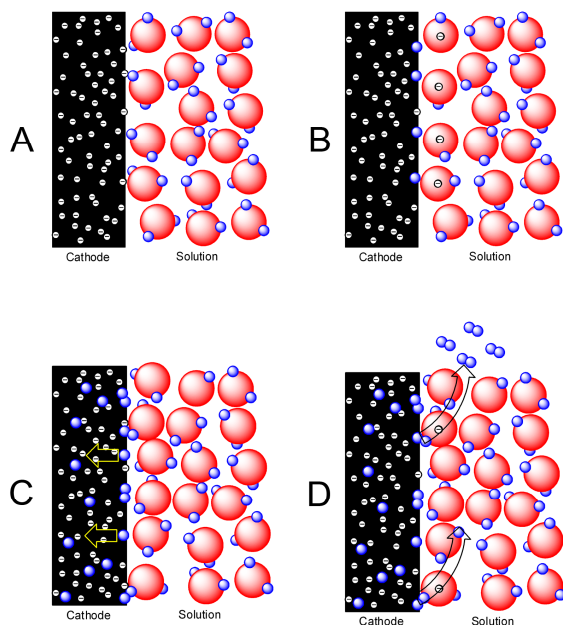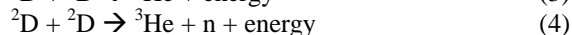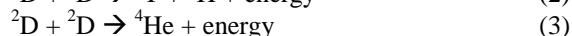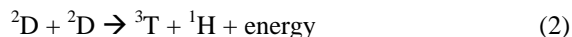Fig. 1 An insulated calorimetric Fleischmann and Pons-type electrolysis cell.[3]

Fig. 2 Electrolysis of D_2O at a Pd cathode (A) to produce D and OD^- (B). Competitive diffusion of D into the cathode (C) versus formation of D_2 gas (D).

The D atoms produced at the surface of the Pd cathode can either form D_2, which is subsequently lost from the electrode surface (Figure 2C); or it can move into Pd cathode lattice in accordance with the well-known ability of Pd to concentrate hydrogen (Figure 2D). The D atoms within the Pd were found to result in an unexpected release of excess heat in some experiments, but only after long induction periods. Fleischmann and Pons claimed that nuclear fusion might be occurring according to reactions 2−4.

$$
\begin{aligned}
&^2D + {}^2D \rightarrow {}^3T + {}^1H + \text{energy} \qquad (2)\\
&^2D + {}^2D \rightarrow {}^4He + \text{energy} \qquad (3)\\
&^2D + {}^2D \rightarrow {}^3He + n + \text{energy} \qquad (4)
\end{aligned}
$$

Most of the scientific community dismissed cold fusion as fallacy, resulting from some combination of error, wishful thinking, and even outright fraud. Foremost amongst the reasons cited for the impossibility of cold fusion was the enormity of the electrostatic repulsion between nuclei, the so-called Coulomb barrier. Upon the recommendation of a panel of scientists, the U.S. government funding agencies essentially closed all funding to this area of work. This appeared to be the end of cold fusion.

IV. POST PONS AND FLEISCHMANN WORK

Ideas, especially ones with merit, are difficult things to kill. Research in LENR did not simply stop. Rather, it essentially went "underground", being pursued in various dedicated labs laboratories worldwide, including in the U.S. During the last 23 years, much progress has been recorded despite difficulties not only in terms of funding, but also in the area of publication where both editorial staffs and reviewers are often prejudicial about the very idea of LENR.

During this time in exile, there were many standard-bearers in the field, notably Prof. George Miley (Univ. of Illinois), Prof. Peter Hegelstein (MIT), Francesco Piantelli (Univ. of Siena) and others who made important contributions. In our brief discussions here we will focus on the work at the U.S. Navy's SPAWAR group, headed up by Pamela Mosier Boss and Stanislaw Szpak.[4] These researchers improved the Fleischmann/Pons electrolysis apparatus and procedure. They demonstrated co-deposition of Pd and D by electrolyzing solutions of Pd^{2+} in D_2O. This process is examined in Figure 3. Several important factors are apparent: Co-deposition produces a roughened surface of fresh Pd having a greater surface area. Freshly reduced deuterium atoms are entrained within this new Pd surface, increasing D loading, a factor that appears to be important in initiating LENR.
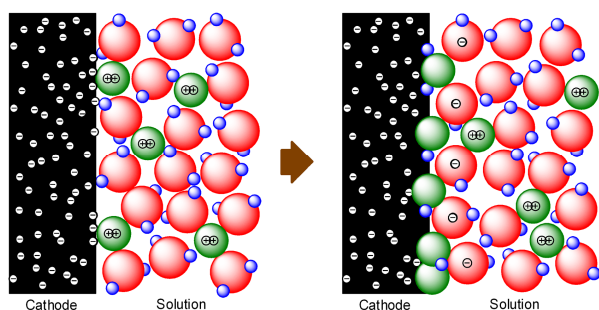
Fig. 3 Electrolytic co-deposition of Pd and D at a cathode surface.

The SPAWAR researchers were able to initiate heat generation in their improved cells far more quickly and reliably that could Fleischmann and Pons. In addition, careful work by these and other researchers demonstrated not only heat production, but also evolution of 4He, neutrons, and ^{3}T (tritium). Perhaps of greatest significance amongst their findings was the confirmation of secondary fission behavior in the Pd cathode. These finding included the identification of "triple tracks" of energetic particles in CR-39 allyl glycol carbonate film. These tracks are indicative of energetic ^{12}C fission to three alpha particles. In fact, these events are essentially indistinguishable from those created by ^{241}Am. Regions of pitting and eruption in the Pd cathode, as identified by electron microscopy were further examined by energy-dispersive X-ray spectroscopy (EDX). EDX revealed a variety of light elements, suggesting secondary fission of energetic Pd fusion products.

V. THE CURRENT STATUS OF LENR

To date, LENR has largely been investigated in the context of electrolysis cells. The experimental complexity of the apparatus and the chemical complexity within solution and at the solution/solid interface have made the results challenging to fully interpret. For example, in the Fleischmann/Pons experiment, induction periods were often on the order of weeks, necessitating the repeated addition of D_2O to compensate for evaporation. This added solvent necessarily brought with it various impurities. In addition, long-term electrolysis is bound to generate unexpected byproducts from the solvent, supporting electrolyte, electrodes, and even the glassware used. The latter could be of importance with regard to boron, which is found in Pyrex glass and might be implicated in LENR activity (see below). For reasons of simplicity and cleanliness of operation, there is no doubt that LENR must become decoupled from electrochemistry if it is to be of use in energy generation.

There are a number of scientific difficulties that plague LENR. These include high D loadings that are apparently needed. It has proved difficult to initiate LENR at loadings under 0.9 D/Pd. High current densities have also been needed for initiation; however, current density might be less critical so long as the Pd is well loaded with D. The structural nature of the Pd, especially the surface, appears to be of great importance. The success of rapidly deposited Pd, as demonstrated by the SPAWAR group, implies that non-equilibrium structures are likely important. These might take the form of large lattice vacancies or metal self-interstitials. A critical dependence on micro- or even nanostructure would help explain the reproducibility problems that are so notorious in LENR work. LENR activity is known to be poor when using very smooth cathode surfaces. It might be that activity does not arise until the surface has been sufficiently roughened via electrolytic etching and redeposition. This problem is potentially worsened by spontaneous annealing of the electrode that would tend to occur under the elevated temperatures generated by active LENR.

Scientific problems are not the only ones that will plague attempts to commercialize LENR. The very term "cold fusion" has come to mean false, or even falsified, science. Moreover, the public has a well-documented fear of all things nuclear. This has only been made worse as a result of the 2011 Fukushima calamity in Japan. Although scientists might dismiss them, matters of poor "labeling" and public perception of technologies are of critical importance. The LENR community must come up with a way to reboot the public's impression with regard to both of these labels.

