

# FUSION facts

A Monthly Newsletter Providing Factual Reports On Cold Fusion Developments

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FUSION FACTS

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## COMING IN MAY 1991

*Fusion Facts* will report on a theory of cold fusion developed by a nuclear scientist whose has been working on "hot fusion" developments. Will this theory convince the nuclear physicists? **The author says, "Yes."**

## ERRATA

Please note that we labeled the February issue as being Volume 2 No. 7, it should be No. 8. We also labeled the March issue as No. 8, it should be No. 9. Even worse, the February headers were labeled March instead of February. Our apologies.

## A. SOVIET COLD FUSION HEATS UP.

Two important new developments from USSR.

### 1. FIFTEEN MILLION RUBLES ALLOCATED FOR FOUR-YEAR EFFORT TO 20 LABORATORIES.

Courtesy of Dr. David Worledge, EPRI

Dr. David Worledge recently attended a "Workshop on Nuclear Fusion Reactions in Condensed Media" held at Dubna in the Soviet Union. During the conference it was announced that fifteen million rubles was being allocated for cold fusion research over the next four years. About 20 laboratories were expected to be involved in this research activity.

*Fusion Facts* will try to get copies of the papers presented at the conference and report on these papers as soon as possible. We welcome the USSR to the club of nations who have found the development of cold fusion to be of sufficient national interest to provide funds. This Club now consists of **China, India, Japan, and USSR**. We hope that the U.S. DoE will soon learn that cold fusion could play an important role in the energy policy of the United States.

### 2. RUSSIAN SCIENTISTS ACHIEVE EXCESS HEAT FROM GAS-PLASMA DEVICE.

Courtesy of John Marshall, Surface Solutions, Inc.

**First**, Pons & Fleischmann with a heavy-water cold fusion cell; **second**, Liebert and Liaw's molten-salt cold fusion cell; and **third**, Karabut et al. report excess heat from a gas-discharge deuterium-Pd device. The devices that can produce excess energy from nuclear reactions in a metal lattice at relatively low temperature are increasing in number. Here is a report on the latest:

A.B. Karabut, Ya.R. Kucherov, I.B. Savvatimova (Scientific Industrial Association "Lutch", Podolsk), "Cold Fusion Observation at Gas-Discharge Device Cathode", Presented at Anniversary Specialist Conference on Nuclear Power Engineering in Space, May 15-19, 1990, Obninsk, Institute of Physics and Power Engineering.

## EDITOR'S ABSTRACT

Bursts of up to  $10^6$  neutrons per second were measured using a gas-discharge device containing low pressure deuterium gas and a Pd cathode. Electrical discharge voltage was varied from 50 to 600 volts and current from 10 mA to 600 mA through the 1 sq cm surface of the Pd foil mounted on the cathode. A calorimeter was used to measure the output power which achieved as high as 120% to 150% of the input electrical power.

At a deuterium gas pressure of about 500 Pascals (approx 0.1 psia), the neutron emission begins after (typically) about 100 seconds. The Pd on the cathode consisted of a 0.1 mm foil with 1 sq cm of surface exposed to the electrical discharge. The temperature of the device increases gradually with the combination of electrical discharge heating and heat from nuclear events. In the experiment described in the paper, over a 500 second period, the temperature rose from about 20 C to 80 C with two predominant neutron bursts peaking at about 180 seconds and about 280 seconds.

The neutron emissions rose to a peak of about 1 million neutrons per sec.; fell to about 100,000 n/s; rose to a sustained peak (several seconds) in excess of 1.5 million n/s and gradually fell to about 400,000 n/s over the 500 second period charted. During this process the temperature was rising. It may be that the larger bursts of neutrons would correlate with Dr. Robert T. Bush's Transmission Resonance Model which predicts a strong variation with nuclear events with temperature.

The paper notes that the reactions stopped when the palladium temperature reached 500 K, using deuterium. Preliminary oxidation of the palladium prevented the effect completely.

The authors conclude with the following statements: "As a result we can conclude that the values of the neutron flux with glow discharge in deuterium are some orders higher than those in electrolytic cells. . . . If we consider D-D reaction to follow two known channels and the probability of  $D+D \rightarrow T + p$  reaction to be  $10^8$  to  $10^9$  orders [sic] higher than  $D + D \rightarrow {}^3\text{He} + n$ , then our calorimeter measurements ( $10^3$  Joule of excessive heat) correlate with the neutron flux value."

There are some gaps in the reporting provided by the authors. We would like to see some tables of data and more details as to the exact dimensions of various parts of the experimental apparatus. However, we applaud the work as being a third method by which cold fusion excess power can be obtained. The results, if duplicated by other scientists, will greatly help to stir the interest in cold fusion. It may be this work which has provided the political encouragement for the USSR to allocate \$15

million rubles for cold fusion research for the next four years.

## B. INTERNATIONAL PATENT APPLICATION: SCHOESSOW

By Michael Dehn, Associate Editor

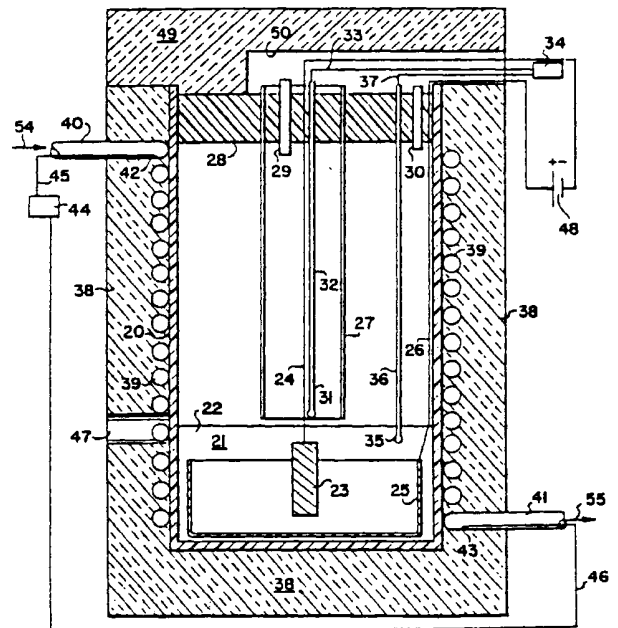
An international patent application by Dr. Glen J. Schoessow of the University of Florida has now been released to the public.

### Title:

Electrochemical Nuclear Process and Apparatus for Producing Tritium, Heat, and Radiation.

### Abstract:

A process for the preparation and recovery of tritium, heat energy, and radiation energy by electrolysis of a liquid medium (21) containing deuterium oxide in an electrolytic cell having a cathode (23) of palladium, or certain other elements by operating the process at about 10 to 300 C; and an apparatus for this process wherein the cathode (23) comprises a central solid geometrical mass and the anode (25) is an open top cup-shaped vessel positioned adjacently below and encircling the cathode (23).



[The items in the figure not described in the abstract represent provisions for calorimetry, gas recombination, and current supply. Ed.]

## EDITOR'S COMMENTS

Previously, two of the early cold fusion international patent applications were made public. The Pons-Fleischmann international patent filing was reviewed in the January 1991 issue of *Fusion Facts*, and an application by Matsushita Ltd. of Japan in the March 1991 issue.

The Schoessow patent application specifies a different anode geometry which may be responsible for the reportedly reproducible results.

**Summary:**

In the "Detailed Description and Best Mode of the Invention", the following comments are made:

"The process of this invention relates to an electrolysis procedure with the cathode being a metal from Groups 3B, 4B, 5B, 6B, 7B or 8 of the Periodic Table of Elements or alloys thereof and the anode being platinum, gold, and elements of the Lanthanide Series or the Actinide Series of the Periodic Table of Elements or alloys thereof."

"The anode is an encircling dish-like structure 25 which may be in the form of a shallow pan, or cup, with a perimeter wall, in this case generally cylindrical and equally spaced radially from the central cathode 23. Other shapes than circular and cylindrical are also useful, e.g., square, triangular, or the like. Anode 25 may be a structure impermeable to fluid flow, or it may be made permeable to fluid flow in the form of a screen, woven wire, perforated plate, or the like...The amount of electrolysis current required may vary for different embodiments of the invention but is generally about 5-25 volts and 0.1-10.0 amps, D.C."

"It has been found to be advantageous to pretreat the cathode before use in the electrolysis process of this invention. Preferably the surface of the cathode is roughened, e.g., with a file to remove the glossy finish, and also to abrade the surface, e.g., by cutting minute grooves into the surface by the edge of the file or other similar procedures."

"It is believed that the ratio of heat output/heat input and the rate of production of tritium and radiation is enhanced by a pretreatment given to the cathode. The preferred treatment is to heat the cathode to about 400 C in an inert gas, e.g., nitrogen, argon or helium, cooling the cathode to room temperature, and abrading the surface, e.g. by filing, to remove about 0.1 mm."

Elsewhere, it is noted that the preferred electrolyte is D<sub>2</sub>O containing 0.05-0.2 M of LiOD or another Li<sup>+</sup> or OD<sup>-</sup> salt, and that the D<sub>2</sub>O could contain lesser amounts, up

to 30%, of H<sub>2</sub>O. It is also suggested that the anode could be "any of the noble metals, i.e. those of the gold and platinum families, esp. nickel, palladium, platinum, copper, silver, and gold." In claim 9, a different list of preferred anode materials is given: Pt, Ni, Au, Ce, Pr and Th. Preferred cathode materials listed in claim 7 are La, Zr, Hf, Cr, Re, Co, Ni, Cu and Pd. Furthermore, it is noted that the anode and cathode must be of dissimilar elements; neither anode nor cathode may combine elements from both groups, nor may La, Ac, Pt or Au be used for both electrodes even though these elements appear on both lists.