There are real safety issues associated with LENR. These include safety from physical, chemical, and nuclear hazards. Physical hazards are associated with pressurized gases and high temperatures that would accompany LENR energy generation. Use of pressurized hydrogen would also create a serious risk of chemical explosion. Finally, since the physics of LENR are not clear, neither can the risk of high energy radiation from such equipment be assessed with any confidence at this point. All of this will lead to need for regulatory oversight of the LENR industry, should one ever arise.

Lastly, and very importantly, it should be born in mind that LENR would be a highly disruptive technology. It is in the interest of the fossil fuel industry to maintain their near hegemony over world-wide energy production. And where there are great financial interests, political interests follow. The hot fusion community is well-funded and is notoriously hostile toward LENR. No doubt the challenges to LENR technology gaining a foothold will be great.

VI. METAL HYDRIDES

Since LENR appears to involve fusion or some other exotic phenomenon operating on hydrogen within a metal lattice, we need to take a close look at the chemical compounds that are formed between hydrogen and various metals (Figure 4).[5] Much like carbon, hydrogen can be considered an "electroneutral" atom. In other words, it does not have a pronounced tendency either to gain or lose electrons at the expense of other atoms. Metals, by way of contrast, are always electropositive to some extent. Therefore, metals are prone to donate one or more electrons to other atoms, including hydrogen in some cases. The highly electropositive metals in groups 1 and 2 (shown in red in Figure 4) donate one or two electrons to hydrogen. The reduced hydride ion (H^-) forms an ionic lattice with the oxidized metal ion. However, in the resulting saline hydrides, the metal-hydrogen spacing is almost certainly too great and the nuclear interaction too small to enable any LENR activity.

Fig. 4 Metal hydride types and formulas.

As we move from left to right across the periodic table, we encounter a very different sort of hydride compound. Metallic hydrides, which are typical of the early transition metals, feature relatively undisturbed metallic lattices with hydrogen atoms located in interstitial sites. Unlike in the saline hydrides, metal-metal bonding is intact in the metallic hydrides. Also unlike the saline hydrides, metallic hydrides tend to show highly flexible degrees of hydrogen uptake. In closest packed metallic networks, there is one octahedral interstitial site and two tetrahedral sites per metal atom. But all of the interstitial sites do not have to be filled. Although there is usually a preference for occupation of octahedral over tetrahedral sites, the distribution of hydrogen atoms across a particular type of site tends to be quite random. Overall, some trends in metallic hydrides may be identified. When hydrogen enters the interstitial sites, it tends to expand the metal lattice slightly. Hydrogen concentrations of greater than that encountered in liquid H_2 are found in some cases. The resulting compounds are usually non-stoichiometric and often possess fairly poor crystallinity, making their characterization tricky. An interstitial radius of greater than about 0.4 Å is needed for hydrogen inclusion. And the minimum tolerable H···H distance is about 2.1 Å.

Binary metal hydrides are either unstable or unknown for most of the later transition metals. However, the group 10 metals Ni and Pd represent two important exceptions to this trend. These are the two metals for which hydrogen LENR has been demonstrated. Both of these metals crystallize in face centered cubic (FCC) unit cells with closest packed atoms. We will look closely at Pd, which has been studied via in situ neutron diffraction during D_2 infusion.[6] The cubic unit cell for pure Pd has a lattice parameter, $a = 3.891$ Å. Hydrogen atoms enter octahedral sites, yielding two possible phases, both of which retain the FCC Pd lattice. α-PdH_x (x < 0.05) is a solid solution, with lattice parameter, $a = 3.894$ Å. β-PdHx allows much more hydrogen, with $x =$ about 0.6 or even higher, $a = 4.04$ Å. Through the action of electrolysis or high pressure infusion, x values of ≥ 1 can be achieved. At this level of loading, all the octahedral sites are filled (see Figure 5), and tetrahedral sites must be used, leading to greater disruption of the Pd lattice. Conversely, non-equilibrium deposition of defective metal can allow for greater H/D concentrations locally. Significant amounts of hydrogen are lost when electrolysis is halted or upon exposure of H-infused Pd to elevated temperatures.
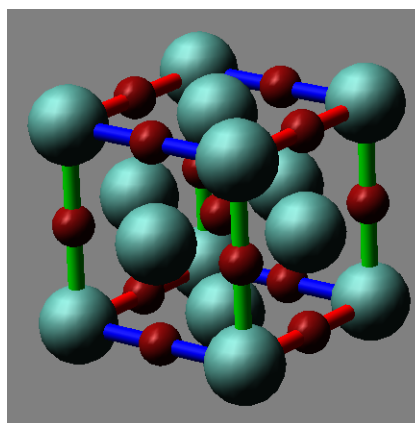

Fig. 5 The cubic unit cell of PdH.

Palladium is unique in the periodic table with regard to its ability to form interstitial compounds containing large amounts of hydrogen. Metallic behavior, including high levels of ductility, is retained. It is believed that high H/D mobility is behind this behavior. What is more, when a solid solution between Pd and Ag is formed, the storage capacity of hydrogen becomes even greater.[7] The Pd/Ag alloy retains the FCC lattice with random distribution of Ag atoms. Hydrogen permeability is maximized in Pd alloys

containing about 20−23% Ag; above this value the hydrogen capacity of the material falls off sharply. To my knowledge Pd/Ag has not been investigated in LENR systems. Other Pd or Ni alloys might be of interest as well.

Another new direction for LENR research is represented by mixed metal hydrides. To date, significant research has focused solely upon single metal systems, notably Ni and Pd. However, binary metal systems that form hydrogen-rich hydrides are well known. Several examples are listed in Table 1.[5] In each case listed the binary combination of metals is composed of a metallic (or ionic) hydride former and a covalent hydride former. In other words, a combination of more electropositive metal, which forms stable metal hydride, and less electropositive metal, which forms unstable metal hydride, is used. Materials such as these that feature high hydrogen uptake in the presence of transition metals should be considered as possible LENR substrates using a combination of computational and experimental methods.

Table 1. Properties of Some Mixed Metal Hydrides

Hydride	$LaNi_5H_{6.7}$	$FeTiH_{1.8}$	$TiCr_{1.9}H_{3.6}$	Mg_2NiH_4
Hydrogen/Metal ratio	1.1	0.9	1.28	1.3
Weight capacity, %	1.5	1.8	2.5	3.8
Volume capacity, g/dm^3,[a]	140	95	126	96
Equilibrium Pressure at 25 °C, atm	0.11	0.10	0.70	0.00001
Temperature for 1 atm H_2, °C	10	0	−60	250
ΔH of Plateau Desorption, kJ/mol	−31.8	−33.8	−26.2[b]	−64

[a]Liquid H_2 = 71 g/dm^3. [b]Value measured for $TiCr_{1.9}H_{2.5}$.

VII. AD-ATOMS

There is no reason to assume that nuclear interactions between H/D are restricted solely to the hydrogen and metal atoms. Calculations have shown that B, Li, and F are likely to react with H/D in metal lattice, with energy release in each case:[8]

$$B^{11} + H^1 \rightarrow 3\ He^4 + \ldots \quad (5)$$
$$B^{10} + H^2 \rightarrow 3\ He^4 + \ldots \quad (6)$$
$$Li^7 + H^1 \rightarrow 2\ He^4 + \ldots \quad (7)$$

In addition ^{19}F shows five potentially favorable pathways, including H/D fusion to ^{20}Ne, ^{21}Ne or ^{16}O and ^4He. It is interesting that boron, lithium and fluorine all exhibit relatively low natural abundances. We have postulated that these elements, boron in particular, might be associated with LENR-driven geo-nuclear activity, an assertion that is supported by the occurrence of significant concentrations of boron in volcanic ejecta. As noted above, it is more than conceivable that Pyrex-derived boron might have slowly leached into the Fleischmann/Pons cells over long electrolysis periods, possibly initiating LENR activity. Such leaching of boron from borosilicate glass has been demonstrated to occur at relatively high pH.

IV. CONCLUSIONS

As LENR moves away from the laboratory and toward the marketplace, it will necessarily leave the constraints of electrochemistry behind. There are two obvious directions that may be pursued in constructing LENR devices. The first of these is a fluidized bed-type system that utilizes fine metal particles suspended in a gaseous stream (H_2 or D_2, presumably). This appears to be the route chosen by the Italian and Greek companies that are claiming to be on the verge of LENR commercialization. The advantages of such a design include relatively simple design, continuous reactant flow, elimination of the solvent boiling temperature constraint on working region, and the ability to use the effluent gas as the heat transfer fluid. Alternatively, an LENR device could be designed to use a suspension of metal particles in a liquid medium (Figure 6). Most likely that medium would be a molten salt. In this case hydrogen or deuterium could be chemically generated, for example from $NaBH_4$ or $NaBD_4$. Boron, lithium, fluorine, or other ad-atoms could be incorporated into the molten salt mixture used. In this case an external heat carrier would be needed to carry away the excess energy produced.
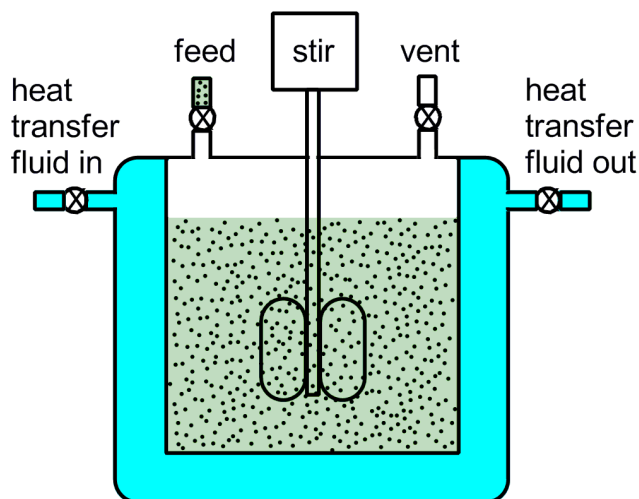
Fig. 6 Possible molten salt LENR batch reactor design.

In summary, significant experimental confirmation has followed original cold fusion claims of Fleischmann and Pons. Two systems, Pd/D and Ni/H, now consistently show excess heat production. Production of high energy particles and secondary nuclear fission events have also been confirmed. During the on-going research and development of LENR, a wider range of mixed metal hydride substrates should be considered, as should the use of ad-atoms, such as boron. Finally, as LENR is moved toward commercialization, a number of safety, regulatory, and market considerations must be taken into account. In addition, both gas/solid and liquid/solid reactors should be considered.
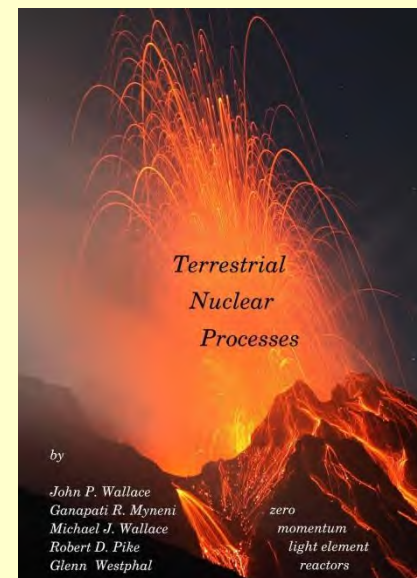
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Terrestrial
Nuclear
Processes

by

John P. Wallace
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Michael J. Wallace
Robert D. Pike
Glenn Westphal

zero
momentum
light element
reactors

International Symposium on
Hydrogen in **Matter** (ISOHIM)

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Talk Outline

- Why LENR?

- Fleischmann and Pons Work

- Post Fleischman & Pons Findings

- Where to From Here?

- Metal Hydrides

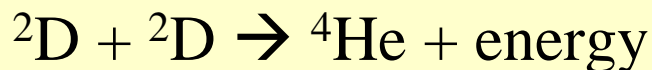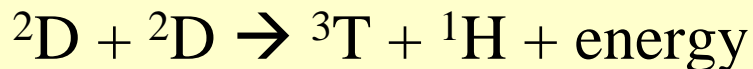- Chemical Considerations Moving Forward

- Conclusions

Why LENR?

- Low-cost energy using common materials

- Nearly carbon-neutral

- Simple, compact, low-maintenance devices

- Off-grid operation

- Low radiation, run-away reaction dangers (?)

- Applications:

  Electricity generation, Heating, Desalination, Vehicular, Aeronautics, Space applications
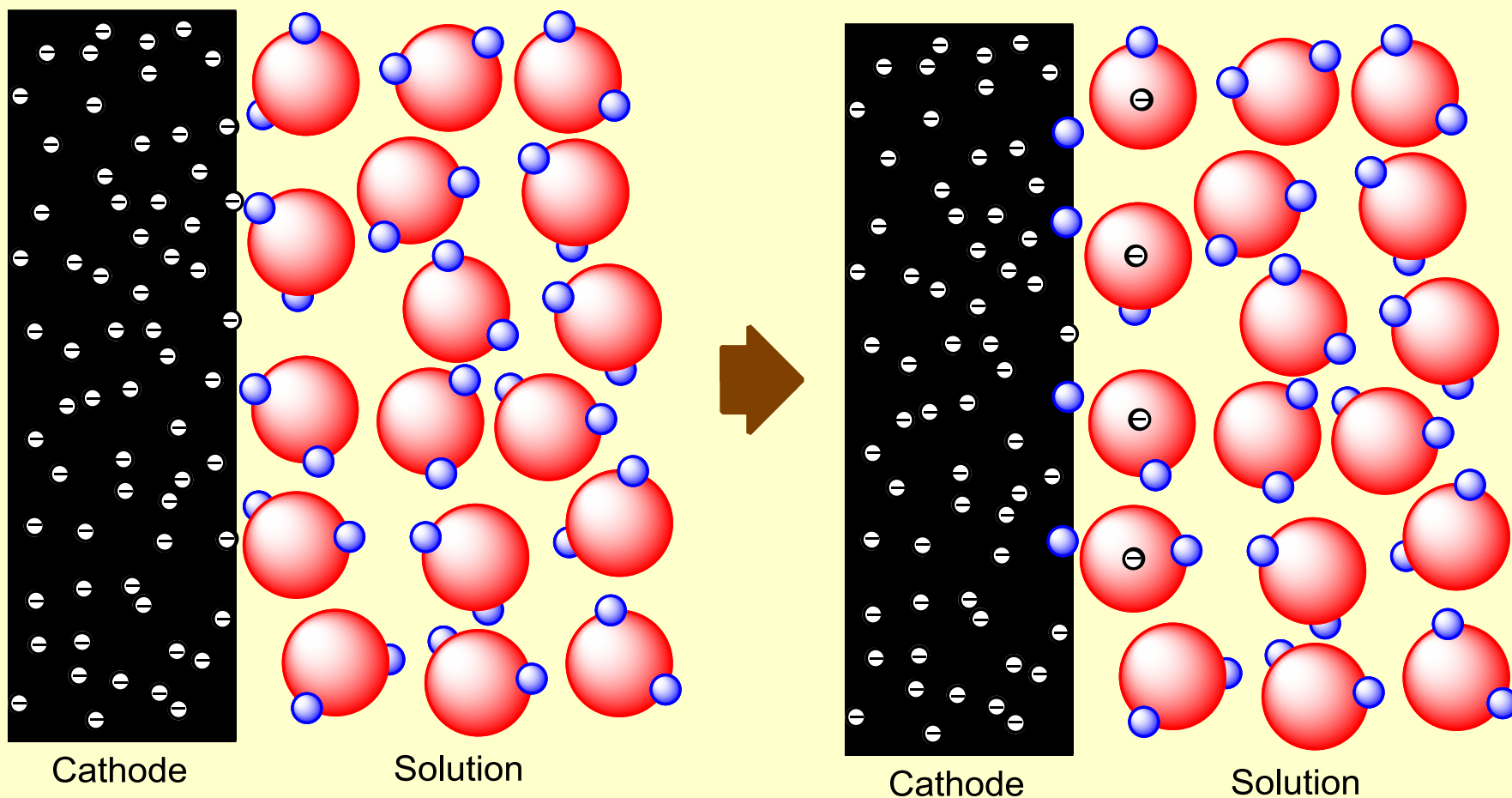
Fleischman & Pons Cells