While alternate configurations such as cells with multiple anodes and cathodes are also indicated to be possible, "It appears to be important, however, to maintain a solid cathode surrounded by cup-shaped walls of the anode." It is also stated that while the anode may be solid or porous, "It is preferable for the anode to be a solid impervious structure."

As potential alternatives to the indicated annealing procedure, annealing in vacuum or high-temperature annealing are also mentioned. Provisions for gas recombination, heat extraction, and pressurization of the cell to allow operation above 100 C (up to 300 C) are noted as possible improvements for commercialization.

One possible ambiguity should be noted: The description of the anode as a "shallow cup" could be interpreted by different readers as referring either to the aspect ratio between the anode height and diameter, or to the anode being shorter than the cathode. In this latter case, the term merely restates that the anode should surround only part of the cathode, and the aspect ratio of the anode is not discussed. The figures in the application, unfortunately, do not give a clear-cut answer. While a small anode aspect ratio is in fact shown in Figure 1 [reproduced in the abstract], the multiple anode/cathode schematics show the opposite aspect ratio. Thus, it is possible that the ratio in the first figure may simply be a drafting convenience.

**Experimental Results:**

The following calorimetric data, obtained using flow calorimetry, is reported:

RUN	COMMENTS	DAYS	HEAT OUT/ HEAT IN
1	Pd Block, Pt Cup	9	1.63 Average
2	same	9	1.04 Average
3	Pd bar, Pt Cup	66	1.2 to 1.5
4	Added up to 30% H <sub>2</sub> O	3	1.2 down to 0.98
5	Lowered Elect.Level	8	1.5 down to 1.2

6 Pd Bar, Pt Cup	60	1.3 Average
7. U Cathode	3	1.10 Average
8. H <sub>2</sub> O + LiOH	10	0.90 Average
9. Pd Bar, Pt Cup	58	1.61 Average
10. Zr Bar, Pt Cup	14	1.47 Average
11. Ti Bar, Pt Cup	4	1.30 Average
12. Pd Bar, Ni Cup	4	Up to 2.50

D<sub>2</sub>O with 0.1 M LiOD was used in all of the above runs except run 8 (the H<sub>2</sub>O/LiOH control) and run 2 (LiOH/D<sub>2</sub>O, equivalent to LiOD/D<sub>2</sub>O with a small amount of deliberately added H<sub>2</sub>O). Run 2 showed no excess heat, and run 8 showed little excess; all other runs showed at least 10% excess heat. Furthermore, it was estimated from data such as run 8 that the heat production was underestimated by approximately 10%, as heat losses through the calorimeter insulation were neglected.

Data for one run is also broken down on a daily basis, showing variations from 11% to 149% excess over a 9-day period. The highest excess (on day 9) corresponded to 1172 BTU (approximately 1.8 MJ).

The tritium measurements presented for one of the runs also provide confirmation of the cold fusion claims. The tritium decay rate increased from 2000 dpm to slightly under 50,000 dpm over 70 hours.

### **Analysis of Experimental Data:**

If the above experimental data can be reproduced by "one skilled in the art, without undue experimental effort", then the patent has been properly presented in accord with the expectations of patent regulations. **More important, there should be little further discussion about whether cold fusion is a reality if several laboratories are able to report that the Schoessow invention has been successfully replicated.** Unfortunately, the Schoessow patent application does not disclose the precise dimensions of the cell used, or of an optimum cell configuration.

The peak excess power levels reported are both particularly high and sustained: up to 150% excess in run 12, and an average of 61% excess sustained over 58 days in run 9. It is quite conceivable that these results do not represent the maximum attainable with an optimum cell configuration, and that not only reproducibility but also even higher yields are possible.

It is also interesting to note that the data indicates that even metals which form hydrogen-blocking oxide films in solution (uranium and titanium) can be used as cathodes. One reason why such metals may have been avoided by most previous experimenters because the surface oxides

could be expected to slow the loading rate and to decrease the loading which is eventually attained.

### **Comparison with Previous Patents:**

One of the preferred cell specifications in the Schoessow patent application (heavy water, 0.1 M LiOD, platinum anode, cylindrical palladium cathode) is essentially the same as in the initial Pons-Fleischmann electrochemical cell with one important exception: the configuration of the anode. The anode is specified as being cup-shaped, with the cathode having part of its length above the cup. [See the figure in the abstract but recognize that the drawing may not be to scale, but merely conceptual.] In addition, beneficial pretreatments are described, and experimental data for two of a wide variety of other metals besides Pd is given.

The Matsushita patent application also indicates a large number of possible hydrogen-absorbing cathode materials, but these are alloys of two or more elements which, in certain stoichiometric proportions, form hydrogen-absorbing "Laves phases" (types 14 or 15). 32 specific examples of crystalline transition metal alloys are listed as having maximum H/metal ratios greater than 1, and 32 examples of amorphous alloys.

No set cell geometry is recommended; while one figure shows a cathode which could be interpreted as projecting above the top of a cylindrical anode, another diagram depicts a totally different geometry in which anode and cathode are simply two plates side by side, a configuration which is not ordinarily used because the resulting loading would presumably not be as efficient as if a surrounding anode is used.

### **Effects of Geometry:**

While extensive speculation on possible mechanisms by which such an anode geometry could result in an improvement in output or reproducibility is beyond the scope of the present article, it is clear that potentially significant changes can occur. For example, this geometry may result in significant nonuniformity in a number of factors such as loading rates and the extent of electrodeposition of impurities.

Some theories (such as that of Dr. Robert Bush of Cal Poly) indicate a narrow range of conditions in which fusion occurs. Thus, such a geometry may ensure that in some portion of the cathode, the proper conditions are reached without being overshoot. Furthermore, even if continuing electrochemical changes or the cold fusion process itself perturb the system significantly, this could allow fusion to continue to occur in at least some portion of the cathode.

## C. NEWS FROM THE U.S

### NEW YORK - "BOOST FROM NAVY"

Jerry E. Bishop, "Utah Funds for Cold Fusion Run Low Just as Concept Gets Boost From Navy", *Wall Street Journal*, April 8, 1991, page B-4.

The WSJ report, as usual, combines some exciting positive news about cold fusion with a negative-sounding story about the diminishing funds for the National Cold Fusion Institute at the University of Utah. The good news is the report of the work at the Naval Weapons Center at China Lake, Calif., where Dr. Miles working with Dr. Bush at the University of Texas at Austin performed **an elegant experiment showing that <sup>4</sup>He is the nuclear byproduct of cold fusion.** The article quotes an anonymous scientist who declared that the paper leaves some questions unanswered that leaves him/her uneasy. For a review of the paper see *Fusion Facts* lead article in the March 1991 issue. The Bush, Lagowski, Miles, & Ostrom paper will appear in the *J. Electroanal. Chem.* in the near future.

### PHILADELPHIA - OUT BUT NOT DOWN

Courtesy of Dr. Eugene Mallove

Staff, "Cold Fusion: Out But Not Down?", *Science Watch*, Jan/Feb 1991, page 6.

#### EDITOR'S COMMENT

*Science Watch* publishes a periodic report on "WHAT'S HOT IN PHYSICS..". This report is a listing of the ten most cited papers in physics. For this issue (reporting on the September/October 1990 papers), the top paper was on superconductors, the second paper was the Fleischmann & Pons paper on cold fusion [*J. Electroanal Chem*, **261**, (2A), pp 301-8, 10 Apr 1989.], and the third most cited paper was Jones et al., on cold fusion [*Nature*, **338** (6218), pp 737-40, 27 April 1989].

The article notes: "Several of the usual themes return to this period's collection of hot papers in physics, including one topic whose demise was confidently -- and, it would seem, prematurely -- predicted by *Science Watch*."

Although possibly shocked at the resurrection of cold fusion, the staff of *Science Watch*, made a careful review of the 38 articles citing Fleischmann and Pons. **They found that 22 of the 38 papers offered supporting evidence that would allow the papers to be counted as "positive" in support of cold fusion (5 were negative, the others noncommittal).**

(Courtesy of Drs. Liebert and Liaw)

Bor Yann Liaw, Peng-Long Tao, Patrick Turner and Bruce E. Liebert, "Elevated-Temperature Excess Heat Production in a Pd-D System," submitted to *J. Electroanal. Chem.*

#### EDITOR'S COMMENTS

This preprint represents an update of the authors' report on their molten-salt electrolysis experiment [B.Y. Liaw, P.L. Lao, P. Turner and B.E. Liebert, "Elevated Temperature Excess Heat Production Using Molten-Salt Electrochemical Techniques," Proceedings of the Special Symposium on Cold Fusion, World Hydrogen Energy Conference #8, Honolulu HI, July 22-27, 1990], which (due to its importance) was also printed in its entirety and discussed in the October 1990 issue of *Fusion Facts*. The important fact is that the authors measured heat outputs 600-1500% greater than the electrolysis energy input over approximately 100 hours.

Although the present paper does not yet include calorimetric data from further experiments, it does provide additional information on the initial experiment. For instance, it is noted that the 50-80 W power to the heating tape used to maintain the elevated temperatures could be controlled to  $\pm 0.1$  W. Also, that the high heat conductivity of the cell (resulting from the good conductivity of the melt and metal parts) would minimize problems due to localized heating. In addition, that measured heat outputs in LiH control experiments matched predicted values, and that output in the two LiD experiments fell back accurately to the calibration curve after the LiD was exhausted. It was also noted that the cell was operated under constant voltage and that the time constant of the calorimeter was unusually long, 5-6 hours.

In addition, it was noted that the salts typically contain significant amounts of water, which will react with and consume the added LiD. Thus, the experimenters waited at least a day between melting of the salts and addition of the LiD.