- Electrolysis of $D_2O/LiOD$

- D_2 partitions between gas release and concentration into Pd cathode lattice

- Heat release after long induction

- Proposed fusion

$$^2D + {}^2D \rightarrow {}^3T + {}^1H + energy$$

$$^2D + {}^2D \rightarrow {}^4He + energy$$

$$^2D + {}^2D \rightarrow {}^3He + n + energy$$
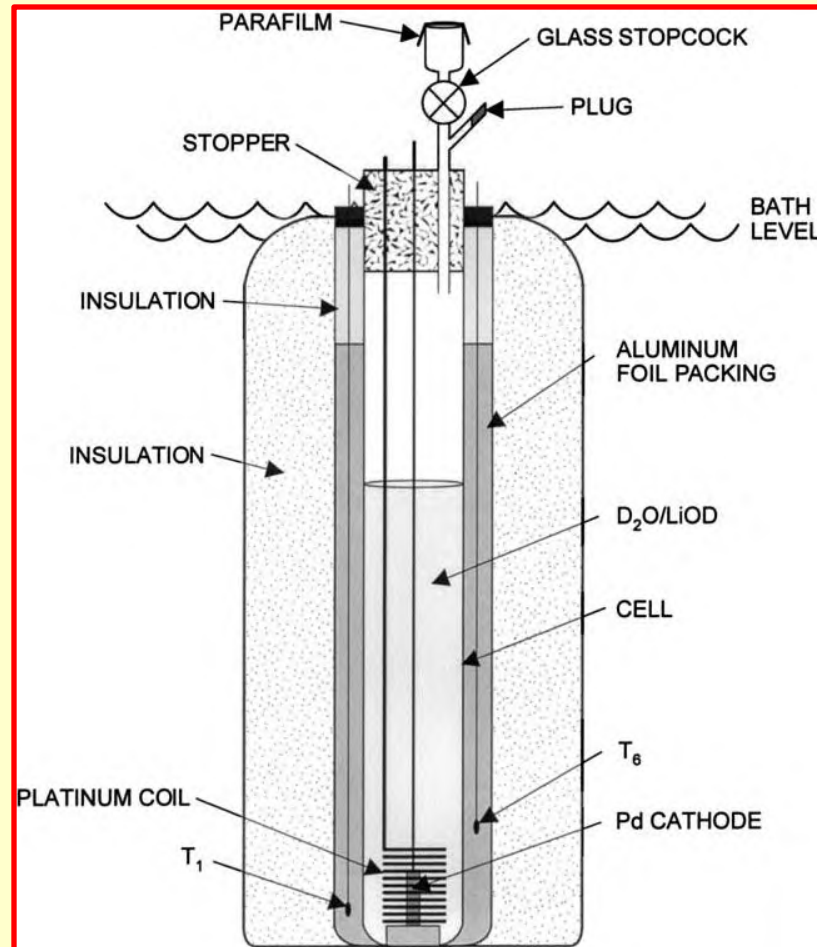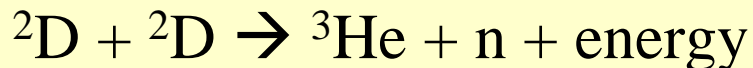
M. H. Miles, *J. Electroanal. Chem.* **482** (2000) 56–65.

Fleischman & Pons Cells

Electrolysis of D_2O at Pd Cathode

Cathode   Solution   Cathode   Solution

Fleischman & Pons Cells

D: Lattice Infusion vs. D_2 (g) Formation

Cathode   Solution   Cathode   Solution
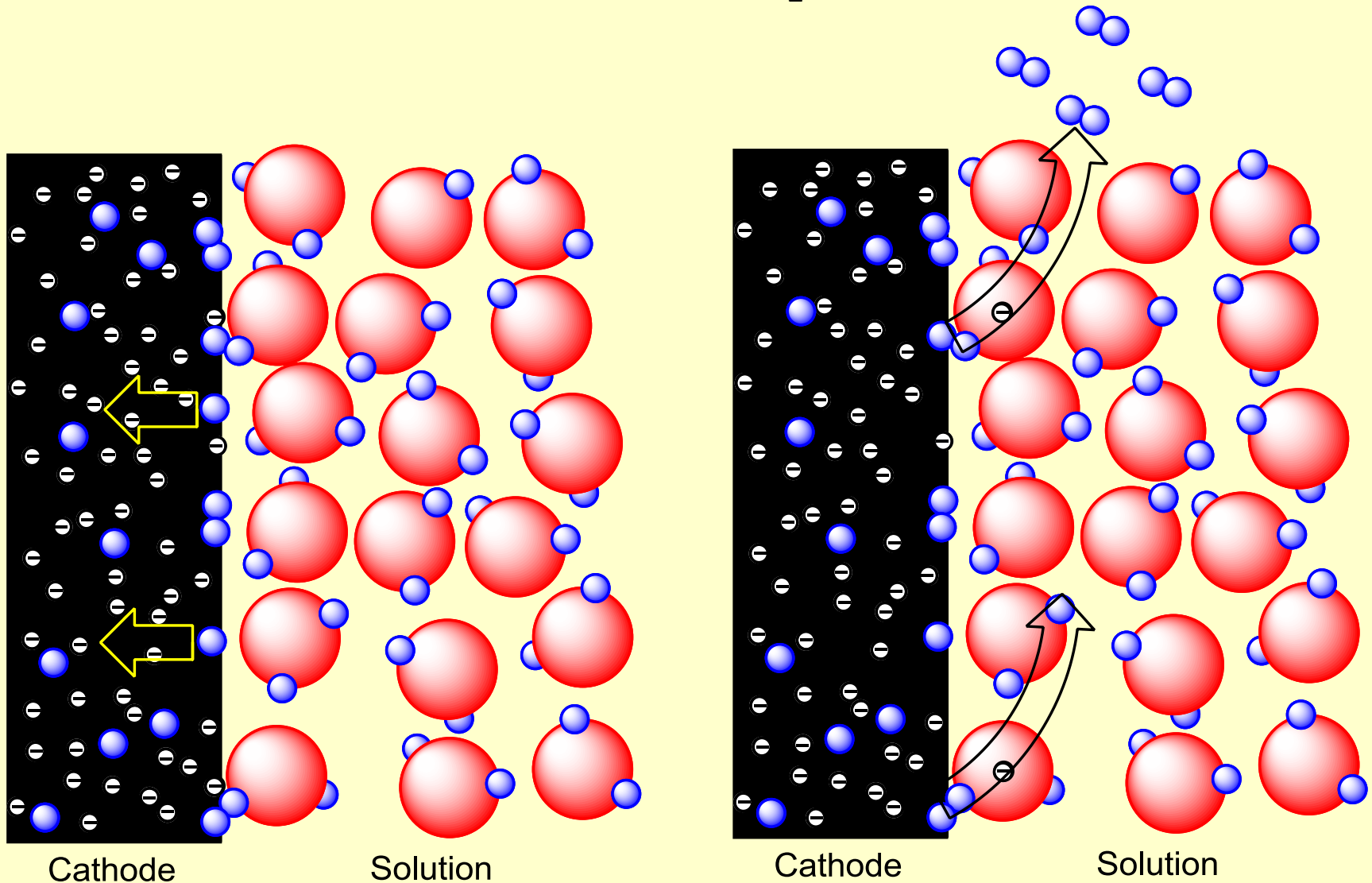
Fleischman & Pons Outcome