In addition to the experimental data presented at the symposium, this paper also presents results from scanning electron microscopy (SEM) and microprobe (EDX) studies of the electrodes. Electrolysis was found to result in recrystallization of dendritic or needle-like Pd structures, and in deposition of Fe (probably from the steel used as conductors and welded to the electrodes) and Zn (probably from the Al cathode) which covered a fraction of the Pd surface. The Pd used was quite porous as a result of gases introduced during torch melting; typical pore sizes were 3-5 microns and typical grain sizes were 300-500 microns. Following electrolysis, typical pore

## U OF HAWAII - MOLTEN SALTS

sizes increased to 10-50 microns, with some up to 100 microns, grain structure was no longer visible, and the samples became quite brittle. The Pd microstructure was suggested to be important in determining whether cold fusion reactions occur.

Finally, the paper notes confirming analyses by an outside laboratory in which elevated  $^4\text{He}$  levels were measured in the anode after the experiment as contrasted with similar measurements in the unelectrolyzed Pd [as reported at the BYU cold fusion conference, *Fusion Facts*, November 1990].

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## U OF ARIZONA - THEORY

R.H. Parmenter and Willis E. Lamb Jr., "Cold Fusion in Palladium: A More Realistic Calculation," *Proc. Natl. Acad. Sci. USA* **87**, 1990, pp 8652-8654.

### ABSTRACT

The Thomas-Fermi-Mott equation is modified to take account of the fact that conduction electrons in a metal may be considered to have an effective mass at wave numbers comparable with or less than the inverse Debye screening length, but they should be considered to have the free-electron mass at much larger wave numbers. This modification allows for a more realistic calculation of the fusion rate of deuteron pairs in palladium, this rate being  $10^{-23} \text{ sec}^{-1}$ , comparable with some experimental results. The Oppenheimer-Phillips process enhances the rate by a factor of 2.262.

### EDITOR'S COMMENTS

This paper represents an extension of earlier work by the authors [*Proc. Nat. Acad. Sci. USA* **86** pp 8614-8617 and **87** pp 3177-3179], reviewed in the July 1990 issue of *Fusion Facts*. In the initial paper, quite high fusion rates are calculated in PdD due simply to screening by electrons with high effective masses. The present paper, which takes into account the fact that the increase in screening ceases to apply at very short distances, calculates rates  $10^5$  times lower, but still comparable to those measured by Dr. Jones of BYU. A slight increase in the tritium/neutron ratio is predicted.

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## D. NEWS FROM ABROAD

### ITALY - NEGATIVE EXPERIMENT

(Courtesy of Dr. Samuel Faile)

A. Alessandrello, E. Bellotti, C. Cattadori (Gran Sasso), C. Antonione (U of Torino), G. Bianchi, S. Rondinini, S. Torchio, E. Fiorini, A. Giuliani, S. Ragazzi, L. Zanotti (U

of Milano) and C. Gatti (Centro C.N.R. per lo Studi delle Relazione tra Strutture e Reattiva Chimica, Milano), "Search for Cold Fusion Induced by Electrolysis in Palladium," *Il Nuovo Cimento* **103A**, 1990, pp 1617-1638.

### EDITOR'S COMMENTS

Although no increases in heat, neutron, tritium, gamma radiation or helium were measured during the electrolysis, this experiment was quite interesting in that an attempt to enhance cold fusion by stressing the cathode was made. The Pd and Ti cathodes were gradually stretched using a constant strain rate testing apparatus. This mechanical stressing was indicated to have several possible effects: increased local deuterium concentration and possible overall loading increases due to surface alteration, cracking, and dislocation movement. It was noted, however, that loading in this experiment may have been lowered by the fact that much of the electrode surface was not in contact with the electrolyte.

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## USSR - NEUTRON EMISSION

(Courtesy of Dr. Samuel Faile)

Yu. A. Bashkirov, R. Kh. Baranova, B.G. Bazanin and M.V. Kazakova, "Neutron Emission in Electrolysis of Heavy Water," *Pis'ma Zh. Tekh Fiz.* **16** (19), 1990, pp 51-55 (in Russian).

### SUMMARY

An attempt was made to record 2.45 MeV neutrons during cold fusion. For the measurement, simultaneous use was made of a commercial thermal neutron counter of type SNM-56 (filled with a mixture of He 97% + Ar 3%, placed in a paraffin absorber 3.5 cm thick) and a device for recording recoil protons in an organic scintillator, with photomultiplier noise suppression. The explosive nature of neutron emission was recorded simultaneously by the 2 detectors, which excludes any systematic instrumental error. Pd, Ti, and Au electrodes all showed neutron emission above background levels for both ordinary and heavy water electrolytes, with the latter neutron yields being somewhat greater than the former.

### EDITOR'S COMMENTS

This is one of the few experiments reported in which apparently positive results have been reported using ordinary water as well as  $\text{D}_2\text{O}$ , and non-hydrogen-absorbing cathodes such as gold. Thus, other sources such as cosmic ray showers must be suspected. Had controls been negative (especially if run simultaneously), as has often been the case in other experiments, evidence of a cold fusion process would have been strengthened.

## USSR - EXCESS HEAT FROM GAS DISCHARGE DEVICE.

See the lead article on page 1 of this issue.

## E. SHORT ARTICLES

### ELECTROCHEMISTRY PRIMER

By Michael Dehn, Associate Editor

As pointed out in the original paper by Fleischmann and Pons [1], the usefulness of electrolysis for the introduction of high concentrations of hydrogen (or its isotopes) into noble (not readily corroded) hydrogen-absorbing metals such as palladium has long been recognized. (A review paper [2] notes papers on electrolytic charging of Pd with H dating as early as 1866-8.)

Furthermore, the Fleischmann-Pons paper calculates that the deuterium uptake possible in electrolytic loading of Pd may be equivalent to that produced by  $D_2$  gas pressures on the order of  $10^{26}$  atmospheres, thus making electrolysis experiments potentially superior to those using gas-loading (in which the sample is deuterated by exposure to pressurized  $D_2$  gas). Other sources have disputed the magnitude of the calculated equivalent pressure [e.g. 3, 4], but previous work [e.g. 5] nevertheless indicates it may be high.

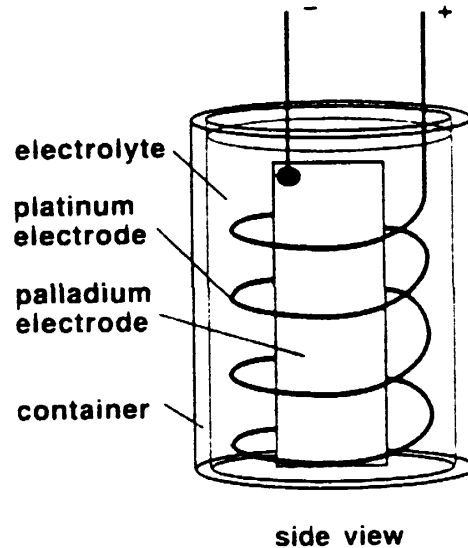
#### Experimental Setup

An electrochemical cell consists of two electrodes immersed in an electrically-conducting liquid and connected to a DC power supply which generates a current flow between them. The electrode connected to the positive terminal is termed the anode, and the electrode connected to the negative terminal is termed the cathode. The solution is termed the electrolyte.

Most often, the anode is either a wire spiral or a solid or mesh cylinder surrounding a cylindrical cathode, since this gives an approximately uniform current distribution at all points on the cathode surface. However, other geometries have also been tried. (For example, in experiments designed to measure emission of charged particles or X-rays, the cathode may even be made the wall of the cell, so long as the outside is coated to prevent deuterium escape. See patent article beginning on page 2.)

In typical heavy water cold fusion electrolysis experiments, the cathode is composed of a hydrogen-absorbing metal such as Pd (a few millimeters in diameter and a few centimeters in length), and a relatively inert material such as Pt is used as the anode.

The electrolyte ordinarily consists of  $D_2O$  (heavy water) in which salts have been dissolved to provide the desired electrical conductivity. For example, a 0.1 mole/liter solution of lithium deuterioxide (0.1 M LiOD) is often used; this dissolves to give  $Li^+$  ions and  $OD^-$  ions. Such a solution can be prepared simply by placing an appropriate amount of Li metal in  $D_2O$  (0.694 grams Li per liter) and allowing it to dissolve.



Schematic of an Electrolysis Cell

The above figures is adapted from E. Batalla et al., *Solid State Commun.* **71**, 1989, pp 806.

#### Voltage and Current

Cell voltages are most often on the order of 5-20 volts, and cell resistances on the order of several ohms. Current densities used are typically a few hundred milliamperes per square centimeter of cathode surface area ( $mA/cm^2$ ), giving total currents of several tenths to a few amperes.

The electrical resistance will decrease as the electrolyte concentration is increased, or as the spacing between anode and cathode is decreased. The resistance also depends on whether  $H_2O$  or  $D_2O$  is used;  $D_2O$  electrolytes have significantly lower conductivity, and thus higher resistance.

Most commonly, cells are operated at constant current ("galvanostatic"): the power supply regulates the current to the desired value, and voltage varies as necessary to maintain this level despite any variations in the cell resistance. Alternately, some experiments are operated at constant voltage ("potentiostatic"), with current allowed to vary in response to resistance changes. If calorimetry is to be performed, both voltage and current would also be monitored or recorded to calculate the input power.

The relationship between current  $I$  and voltage  $E$  is given by

$$E=IR,$$

where R is the resistance. Input power to the cell is given by

$$P = IE = I^2R,$$

where P is the power.

Higher cell resistance will result in an increase in input voltage and power if the cell is operated at constant current density, but a decrease in input current and power if the cell is operated at constant voltage.

As discussed by some authors [e.g. 6], both erratic fluctuations and gradual changes in the cell operation with time may be anticipated. For example, cell resistance will be increased by gas bubbles on the electrode surface and between the electrodes, which can result in rapid fluctuations in voltage or current. In addition, use of open cells (in which gas formation results in steady D<sub>2</sub>O loss) will cause a gradual increase in the electrolyte concentration, and thus a decrease in resistance. Increases in cell temperature will decrease resistance and also decrease deuterium solubility in cathode materials such as Pd. Finally, cell resistance may increase or decrease with time due to progressive changes in the electrode surfaces, due to loading, oxide formation on the anode, and any other chemical changes. (Even highly oxidation-resistant noble metals such as Pt can form surface oxide films or dissolve if used as anodes at high current densities.)

#### Electrolytic Loading - Principles

In general, electrochemical reactions can be treated as consisting of two "half-reactions". In the oxidation half-reaction, a chemical species yields up electrons. In reduction, a species gains electrons. If these reactions do not occur at the same location, the site of the reduction is the cathode, and that of the oxidation is the anode.

In D<sub>2</sub>O cells, the current flow results in electrolysis of the D<sub>2</sub>O to form D<sub>2</sub> and O<sub>2</sub> gases. The overall chemical reaction can be expressed as  $2 \text{D}_2\text{O} \rightarrow 2 \text{D}_2 + \text{O}_2$ . In alkaline (basic) electrolytes (such as LiOD in D<sub>2</sub>O), the reduction reaction at the cathode can be expressed as  $2 \text{D}_2\text{O} + 2 \text{e}^- \rightarrow \text{D}_2 + 2 \text{OD}^-$ , and the oxidation reaction at the anode can be expressed as  $4 \text{OD}^- \rightarrow 2 \text{D}_2\text{O} + \text{O}_2 + 4 \text{e}^-$ . The D<sub>2</sub> and O<sub>2</sub> can be observed as bubbles continually forming at the electrode surfaces.

The electrical charge per mole of electrons is given by Faraday's constant, 96,485 Coulombs/mole. Thus, ideally, passage of this quantity of electrons through the electrolysis cell can form 1/2 mole of D<sub>2</sub> gas and 1/4 mole of O<sub>2</sub> gas.

In practice, other electrochemical reactions are also possible (for example, if the gas produced at one electrode crosses over and reacts at the other, or if the gases recombine elsewhere to reform D<sub>2</sub>O). However, these

reactions are typically minor: Measurements of the gas volumes generated (in open cells), or of the volume of D<sub>2</sub>O reformed if the gases are passed over catalytic recombiner such as heated Pt (in closed cells), show that in actual practice cells are often characterized by nearly 100% "Faradaic efficiency" at high current densities.

If the cathode material is capable of absorbing deuterium, a portion of the deuterium liberated by the electrolysis can enter the cathode rather than combining on its surface to form D<sub>2</sub> gas. This deuterium (or hydrogen) loading can thus actually be treated as a multi-step process, as pointed out in the original Pons-Fleischmann paper [1] and since [11]. D<sub>2</sub>O reduction forms adsorbed D on the cathode surface, a fraction of the *adsorbed* D's are *absorbed* into the lattice, and these then diffuse deeper into the cathode. (Adsorption involves attachment of a species to a surface, while absorption involves passage of the species into the interior.)

Except initially, the loading rate is often not limited by the rate of electrolysis or by the rate of diffusion of D<sup>+</sup> in Pd. Instead, loading will often depend on competition between incorporation of adsorbed D's into the lattice with combination of adsorbed D's to form D<sub>2</sub>.

Initially, the absorption of deuterium (or hydrogen) may be sufficiently rapid that visible gas evolution at the cathode does not commence for several minutes after electrolysis is started. As time progresses, the rate of loading of the cathode with deuterium will decrease, as the loading asymptotically approaches its ultimate value. The ultimate D/Pd ratio is generally thought to be between 0.6 and 1.0 in most cold fusion electrochemical experiments.

Theoretically, loading will eventually stabilize, and the net cathodic reaction will be reduction of D<sub>2</sub>O to form D<sub>2</sub>. In actual practice, oscillations in loading have been suggested to be possible [e.g. 7], resulting in alternating periods of net outgassing and net absorption. (This should also be reflected in corresponding fluctuations in the rate of D<sub>2</sub> gas evolution from the cathode.)

#### Extent of Loading

The extent of deuterium loading of Pd is typically expressed in terms of an average D/Pd ratio. However, while dissolution of small amounts of deuterium in Pd initially produces alpha palladium deuteride, a phase transition occurs at higher loadings. The average D/Pd ratio at which this occurs depends on temperature, but near room temperature will be well below D/Pd = 0.1. At this point, addition of further deuterium will convert a portion of the alpha phase to beta palladium deuteride, with a D/Pd ratio near 0.5. This process continues until only beta PdD<sub>x</sub> is present.



The loading attainable in an electrolysis cell will be a function of the cathodic overvoltage, which is in turn a function of the cathodic current density. Even low current densities can yield average D/Pd ratios greater than 0.5, as gas evolution during even minimal electrolysis results in exposure of the cathode surface to  $D_2$  gas at the ambient pressure (1 atmosphere, assuming the cell is not pressurized.) Fleischmann points out that the concentration of  $D^+$  in a Pd lattice which is in equilibrium with  $D_2$  under these conditions could produce a D/Pd ratio of 0.6-0.7 [11].

Above D/Pd=0.5, however, increases in loading require the forcing of additional deuterium into the beta phase, rather than conversion of more alpha  $PdD_x$  to beta  $PdD_x$ . Further, as will be discussed in the next section, loading is typically related to the **logarithm** of the current density. Thus, the increase in loading with greater current densities drops **rapidly** at higher loadings. The dependence of loading on current density, discussed below, can be strongly dependent on cathode surface properties. However, even under favorable surface conditions and current densities of several hundred mA/cm<sup>2</sup>, average loading would typically still be less than 1.0.

It should be noted that some degree of nonuniformity in current densities may result from the typical lack of perfect symmetry in anode and cathode geometries. In extreme examples, this may become visible to the naked eye as less radial expansion of one end of the cathode, or as bending of the cathode, because less-highly-loaded regions will undergo less expansion. On a smaller scale, surface asperities (sharpness) may also result in locally higher loading.

Typically, experimenters have endeavored to keep the cathode completely immersed in the electrolyte in order to prevent deuterium from recombining on the exposed surface to form  $D_2$  or  $D_2O$ , since the resulting diffusion of deuterium out through this end could decrease loading in the entire cathode. Similarly, the electrical lead attached to the cathode should be made of a metal which does not absorb hydrogen (deuterium) [e.g. 8].

It should also be noted that interruption of the electrolysis current will cause loading to decrease, since the electrolysis process has resulted in supersaturation of the cathode with deuterium (i.e. the concentration of D in the lattice is suddenly higher than that which would be in equilibrium with the deuterium dissolved in the electrolyte). Depending on the degree of supersaturation (D/Pd ratio) and the effect of the cathode surface characteristics on the rate at which deuterium atoms can combine to form  $D_2$  on the surface, this outgassing may be rapid enough to cause visible bubbling when the current is interrupted. Furthermore, several experiments

in which excess heat production did not resume following interruption of the current suggest the possibility that additional changes can also occur in such an interruption and resuming of current flow.

A final factor which can affect the degree of loading attained is the cathode metallurgy. For example, lattice defects can provide additional sites for deuterium, while alloying with even several percent of other metals can decrease the solubility of hydrogen isotopes significantly.

#### Overvoltage and Electrode Surface Properties

Much of the voltage drop between anode and cathode in a typical cell will occur across the electrolyte. As previously mentioned, this results from the limited electrical conductivity of the electrolyte. Additional voltage drops also occur, however, at the anode and cathode surfaces (even in the absence of electrically-insulating oxide films on the electrode surface).

Furthermore, these interfacial effects may be strongly dependent on the surface characteristics (both chemical and metallurgical) of the electrodes. The voltage drop at the surface of the electrode, or change in the electrode voltage due to the occurrence of the reaction, is frequently referred to as the overvoltage or overpotential. [See also ref. 17, reprinted immediately following this primer.] Increased loading may result from the increase in cathodic overvoltage with increasing current densities.

In Pd loading, before equilibrium is reached, the cathode overvoltage will typically change rapidly as the alpha Pd deuteride phase is formed, then remain stable for an extended period of time as the alpha deuteride phase is converted to the beta phase, then rise again when only the beta phase remains [see e.g. 9].

Often, over a certain range of conditions, the final overvoltage reached will be proportional to the logarithm of the current density: i.e. every 10-fold increase in the current per unit area would result in a unit increase in the overvoltage. The rate at which the overvoltage increases with increases in  $\log(\text{current})$  is termed the "Tafel slope". For  $D_2$  formation on a clean Pd surface this value may be approximately 0.2 V per decade (10-fold current change) at low to moderate current densities [e.g. 10]. Under other conditions, however, this behavior may be altered by the factors discussed in the next section.

Fleischmann and Pons indicate that overvoltages at Pd cathodes during  $D_2O$  electrolysis may readily approach 1 V at current densities of a few hundred mA/cm<sup>2</sup> [e.g. 1, 11], with values of up to 2 V being conceivable. However, although measured changes in the cell voltage or current may reflect changes in the overvoltages, the actual overvoltage values are only rarely determined in

cold fusion experiments, since this requires measurement of the potential difference between the cathode surface and that of a reference electrode. Measurements of overvoltages [e.g. 10, 12] or related quantities [e.g. 13-15] have, nevertheless, occasionally been performed in companion experiments.

### Effects of Other Compounds

It has long been known that the presence of a variety of other compounds in the solution can affect the  $H_2$  ( $D_2$ ) formation and hydrogen (deuterium) absorption reactions by affecting the cathode surface. Fleischmann and Pons [e.g. 1, 11] and other authors [e.g. 2, 10, 12, 13, 16-18] have also discussed the possible importance of such effects in cold fusion experiments and/or measured such effects. (One author [12] states, "One of the typical characteristics of the hydrogen evolution reaction is its extreme sensitivity to various impurities present in the solution.")