Undisputed

- H/D concentrates into Pd cathode during electrolysis

- Not much else

Disputed

- Calorimetric results

- Unambiguous detection of ^{4}He, ^{3}He, ^{3}T, neutrons, and gamma

Post Fleischman & Pons Accomplishments
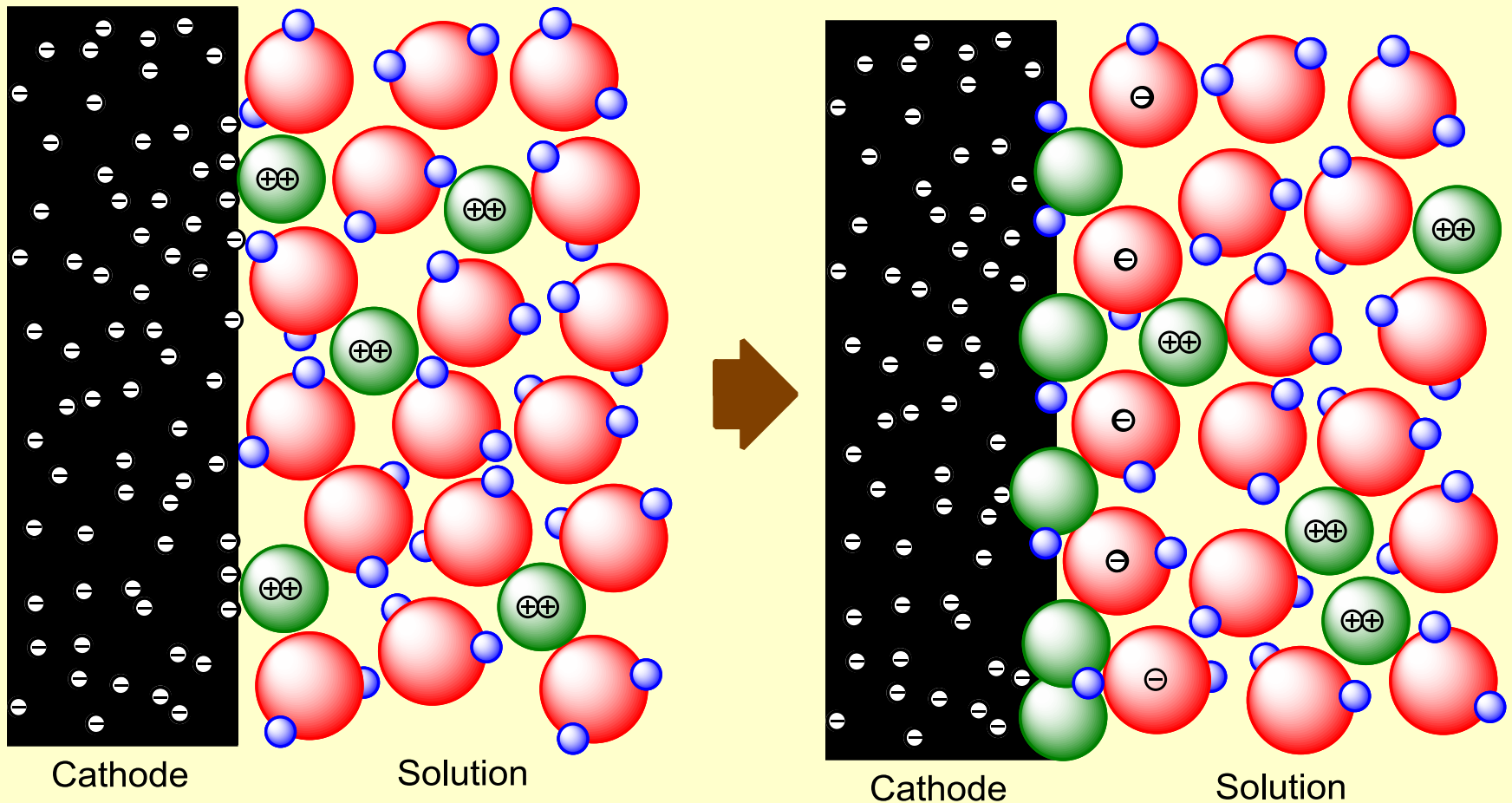
Mosier Boss & Szpak, SPAWAR

- Codeposition of Pd & D increase both surface area and D loading.
- Nano-sized "explosions" indicating energy bursts with EDX signature of heavy element generation.
- Confirmation of n, p, gamma

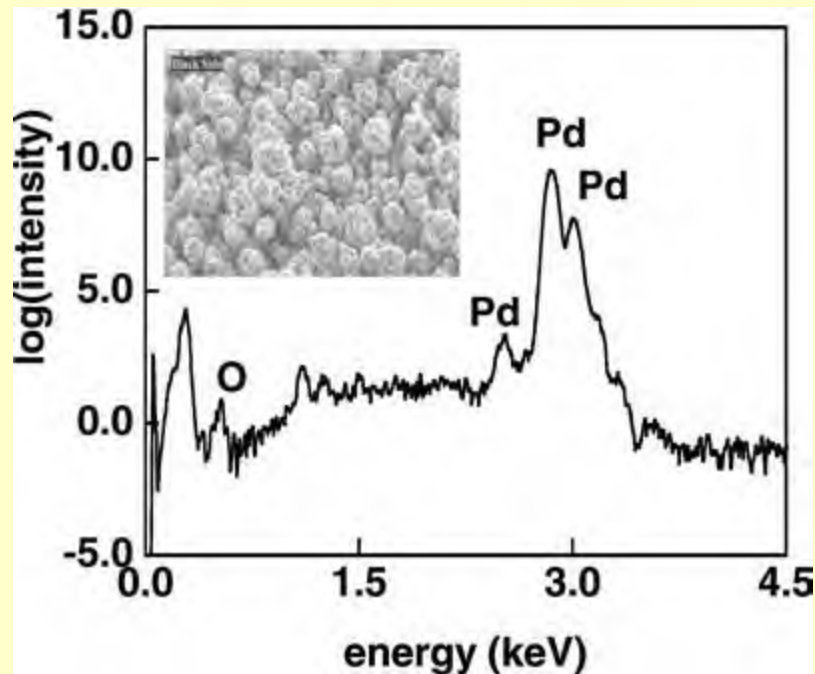S. Szpak, P. A. Mosier Boss, C. Young, F. E. Gordon, *Naturwiss.* **92** (2005) 394–397.
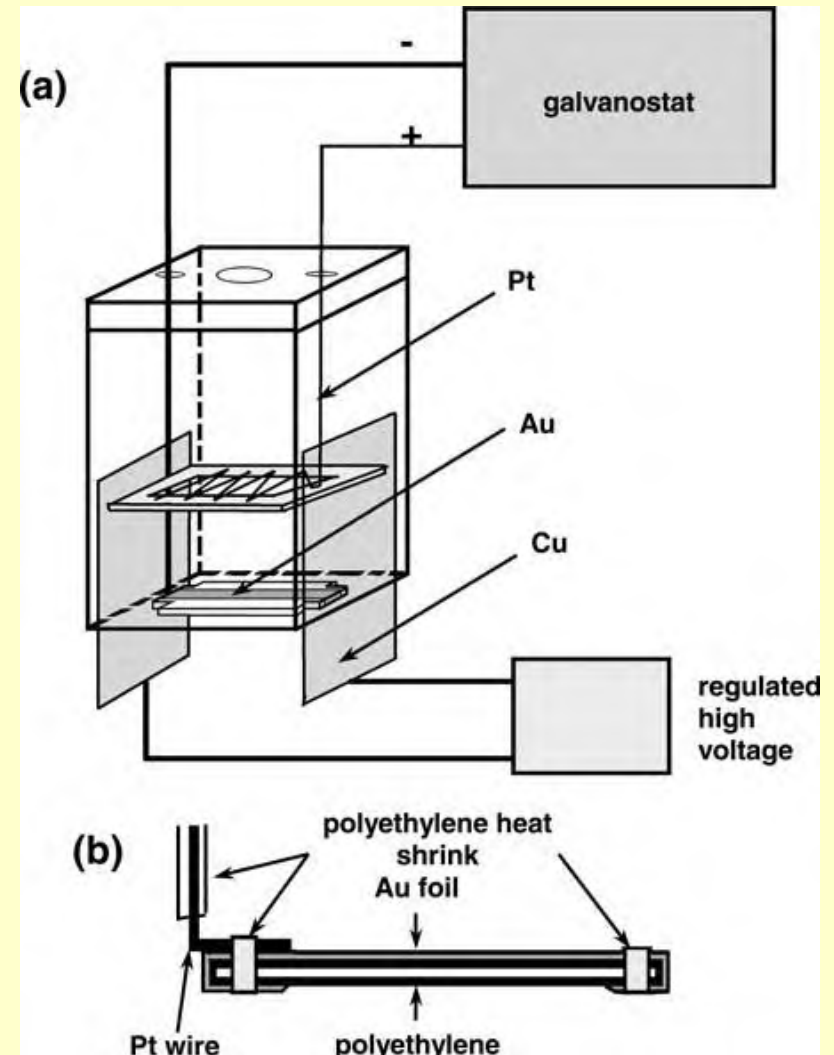
Post Fleischman & Pons Accomplishments