Substances which, when they adsorb to the cathode surface, interfere with the reaction of surface D atoms to  $D_2$  may increase the overvoltage and the attainable loading. (The terms "hydrogen evolution poisons" or hydrogen uptake "promoters" are both used to describe such substances.) A wide variety of such substances is known, and some can have dramatic effects even at ppm (part-per-million) concentrations or less [see e.g. 2]. On the other hand, substances which interfere with hydrogen uptake (by coating the cathode surface, or by favoring recombination to form  $D_2$ ) can decrease it. In addition to changes in the degree of loading attained, changes in the rate at which the equilibrium loading is reached may also occur.

For example, platinum is typically an even better catalyst than palladium for the reaction between atomic and molecular hydrogen or deuterium, so that deposition of Pt on a Pd cathode ("platinization") may result in substantial reductions in the cathodic overvoltage. Most other metals, on the other hand, are poorer catalysts of  $D_2$  formation, and would typically raise the overvoltage.

It should be noted that some substances may affect both of the competing reactions; for example, one study of the effect of cyanide in 0.1 M LiOD found that desorption was essentially completely prevented, but hydrogen uptake was also slowed [13]. The effect may also be sensitive to the quantity of the substance; for instance, slight palladium oxide buildup has long been suggested to assist in the speed of hydrogen uptake [refs. in 19], yet thick oxide films would presumably block uptake. Finally, the effect may vary depending on such factors as the cathode composition and pH, such that substances which promote hydrogen uptake in ferrous metals in acid solutions, say, may have a different effect for Pd in alkaline solutions such as LiOD [13].

In actual practice, the situation may also be complicated by the fact that the overvoltage may depend on which step in the mechanism is the one limiting the rate of the reduction reaction. Thus, the relation between current and loading may be different for different ranges of current density.

Furthermore, the overvoltage may be altered by factors which alter either the intercept or the slope of the current-overvoltage curve.

The intercept is affected by the ability of the metal to catalyze the electrochemical reaction at zero current; this is frequently given by a quantity known as the "exchange current density",  $i_0$ . Metals such as Pd and especially Pt have especially high values for the  $D_2$  formation reaction, resulting in a favoring of  $D_2$  formation over D absorption.

The rate at which the overvoltage increases with current density is given by the Tafel slope, which may also be changed by surface deposits. For example, in one study [10], a dramatic increase in the overvoltage due to a change in the Tafel slope (as defined in the previous section) from 0.2 to 1.8 V/decade was measured at high current densities for an electrode on which Pb and Zn impurities had deposited.

Tabulations of data on exchange current densities and overvoltages for the hydrogen evolution reaction on different metal surfaces under particular conditions are readily available in electrochemistry textbooks and other sources [e.g. 20]. The trend in overvoltages for the deuterium evolution reaction can be expected to be similar, although there may be differences in the actual values. (One review of cathodic overvoltage in cold fusion [17] notes data on deuterium overvoltage differences as early as 1935.)

In addition to affecting loading, deposition of impurities on the cathode surface during prolonged electrolysis has also been suggested to affect the cold fusion reaction directly [21]. In this hypothesis, the high electrical fields at the tips of dendritic deposits of impurities such as Ni, Fe or Cr may result in arcing across  $D_2$  bubbles on the tips, resulting in the acceleration of  $D^+$  ions to much higher energies. One theory (the TRM model of Dr. Robert Bush of Cal Poly) also suggests that the overvoltage itself may play a direct role; in this case, reduction of the overvoltage (by deposition of platinum or lowering the current density) may under some circumstances raise the fusion rate even though it lowers the loading.

### Sources of Other Compounds

Other substances can include impurities in the electrolyte or other cell contents, residues left behind by cathode surface cleaning procedures such as acid treatment [e.g. implied in 13], and deliberately introduced additives. It should be noted that during electrolysis, other positively-charged species in the electrolyte will tend to migrate to the cathode, and may be reduced there. Thus, metal ion impurities present in even part-per-million levels in the electrolyte or leached from the walls of the cell may be electroplated onto the surface of the cathode. If electrolyte volumes are sufficiently small, impurities present in even part-per-million quantities may be able to form a monolayer (1-atom-thick layer) covering the cathode surface.

In addition, even highly oxidation-resistant metals such as Pt can slowly dissolve if used as anodes, and the resulting metal ions can again be redeposited on the cathode [e.g. 10]. (This is also the reason why many surface impurities, and also absorbed hydrogen isotopes, can be removed by "anodic stripping", in which the electrode to be cleaned is temporarily run as the anode.) If non-noble anode materials such as Ni are used, the cathode may rapidly develop a visible surface coating of this material's oxide.

Furthermore, it should be pointed out that certain negatively charged compounds such as cyanide,  $CN^-$ , may not only affect the cathodic reaction, but also react with certain anode materials such as Pt to form complexes. In this case, greatly accelerated dissolution of the anode material and its redeposition on the cathode may also result [14].

### Lithium

A further possible reaction which has been considered by various researchers [e.g. 10, 12, 16, 22-24] is the deposition of lithium at the cathode surface during electrolysis under certain conditions. The impetus for such studies has been the observation by Appleby [25] that excess heat generation in electrolysis ceased when LiOD was replaced by NaOD, suggesting that Li either has an electrochemical effect on deuterium loading or participates in the nuclear reaction. Possible forms for a Li layer could conceivably include solid LiOD, LiD, Li-Pd alloys and Li metal.

Experimental data has, in fact, shown that the electrochemical effects of Li can differ from those of Na during electrolysis of  $D_2O$  on Pd in alkaline solutions [13]. Analyses have also occasionally detected Li on the surface of Pd cathodes after prolonged LiOD electrolysis [e.g. 16, 26] (as well as under somewhat different conditions [23]). It has also been suggested that other substances may play an important role in allowing such Li deposition to occur [12]. Finally, it has been suggested that the Li may change to an oxide form when the current is interrupted

[16]; effects such as this may provide an explanation of how cell behavior could be changed by interruption of the electrolysis.

### Possible Experimental Modifications

While the electrolysis reaction itself is simple, the preceding discussion has shown that the anode material, cathode surface condition, and impurities in electrolyte can act as hidden variables in determining the loading attained. Thus, some experimenters have analyzed used electrodes (and in some cases also unused electrodes) by electron microscopy and chemical techniques.

In some cases, experimenters may attempt to prevent spontaneous changes in the cathode by "pre-electrolysis"; prolonged electrolysis is performed using a disposable cathode (but the same electrolyte and cell) to cause electrodeposition of any impurities in the electrolyte, and a new cathode is then introduced.

Certain experimenters have also tested the effects of deliberately introduced poisons/promoters such as cyanide [e.g. 13, 14], sulfide [e.g. 27], or other compounds [28].

Experimenters have occasionally also physically modified the cathode surface; for example, the surface area of a Pd cathode could be increased by deposition of additional Pd ("palladization"). One experimenter [29] accomplished this simply by welding additional Pd onto the anode and allowing operation of the cell to dissolve it and electrodeposit it on the cathode, and noted that this technique also had the potential for introducing surface asperities (pointedness) which might result in locally higher current densities and loading.

A final modification which is not uncommon is the use of preloading by prolonged electrolysis at low current densities. This is designed to introduce deuterium at a slow rate in order to minimize the resulting physical disruption of the cathode. (An initial gas loading step could also serve the same purpose.) Such preloading may also result in significant electrodeposition of impurities on the cathode.

### An Alternative Method: Molten Salt Cells

It should be noted that while most cold fusion experiments have used  $D_2O$  for the electrolyte, this limits the maximum temperature quite severely, as the boiling point of pure  $D_2O$  at a pressure of 1 atmosphere is very similar to that of ordinary water (101.4 C). In addition, the choice of cathode materials is severely restricted by the tendency of most metals to form oxide films when exposed to oxygen-containing water. This film will inhibit hydrogen uptake and may also increase cell resistance to unacceptable levels. Thus,  $D_2O$  electrolysis is well-suited

for only hydrogen-absorbing noble metals such as Pd. (Other metals such as Ti could be used given at least a partial coating of a metal such as Pd, but even this could be unsuccessful if the cold fusion reaction turns out to be a surface phenomenon.)

An alternative method which has previously been investigated by researchers such as Dr. Huggins of Stanford [e.g. 30], and very successfully adapted for cold fusion research by Drs. Liaw and Liebert of the U. of Hawaii [31], overcomes both limitations. In this method, the electrolyte is formed by melting salts, since such compounds do so by dissociating into their constituent ions. For example, the U. of Hawaii experiment used a mixture of KCl (potassium chloride) and LiCl (lithium chloride) which melts at approximately 350 C. (The "eutectic" composition of 48% KCl / 52% LiCl was used to give the lowest-melting mixture.) A deuteride such as LiD is then added to the electrolyte to provide a deuterium source. However, this also results in conditions which are highly reducing rather than oxidizing, and thus ordinarily prevents the formation of oxide films on the electrode surfaces. Using this method, the large numbers of other hydrogen-absorbing metals and alloys can be investigated in electrolysis experiments as well.

It is important to note, however, that the LiD dissolves to form D<sup>-</sup>, which migrates to the anode, at which it is oxidized to form D<sub>2</sub> gas. (In contrast, in the D<sub>2</sub>O electrolysis cells discussed up until this point, D<sub>2</sub> gas is formed by reduction at the cathode.) Thus, the deuterium-absorbing metal in a molten salt cell will be the **anode**. In addition, Li<sup>+</sup> ions will not migrate to the electrode being deuterated (as is the case in D<sub>2</sub>O electrolysis), but to the opposite electrode (where in this case it is reduced to Li metal). Thus, any d-Li nuclear reactions would become much less likely. Finally, O<sub>2</sub> formation does not take place, although the salts can undergo other reactions at high voltages.