Codeposition of Pd & D at Cathode

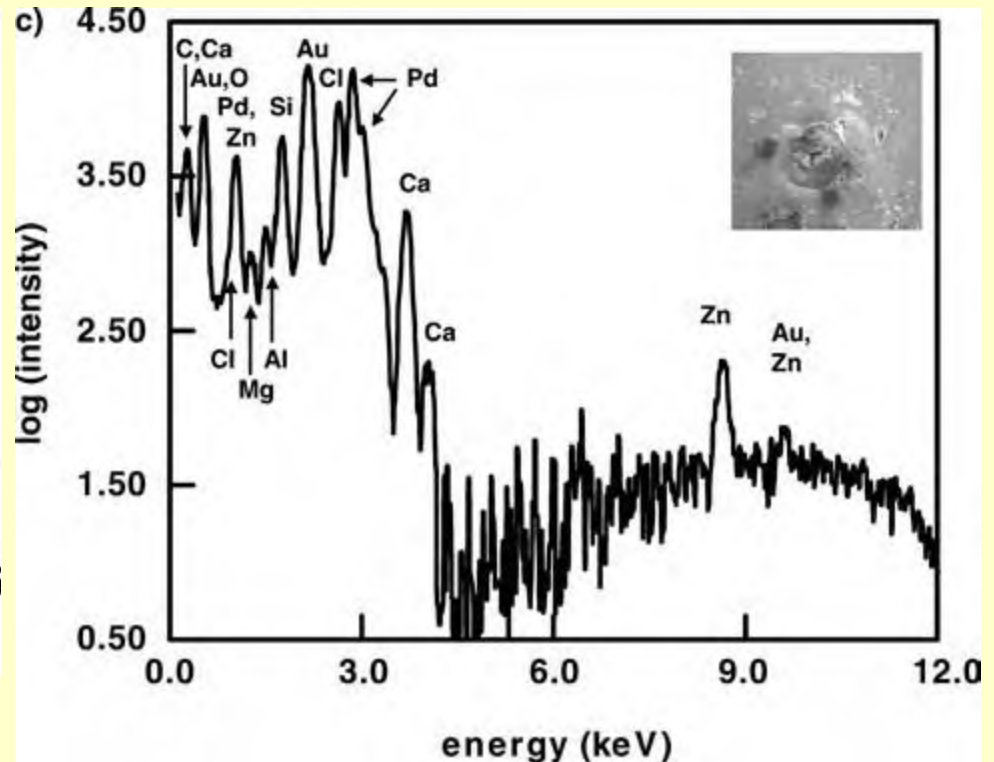Cathode   Solution   Cathode   Solution

Post Fleischman & Pons Accomplishments

Electrodeposited Pd Electrode Surface and EDX Trace

Site of "Blistering" of Electrode Surface and EDX Trace

S. Szpak, P. A. Mosier Boss, C. Young, F. E. Gordon, *Naturwiss.* **92** (2005) 394–397.

Where to from Here?

LENR largely investigated under electrolysis conditions to date

Scientific Difficulties:

- Complex experimental set-up
- High D loading needed: >0.9 D/Pd
- High current density needed for initiation
- Metal surface quality critical
- Rapid metal deposition produces large vacancies
- Non-thermodynamic surface structures formed
- Reproducibility problems

Where to from Here?

Practical/Implementation Difficulties:

- Cold Fusion Label
- Public perception of "nuclear" energy: Fukushima effect
- Nuclear safety
- Chemical safety (hydrogen pressure)
- Regulatory
- A highly disruptive technology

Where to from Here?

What is needed for LENR

- Metal lattice favorable to H_2/D_2 reaction (Pd, Ni)

- Significant metal vacancy space

- Ad-atoms that could enhance nuclear processes (e.g. B, or F)

- Ability to infuse large amounts of hydrogen

- Appropriate thermal, radiation, and explosion safeguards

- Operational control, material and energy management
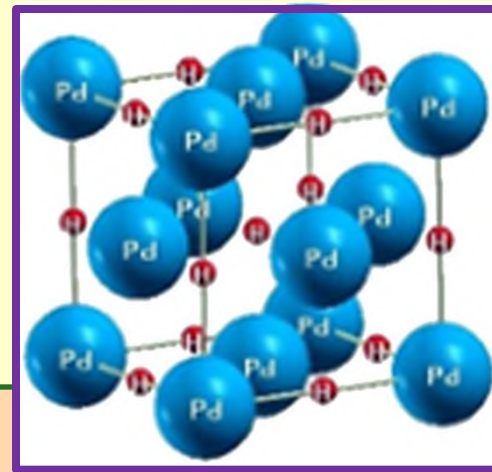
Metal-Hydrides

Saline (ionic)

Covalent

Metallic

Metallic

LiH	BeH$_2$											
NaH	MgH$_2$											(AlH$_3$)$_n$
KH	CaH$_2$	ScH$_2$	TiH$_2$	VH VH$_2$	CrH CrH$_2$	Mn	Fe	Co	NiH	CuH	(ZnH$_2$)$_n$	(GaH$_3$)$_n$
RbH	SrH$_2$	YH$_2$ YH$_3$	ZrH$_2$	NbH NbH$_2$	Mo	Tc	Ru	Rh	PdH	Ag	(CdH$_2$)$_n$	(InH)$_n$ (InH$_3$)$_n$
CsH	BaH$_2$	LaH$_2$ LaH$_3$	HfH$_2$	TaH	W	Re	Os	Ir	Pt	Au	(HgH$_2$)$_n$	(TlH)$_n$ (TlH$_3$)$_n$

Lanthanides all LnH$_2$ and/or LnH$_3$

Metal Hydrides

- Typically *ca.* 1 hydrogen atom absorbed per metal atom

- Usually non-stoichiometric

- Crystallinity often poor

- Hydrogen enters interstitial sites, expanding metal lattice

- Hydrogen concentration often greater than that in liquid H_2

- Interstice radius of > *ca.* 0.4 Å needed for H

- Minimum H$\cdots$H = *ca.* 2.1 Å

- Isotherms used to determine metal-H absorption characteristics

A. P. Guegan, *NATO Adv. Institute. Ser.,* F. Grandjean et al. eds., Kluwer, 1995 77-105.

Palladium Hydride

- In situ neutron diffraction study of Pd/D_2

- Pd is FCC, a = 3.891 Å, H/D enters octahedral sites.