#### Additional Sources of Information

Electrolysis of ordinary water, H<sub>2</sub>O, is a common demonstration in chemistry courses because of its fundamental simplicity and visible effect. D<sub>2</sub>O electrolysis is an analogous reaction. However, these are only specific examples of an entire class of electrochemical reactions. One of the foremost electrochemistry textbooks is by a noted cold fusion researcher, Dr. Bockris of Texas A&M [J.O'M. Bockris and A.K.N. Reddy, Modern Electrochemistry, Plenum Press, New York, 1977]. However, numerous other electrochemistry textbooks have also been published.

Postscript to readers puzzled by the distinction between "d" and "D" in references: The chemical symbol for hydrogen is "H"; to specify the deuterium isotope (<sup>2</sup>H), the

notation "D" may also be used by chemists (e.g. D<sub>2</sub>O). In nuclear physics, however, deuterium nuclei are referred to as deuterons (in the same way that hydrogen nuclei are protons), and are typically designated by the lowercase "d" (analogous to "p" for proton or "t" for triton). Unfortunately, mixing and matching of conventions may sometimes occur in cold fusion articles if authors are discussing both fields.

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## THE ROLE OF CATHODIC OVERVOLTAGE IN ACHIEVING NUCLEAR FUSION BY ELECTROLYSIS OF HEAVY WATER

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### ABSTRACT

Cathodic overvoltage may be a necessary condition for obtaining a high concentration of deuterium atoms in the cathode as required to make cold nuclear fusion by electrolysis of heavy water possible. Such overvoltage may be established or increased by doping of the cathode surface. Palladium may not be the best cathode material.

## INTRODUCTION

Two years ago, Pons and Fleischmann performed electrolysis experiments on heavy water using a Pd cathode and a Pt anode and observed heat effects exceeding the amount of energy taken from the power supply [1]. They attributed the excess heat to the occurrence of nuclear fusion of deuterium deposited on (and in) the cathode. Since it was generally believed that nuclear fusion can take place only at extremely high temperatures, their claim caused great excitement in the scientific community, and all over the world attempts were made to check the correctness of the observation and its explanation. Some used different setups, e.g. with Ti as a cathode [2], Ni as an anode [3]. With Ti also pressure rather than electrolysis was used to form a deuteride.

Various fusion reactions are possible:

- (1)  $2D \rightarrow {}^3\text{He} + \text{neutron} + \text{energy}$
- (2)  $2D \rightarrow T + \text{proton} + \text{energy}$
- (3)  $2D \rightarrow {}^4\text{He} + \text{energy}$

Reactions (1) and (2) are the ones dominant at high temperatures.

Experiments to check the possibility of fusion occurring at or near room temperature were centered on determining the presence and amounts of the reaction products, including heat. It has been claimed that excess heat can be explained by the heat of solution of D in the cathode, and/or the recombination of  $D_2$  and  $O_2$  produced at the electrodes. This explanation, however, cannot be correct. Under stationary conditions (and under such conditions the heat should be measured) the amount of D deposited on and dissolved in the cathode is just equal to the amount of  $D_2$  evolved at the cathode surface; hence the concentration of D in the cathode is constant and no dissolution heat is to be expected. Recombination of  $D_2$  and  $O_2$ , on the other hand, cannot produce more energy than was used in their creation, so here also there is no source of excess heat.

In all areas where the checks were made the results were inconsistent: some people found excess heat [3,4,5,6], other did not [7-10]. A similar difference occurred in the particle determinations. Contradictions also occurred in the theoretical field: some theorists proved cold fusion to be impossible [11,12], other found it possible [13] and even suggested detailed mechanisms [14-16]. A Russian group attributed the effect to microcracks moving 2D's together [17]. However, this model cannot account for effects continuing unabatedly over long periods (as observed). From the positive results a few conclusions can be drawn: the number of neutrons found was always small, ruling out reaction (1) as a major contributor [18]. Further tritium, formed in cells with a Ni anode, occurred in quantities much smaller than would be expected if

reaction (2) were the dominant one [5]. Apparently, if cold fusion occurs, it will be mainly by reaction (3). [This paper was received prior to the Bush et al. paper showing that  ${}^4\text{He}$  is the nuclear byproduct of cold fusion.] Reaction (2) gives a contribution that is about  $10^3$  times as small.

Several committees have investigated the reliability of the experimental material and have concluded that there is no compelling evidence to believe that cold fusion ever occurred. However, they failed to propose an acceptable alternative mechanism to explain the observed excess heat. Fusion, therefore, remains a possibility.

## THE CAUSE OF EXPERIMENTAL INCONSISTENCY

The lack of consistency of the experimental results obtained with cells with a Pd cathode appears to be related to the origin of the Pd used. This is particularly evident in cases where the same authors find positive results with one batch of Pd, negative results with a different batch [19]. Impurity analyses have been made [20], but attempts to link the different experimental results to particular impurities have so far failed. It is certain, however, that the condition of the surface is of prime importance [18,20].

An explanation of the origin of the conflicting experimental results has to be found in the basic requirements for the occurrence of fusion, i.e. the need to have two D nuclei approach each other to a distance of approximately half the distance of the nuclei in  $D_2$ . Electrolysis of  $D_2O$  involves two subsequent cathodic processes: discharge of  $D^+$  ions with dissolution in the cathode of the D atoms formed, and combination of two D atoms to a  $D_2$  molecule and its evaporation at the surface. For an ambient pressure of 1 atm ( $10^5$  Pa), evolution of  $D_2$  can be appreciable only when the concentration of D (and its activity  $a$ ) corresponds to the equilibrium  $2D \rightleftharpoons D_2$ . The correctness of this model has been shown for hydrogen: Diffusion of hydrogen through metal is proportional to the square root of the  $H_2$  pressure as expected for equilibrium  $2H \rightleftharpoons H_2$ . The majority of D or H dissolved in the cathode is present at interstitial sites with one atom per site. In this state the D - D distance can never become sufficiently small to make fusion possible. If we accept a quasi-static model (different from the laser-type model proposed by some authors), a least requirement for fusion is the presence of a certain number of sites containing two or more D's. This is only to be expected when the concentration of D in the cathode is high and its activity large. If equilibrium  $2D \rightleftharpoons D_2$  is easily maintained, high activities of D can only be established by increasing the ambient pressure. If the reaction  $2D \rightleftharpoons D_2$  or the evaporation of  $D_2$  is blocked, however, high activities of D can be more easily - and much more effectively - be established by electrolysis.

Such easy entrance of D but hindered escape is exactly the condition stipulated by Fox [18].

### OVERVOLTAGE AND ITS DEPENDENCE ON IMPURITIES

With blockage of  $D_2$  escape, the cathode voltage required to load the cathode to its higher saturation concentration is increased from the equilibrium value  $V_{EQ} - V_{REF}$ , for  $P_{D_2} = 10^5$  Pa to a non-equilibrium value of  $V^* - V_{REF}$ . Here,  $V_{REF}$  is the voltage of a reference electrode. The difference,  $\Delta V = V^* - V_{REF}$  is called cathodic overvoltage. The increase of activity of D from  $a$  to  $a^*$  is related to  $\Delta V$  by

$$(4) \quad \Delta V = (kT/q) \ln (a^*/a)$$

With  $kT/q$  approx = 1/40 V at room temperature,  $\Delta V = 0.5$  volt leads to  $a^*/a = 10^{8.5}$ . Since  $a$  is proportional to  $p_{D_2}^{1/2}$ , the activity increase  $10^{8.5}$  corresponds to an increase of  $D_2$  pressure by a factor  $10^{17}$ , an increase hardly achievable by raising the ambient pressure. The first authors to point to the effect of cathodic overvoltage on the concentration of H or D in the cathode and its expected favorable effect on cold fusion appear to be Goedkoop for Pd-H [21], and Spinrad for Pd-D [22]. Evolution of hydrogen during the electrolysis of normal water at various cathodes has been found to occur at different values of the cathodic overvoltage. The results seen in Table 1 show that  $\Delta V$  varies from zero for Pd to 0.57 V for Hg and Tl. Apparently,  $\Delta V$  is small for elements of groups I, VI, VII (metals that are known to catalyze the reaction  $H_2 \rightarrow 2H$ ) and large for elements of groups II, III and IV. Blockage of  $H_2$  escape thus seems to vary from metal to metal. Since the blockage is not complete, higher values of  $\Delta V$  (and their larger values of the ratio  $a^*/a$ ) can be achieved by increasing the current density. The time after which  $H_2$  evolution starts to occur increases with increasing  $\Delta V$ , varying from 12 sec for Pt to 60 sec for Ta, demonstrating that overvoltage raises the concentration of H in the cathode and therewith the time needed to reach the activity at which  $H_2$  at  $P_{H_2} = 10^5$  Pa can be formed. It has also been observed that for materials with a low overvoltage,  $\Delta V$  can be increased by alloying with elements having a large  $\Delta V$ . Thus, Fe + Hg has a larger  $\Delta V$  than pure Fe. Whereas H (and D) dissolve throughout the volume of the cathode, overvoltage appears to be determined by the structure and composition of the cathode surface [24]: when impure electrolytes were used,  $\Delta V$  increased during the electrolysis, impurities from the electrolytes being deposited on the cathode surface. The process could be reversed by inverting the polarity of the cell, making the cathode anode.

The results reported for H almost certainly also hold for D, though there may be quantitative differences. Studies

of the electrolysis of  $H_2O - D_2O$  mixtures indicate that the effects of impurities on the overvoltage for D are somewhat smaller than for H [25]. Yet, elements giving a large  $\Delta V$  for H are likely to equally raise  $\Delta V$  for D. Therefore, doping of Pd (with  $\Delta V = 0$ ) with elements at the end of Table 1 must be expected to raise  $\Delta V$  and therewith  $a^*$  for D. The configuration of D pairs at sites containing two D atoms is similar and perhaps indistinguishable from  $D_2$ . Dopants blocking the formation reaction of  $D_2$  at the surface may have the same effect in the bulk, thus tending to decrease the concentration of doubly occupied sites. For this reason it seems advisable to limit doping to the surface.

### POSSIBLE TEMPERATURE EFFECTS; SITE EFFECTIVENESS

The formation of appreciable concentrations of sites with a double or multiple occupancy of D is only a first condition for the occurrence of cold fusion. The largest hurdle - the close approach of two D nuclei - still has to be scaled. This introduces the effectiveness of the site as an additional factor: The occurrence of fusion will depend on the product of the concentration of sites and their effectiveness. So far, we have concentrated our attention on Pd as a cathode material. Yet, other materials should also be considered, not in the last place for economic reasons; these materials could have sites with a different effectiveness.

Metal atoms bordering the site tend to push the D atoms towards the center of the site, thus reducing the D-D distance and therewith increasing the effectiveness. This effect will be the stronger, the smaller the site, i.e., the smaller the radii of the metal atoms.

Evidently, the effect on the effectiveness has to be balanced against the effect on the concentration (determined primarily by the enthalpy of deuteride or hydride formation.). As seen in Table 2, elements Hf, Zr, Sc, Th, La, and Y with molecular volumes  $V_M > 20.7$  cubic angstroms have enthalpies of formation of hydrides becoming more strongly negative with increasing molecular volumes. Hence for these, solubilities and equilibrium activities  $a$  vary in opposite direction with variation of  $V_M$ . Since according to equation (4) for a given  $\Delta V$ , the activity  $a^*$  of D or H in a doped cathode is proportional to  $a$ , for these elements  $\Delta V$  is probably the decisive factor for achieving cold fusion. For the remaining elements, having enthalpies of formation of the hydrides less negative than -120 kJ/mole  $H_2$ , on the other hand, the enthalpies are practically independent of  $V_M$ . Therefore, for these elements it will be the ones with the most negative  $\Delta H$  that have the most favorable value for the product solubility times effectiveness, making Ti the most promising candidate.

Although an increase in  $\bar{a}^*$  undoubtedly causes an increase in the solubility, the relation is far from linear. A computation based on thermodynamic data for the system Pd-H, performed for  $T = 50$  C to avoid complications due to a phase transition, shows that a  $\Delta V$  of 0.5 volt changes the concentration of H from 0.68 to 1 atom H per atom Pd - a relatively small change [21]. The apparent difficulty of achieving full occupancy of sites reflects the existence of a blocking effect by an occupied site on the occupation of neighboring sites. Such blockage has been found for all metallic hydrides, limiting the hydrogen concentration at  $p_{H_2} = 10^3$  Pa to a fraction of its maximum value even for hydrides with the largest enthalpies  $\Delta H$  [27].

Fortunately, marked repulsion between two H's or two D's present at one site is not to be expected as long as the distance between the two nuclei is larger than or equal to the atom-atom distance in  $H_2$  or  $D_2$ . Therefore, formation of an appreciable concentration of doubly occupied sites will not be too difficult.

The effectiveness of the doubly occupied sites will be increased by vibration of the two D's relative to each other and by vibrations of the adjacent metal atoms: in particular, the mode in which these atoms move towards and away from the center will be effective. Since the amplitudes of these vibrations increase with increasing temperature, the site effectiveness will also increase. It is difficult, however, to predict even the direction of the effect on the concentration and the activity  $\bar{a}^*$ ; temperature may change the various factors involved in opposite ways:  $\bar{a}$  probably increasing with increasing temperature, but  $\Delta V$  and  $q/kT$  decreasing. Therefore, the effect of temperature on the rate of cold fusion under stationary conditions is uncertain.

However, at constant concentrations of D as present in a given stationary state, a sudden rise in temperature will affect only the effectiveness of the centers and thus increase the rate of fusion. This effect may explain the observation of bursts of heat in some fusion experiments: heat generated by fusion in one center triggering fusion in neighboring centers. It is likely that cold fusion always occurs in bursts, the observation of separate bursts in some cases but not in others being due to differences in the time lag between bursts: small, frequent bursts being interpreted as a continuous process [4]. The differences may be related to differences in the concentrations of active sites, high concentrations producing small, frequent bursts, low concentrations producing widely separated ones.

### SUGGESTED RESEARCH

In view of the arguments presented above it seems indicated to find elements producing the largest possible

overvoltage for a given cathode material. There are already indications that Ni is a promising dopant [5]. The dopants should be applied to the surface either by deposition from the vapor, by bombardment with ions or more conveniently, by electrolytic deposition. The dopants and the cathode metal form binary alloys able to form ternary deuterides [26]. At the end of the test, the cathode can be purified by making the cathode temporarily anode. Then a different dopant can be deposited.

It may be necessary, however, to establish the proper surface structure by heating after deposition. Also, alternating doping and heating may be used to establish a favorable depth profile. In that case purification of the surface may no longer be so easy.

It is advisable to initially restrict the tests to determinations of  $\Delta V$ , proceeding with the more elaborate cold fusion studies only with the dopants producing the largest  $\Delta V$ . In these studies at least two aspects should be tested: heat and neutrons, heat and tritium, or heat and  $^3\text{He}$  or  $^4\text{He}$ . In the heat experiments, results with electrolysis of  $H_2O$  and  $D_2O$  should be compared as first done by Huggins et al. [4]. The experiments should be performed in a so-called "closed" system, in which the electrolysis products,  $D_2$  or  $H_2$  and  $O_2$  are recombined over a catalyst inside the calorimeter so that excess heat -- corrected for resistance heat -- can be attributed to fusion [4]. The studies should be performed for Pd as well as for metals such as V, Nb, and Ta, known to form hydrides with enthalpies of formation larger than that of P or H, and for metals such as Mo, Cr, Mn, Ni, and Fe forming hydrides with a lower or even positive enthalpy of formation. Ti, of course, has already been investigated [2]. Binary alloys developed for the storage of hydrogen [26] might also be considered.

TABLE I

Cathodic overvoltage in volts for evolution of  $H_2$  under standard conditions for various cathode materials according to Thiel and Hammerschmidt [23].

Cathode	Delta V	Cathode	Delta V
Pd	0.0	Sb	0.233
Pt	$2.0 \times 10^{-6}$	Ti*	0.236
Ru	$4.3 \times 10^{-4}$	Al*	0.296
Os	$1.48 \times 10^{-3}$	C	0.335
Ir	$2.55 \times 10^{-3}$	As	0.369
Rh	$4.0 \times 10^{-3}$	Mn*	0.37
Au	$1.65 \times 10^{-2}$	Th*	0.38
Cu*	$6.7 \times 10^{-2}$	Bi	0.388
Ag	$9.7 \times 10^{-2}$	Ta	0.39
V	0.137	Cd*	0.392
Ni	0.1375	Sn*	0.401



W	0.157	Pb	0.402
Mo	0.168	Zn*	0.482
Fe*	0.175	In	0.533
Cr*	0.182	Hg	0.57
Cu	0.19	Tl*	0.57
Si	0.192		

\* Value determined under slightly different conditions.

TABLE 2

Enthalpies of formation of hydrides in kJ/mol H<sub>2</sub> [26] and atomic volumes of the metal atoms v<sub>M</sub> in cubic Angstroms. Values in brackets are estimated.

Hydride	Delta H	v <sub>M</sub>
ScH <sub>2</sub>	-200	23.2
YH <sub>2</sub>	-225	32.8
LaH <sub>2</sub>	-210	36.9
ThH <sub>2</sub>	-146	32.6
TiH <sub>2</sub>	-126	17.6
ZrH <sub>2</sub>	-165	23.2
HfH <sub>2</sub>	-133	22.2
UH <sub>3</sub>	- 85	20.7
VH <sub>2</sub>	- 54	13.9
NbH <sub>2</sub>	- 60	17.8
TaH <sub>0.5</sub>	- 78	18
PuH <sub>2</sub>	-155	?
CrH	- 16	11.9
MoH	- 12	15.5
WH	[+16]	15.8
MnH	- 9	12.1
TcH	[+36]	14.1
ReH	[+52]	14.7
FeH	+ 14	11.7
RuH	[+42]	13.5
OsH	[+48]	13.9
CoH <sub>0.5</sub>	0	11.1
RhH <sub>0.5</sub>	[+25]	13.7
IrH	[+42]	14
NiH <sub>0.5</sub>	- 6	10.9
PdH <sub>0.5</sub>	- 40	14.6
PtH	[+26]	15.1

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## F. AUTHORS DEBATE ON COLD FUSION

### Transcript of a Debate Between Drs. Frank Close and Eugene Mallove on Cold Fusion as recorded by Wisconsin Public Radio, March 8, 1991.

Courtesy of Dr. Eugene Mallove, M.I.T.

#### EDITOR'S COMMENTS

Frank Close has written a highly skeptical book about cold fusion: **Too Hot to Handle: The Race for Cold Fusion**, which will be published by Princeton Univ. Press in May 1991. Dr. Eugene Mallove has written a book to be published by Wiley in early summer 1991, **Fire From Ice: Searching for the Truth Behind the Fusion Furor**. Dr. Mallove's book is more objective and, as you can see from this transcript, proposes that cold fusion has scientific merit. [Square brackets denote editorial remarks by Hal Fox, Editor-in-Chief, *Fusion Facts*. Nonessential portions have been deleted by the editor in interest of space.]