- α-PdH$_x$, FCC, x < 0.05, solid solution, a = 3.894 Å

- β-PdH$_x$, x about 0.6 or higher, a = 4.04 Å

- D rapidly lost when electrolysis halted, although some remains

- D also lost at elevated temperature

- Lattice disruption can allow larger amounts of D locally

C. T. Dillon, B. J. Kennedy, M. M. Elcombe, *Aust. J. Chem.* **46** (1993) 681-692.

Palladium Hydride
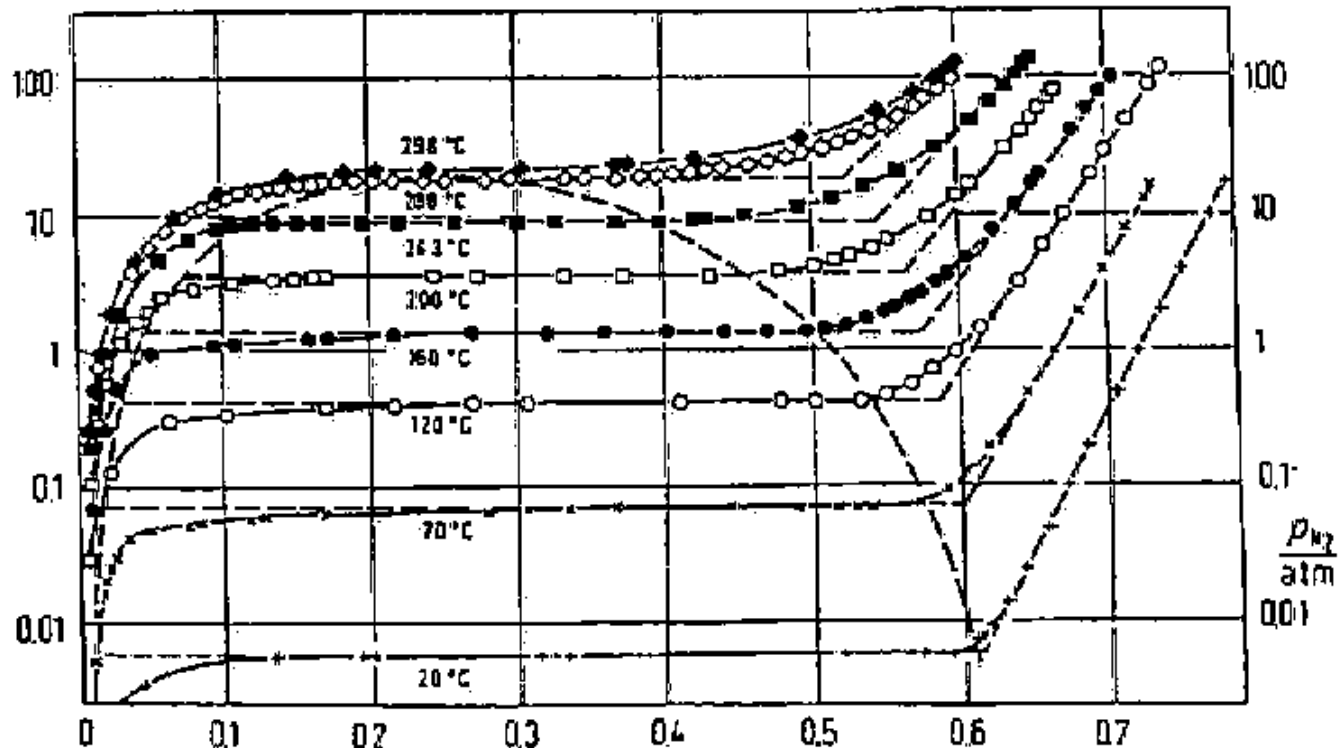
Pd-H Isotherms at 20, 70, 120, 160, 200, 243, 288, and 298 ^{o}C

A. P. Guegan, *NATO Adv. Institute. Ser.,* F. Grandjean et al. eds., Kluwer, 1995, 77-105.

Mixed Metal Hydrides

- Stable mixed metal hydrides formed from combination of

    stable metallic hydride plus unstable covalent hydride

- Examples: $LaNi_5H_{6.7}$, $FeTiH_{1.8}$, $TiCr_{1.9}H_{3.6}$, Mg_2NiH_4

Hydride	$LaNi_5H_{6.7}$	$FeTiH_{1.8}$	$TiCr_{1.9}H_{3.6}$	Mg_2NiH_4
Hydrogen/Metal Ratio	1.1	0.9	1.28	1.3
Weight capacity, %	1.5	1.8	2.5	3.8
Volume capacity, g/dm^3,[a]	140	95	126	96
Equilibrium Pressure at 25 °C, atm	0.11	0.10	0.70	0.00001
Temperature for 1 atm H_2, °C	10	0	−60	250
ΔH of Plateau Desorption, kJ/mol	−31.8	−33.8	−26.2[b]	−64

[a]Liquid H_2 = 71 g/dm^3. [b]Value measured for $TiCr_{1.9}H_{2.5}$

A. P. Guegan, *NATO Adv. Institute. Ser.,* F. Grandjean et al. eds., Kluwer, 1995, 77-105.

Chemical Considerations Moving Forward

Ad-atoms: The Possible Key to Lattice-Assisted LENR

- Nuclear interactions between H/D not restricted to the hydrogen and metal atoms
- Calculations have shown that B, Li, and F are likely to react with H/D in metal lattice, with energy release
- $B^{11} + H^1 \rightarrow 3\ He^4 + \ldots$
- $B^{10} + H^2 \rightarrow 3\ He^4 + \ldots$
- $Li^7 + H^1 \rightarrow 2\ He^4 + \ldots$
- F^{19} shows five potentially favorable pathways, including H/D fusion to $Ne^{20/21}$ or $O^{16} + He^4$
- These elements all exhibit relatively low natural abundances (geo-nuclear activity?)

Chemical Considerations Moving Forward

Some Ideas for the Incorporation of Ad-atoms

Boron
- Borided metals
- BH_4^-/BD_4^- as hydrogen source $\rightarrow$ H_2/D_2 + B
- BF_4^- salts

Lithium
- Lithium alloys
- Lithium salts: e.g. $LiBH_4/LiBD_4$, $LiBF_4$

Fluorine
- Fluoride salts: e.g. CaF_2, $LiBF_4$
- Bifluorides: e.g. $K(HF_2)$, $NH_4(HF_2)$

Chemical Considerations Moving Forward

Gas/Solid System: Fluidized Bed Reactor

- Diluted H_2/D_2 gas directly interacts with solid
- Continuous flow
- Simple design
- Removes solvent boiling temp. constraint
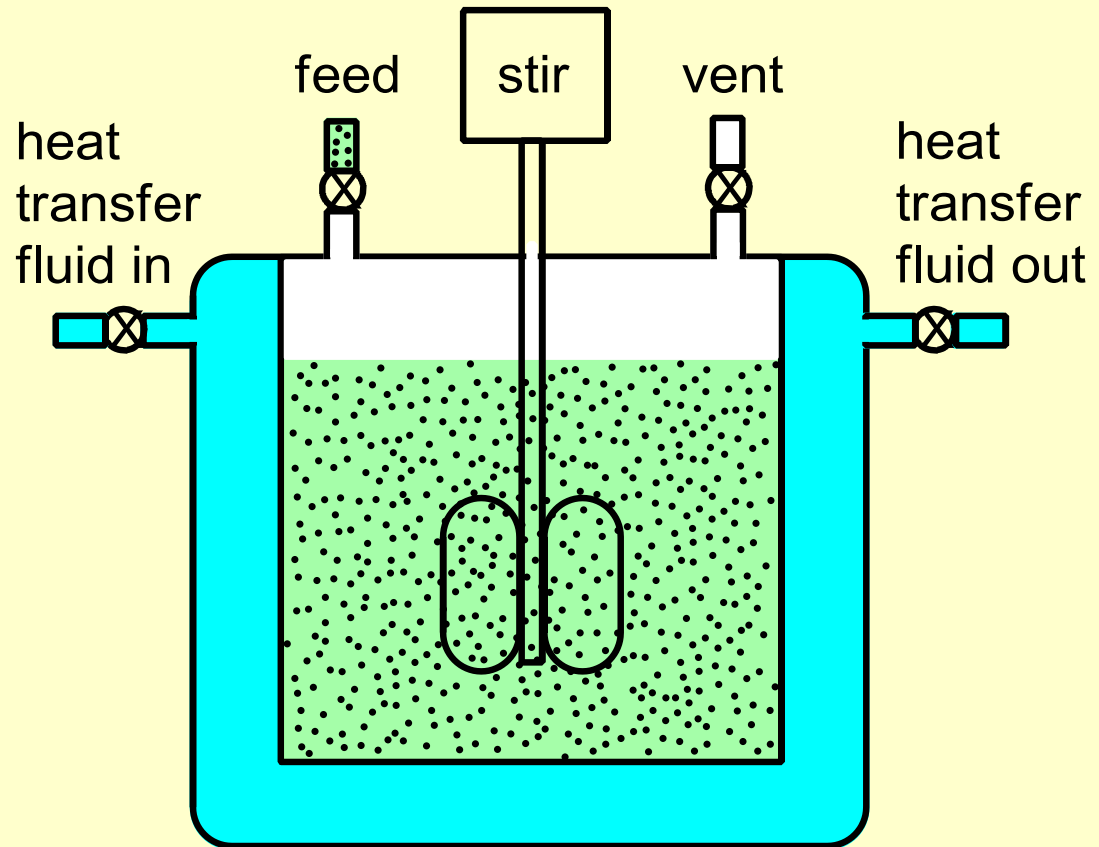- Effluent gas can be used as heat transfer fluid

Gas

Solid

Gas bubble

Solid particle

Gas

Solid
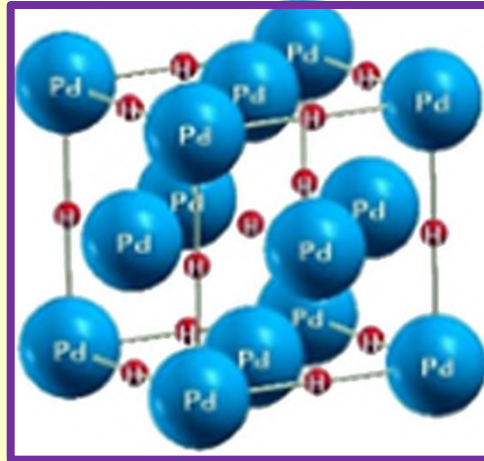
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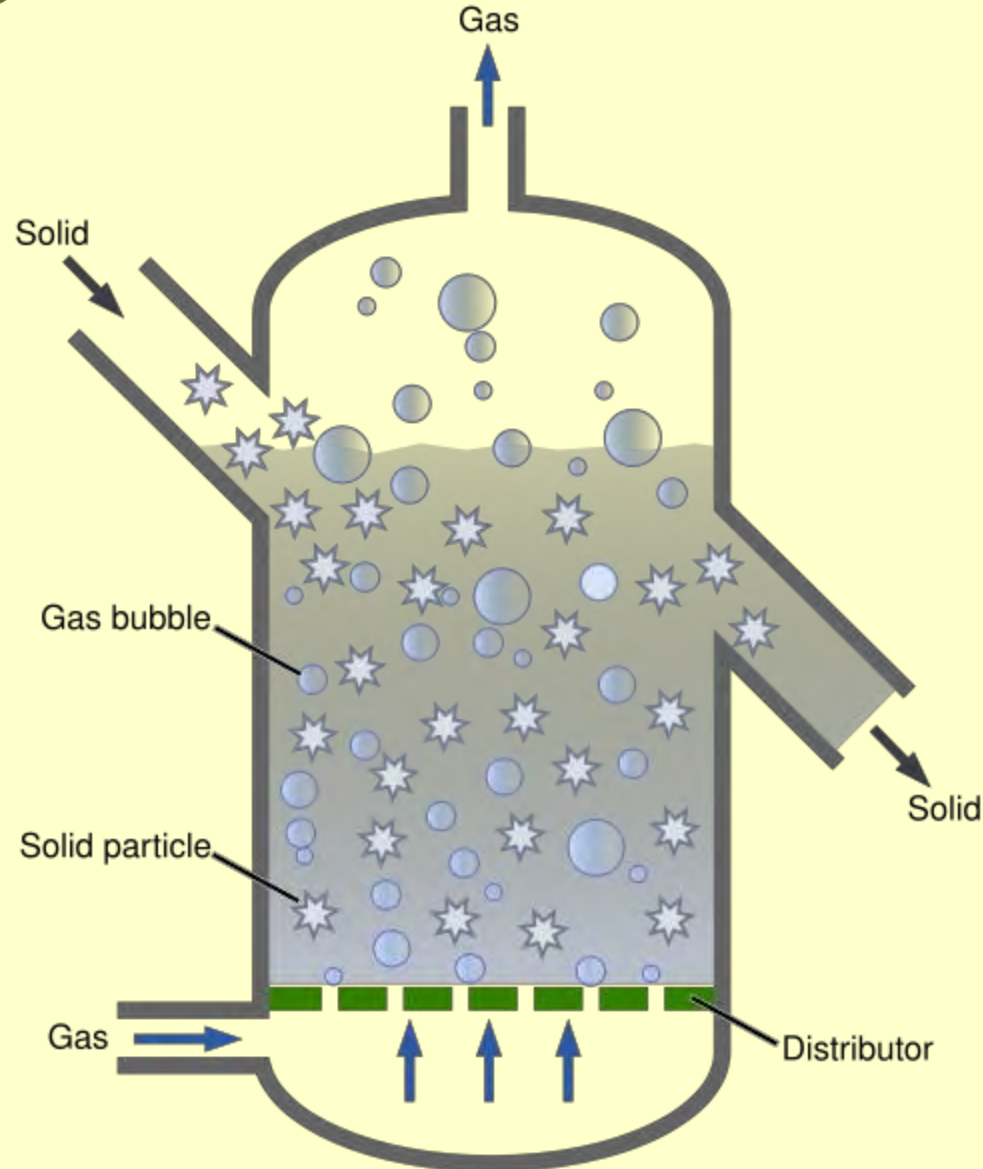
Chemical Considerations Moving Forward

Liquid/Solid System: Batch Reactor

- H_2/D_2 chemically generated ($NaBH_4$)
- Suspended metal particles
- Molten salt carrier
- B or F added in salts
- External heat carrier

Conclusions

- Significant confirmation has followed original cold fusion claim

- Pd/D and Ni/H systems show heat production

- Wide range of metal and mixed metal hydrides to be considered

- Ad-atoms should be considered

- Gas/solid or liquid/solid systems should be considered