#### TRANSCRIPT OF DEBATE

**Moderator:** Let us just chat. It seems to me there are a couple of stories here. One is cold fusion itself and why it has attracted so much interest. The other is the political and scientific milieu in which the cold fusion story developed. I'd like to start with the first of those topics. How come there is so much interest in cold fusion?

**Frank Close:** Well I think that the aim of creating pollution free energy cheaply and abundantly has been going on for forty years in an attempt to reproduce the power of the sun and is a very compelling idea. Especially in the present climate where we have problems

with the greenhouse effect, acid rain, Chernobyl, which was thought to be the prime example of what is "bad" about conventional nuclear power. There was another reason why fusion in general is interesting because [hot] fusion research is very expensive. Fusion research has been going on a long time. It is questionable about how long, if ever, it will be before it [hot fusion] comes to be a useful way of generating power. So the idea that you could achieve fusion very cheaply in a very simple way certainly caught the public imagination. And then the next day after the announcement in 1989 [March 23], the oil tanker Valdez went aground in Alaska and I think increased people's awareness of the environmental problems. And the whole thing was set for people to say, "Oh isn't this wonderful?" ...

**Moderator:** Eugene Mallove, what is cold fusion? What basically happens if cold fusion or fusion even occurs?

**Eugene Mallove:** Fusion is compelling indeed. The idea that a cubic kilometer of the earth's ocean contains enough fusion energy in the deuterium (hydrogen isotope) such that it equals the power of all the world's oil reserves -- that's pretty impressive. So that any time anything, hot fusion or cold fusion, brings up the possibility that we could tap into that enormous energy reserve there is bound to be excitement. In the case of hot fusion, a research program has been going on for four decades - more actually - we are within decades of a practical hot fusion reactor. Commercially whether that can be a success, who knows? ...

**Moderator:** Before you go on could you tell me what happens on the molecular level when we have fusion? How does it differ from fission?

**Eugene Mallove:** Okay. The generic process of fusion is when you combine light elements or their nuclei (the dense central parts) and you fuse them into a more massive atom or nucleus of an atom. And you may end up with certain fragments of those atoms, such as neutrons, protons, or other things coming out in the process. Those things could be used, in the case of hot fusion, for generating energy. In the case of cold fusion if the heat that people have been reporting -- the very extraordinary claims, and evidence for excess power coming out of cold fusion reactions -- if that is real, then the heat coming out of those reactions would have to be of a different sort [as compared to hot fusion]. It would still come perhaps from fusion reactions going on in the solid-state lattice of a metal, but it would not give off the intense radiation that is a natural attendant process of hot fusion.

**Moderator:** Frank Close what did Pons and Fleischmann say happened in their laboratory?

**Frank Close:** Well what they said originally was that when they were passing electric current through a test tube of heavy water in the presence of a metal called palladium--(Palladium sounds exotic but it is the sort of stuff that is used in the fillings in one's teeth)-- that they appeared by their accounting to have produced more heat from the cell than they could understand. And by their accounting they produced heat in vast amounts. They decided then that this could not be an ordinary chemical reaction but must be a nuclear reaction. But they also claimed they had found further evidence for a nuclear reaction. It is not sufficient to measure heat to prove fusion, one must also have nuclear reaction products. For example, when a fire burns you just don't only feel the warmth but you also get the smoke. So there are these products which can tell you what's been going on. They claimed that they had found evidence for neutrons and tritium and gamma rays, the typical attendant products of a fusion reaction. They claimed all of these at the time. But very soon thereafter it was pointed out to them that there were very critical errors in the claims and regrettably the evidence was changed in very bizarre ways which I uncovered in my research. And over the last couple of years most of their original claims have been subtracted from rather than added to [by Fleischmann & Pons]. [However, the literature of cold fusion confirms all of their original findings.]

**Moderator:** By the scientists themselves? By Pons and Fleischmann?

**Frank Close:** Well, many experiments around the world [were begun] at the moment this news came out. People everywhere who had any access to laboratory apparatus were trying to do the experiment for themselves. It was apparently disarmingly easy to do. And it was certainly disarmingly easy to make mistakes. Within a couple of weeks there were the first claims reported that reproduced one or more of the phenomena that had been reported. [E.g. nine groups at BARC in India.] Then over the longer period of time very careful experiments done at the major laboratories began to show that mistakes had taken place in several of the early experiments. ... Well imagine yourself in the position of trying to reproduce a phenomenon in which two reputable scientists claimed to have found and you don't find it. What do you do? Do you stand up and say they are wrong. It might be you that is wrong. So you had better double check and triple check. And the careful experiments that gave the negative results that came from the major laboratories using front-line equipment and very top notch scientists right across the range of science, chemistry, physics, solid-state science. They started finding nothing and these results took two or three months after the first announcement.

**Moderator:** Eugene Mallove, did Stanley Pons and Martin Fleischmann make some mistakes.

**Eugene Mallove:** I want to start by saying that I disagree entirely with Frank Close and his very negative assessment of evidence that has built up since the time that the announcement has occurred. Frank Close ignores an overwhelming case for such things as neutron bursts in various experiments, such things as tritium [production] in over two dozen laboratories around the world. And he also ignores, above all, the very clear evidence that there is unexplained excess power and massive excess energy coming out of cold fusion cells around the world. For example the McKubre group at SRI International, the Appleby group at Texas A&M, Pons and Fleischmann themselves with their much more sophisticated paper which came about a year after their first publication. Oak Ridge National Laboratory, the Scott group, which is right where Frank Close is at the moment. All of these groups reported clear evidence of excess power which cannot be explained on the basis of conventional chemical reactions. ... That fact has led certain people, including Pons and Fleischmann themselves, as well as certain other scientists such as Nobel Laureate Julian Schwinger, such as Prof Peter Hagelstein at MIT, and many other theorists to wonder: "Is there some mechanism that could explain this excess heat and is there some mechanism, above all, that could explain what seems clearly to be the case, namely, that in various conditions of either the original Pons-Fleischmann type of cell or in Deuterium gas-loaded cells, neutron bursts are occurring, tritium is being accumulated, and various other strange high energy charged particles seem to be occurring?" The thing that is very irksome about the Frank Close and other skeptic's viewpoint is that they set up a straw man. **They say, "Look, lets look at it in terms of conventional hot fusion reactions and if we do not find the products that are known to occur in these hot fusion reactions (such as the massive fluxes of neutrons which would definitely occur at those power levels; such as great levels of tritium coming out) then we can safely say there is no fusion."** They say, "If we do not find Helium-4, which is one of the other reaction products that you might expect in a fusion reactions ... that would allow the energy to go into the system in a new way. Then there may be some new process that we skeptics could agree is occurring." However, when they found that there was no Helium-4 (of which there seems to be precious little) they threw their hands up and gave up. **[Announced since is the paper by Bush et al. reporting on helium-4 being measured in roughly the amounts expected by a d+d reaction with the concomitant measurement of excess heat.]** ... It is absolutely too early to throw out the possibility that there is a new power generating source in some of these experiments.

**Moderator:** By new power generating source, are you talking about other than fusion?

**Eugene Mallove:** I'm talking about nuclear reactions. Reactions that cannot be explained on the basis of normal chemical energy. ... That's why, whatever the unknown reactions are, there could be various reaction end products, final products of the reaction, the kind of products that Frank Close and his colleagues seem to want us to find. And indeed they **should** be found. They have to be found if this is ever to be adjudicated as a bona fide nuclear process. But there has been precious little consideration by the skeptics that these products might exist. We cannot say that they don't exist. They may **well** exist. **[Since this debate the evidence for cold fusion has become dramatically more positive.]**

**Moderator:** Could I get back then to my original question? Do you believe that Pons and Fleischmann made any mistakes?

**Eugene Mallove:** Yes, I do. I believe they made mistakes in their neutron measurements, and in fact, the M.I.T. results which simulated the process by which they would see their gamma rays coming from neutrons bombarding a bath of water, this data that they had was entirely in error and, indeed, was an unfortunate mistake ... Some of the evidence against cold fusion, such as from the Harwell Laboratory, such as from Cal Tech (the Nate Lewis group), some of the so-called best evidence against cold fusion is itself on a very, very weak foundation. I have seen and looked deeply into the Cal Tech analysis, and I find it [decision that cold fusion is not real] totally without foundation. A paper has been submitted by a top-notch scientist [Noninski], an electrochemist, to root out those errors and to publish in *Nature* magazine a critique of that [Lewis et al. paper] and show that these famous results of Nate Lewis, for example, were absolutely without foundation. That is, you cannot conclude from Lewis' results, Cal Tech results, that he did not find excess heat. His [calorimetry] analysis is fundamentally wrong. [In addition] The Harwell group has many problems with its calorimetry. In fact, a skeptical physicist, one who is not a strong believer in the heat [from cold fusion], has done an analysis of the Harwell calorimetry, the heat measuring part, and has found it to be, as he says, "a travesty". Now we have *Nature* magazine refusing to publish various positive evidence that leads one to believe that cold fusion could be real. It is absolutely outrageous. ...

**Moderator:** ... Now, Frank Close, I want you to deal with the skeptic's position as Eugene Mallove has described it. Have skeptics thrown the baby out with the bath water?

**Frank Close:** ... [omitted comments on flying saucers] Let's just say a couple of things. The way that science works is that somebody does an experiment, makes a claim, and then that claim is up for examination. **Peculiar**

**and extreme claims require extreme evidence.** It's not a case of turning the tables around and saying it is up to me to explain what is wrong with Fleischmann and Pons and so on and so forth, though in part I may be able to. **But it is up to them in the first instance to present the evidence.** [F.C. requested the emphasis.] And Gene presented apparently a lot of the very positive statements about people seeing large levels of tritium and neutron bursts and clearly visible, unexplained power, which gives the impression that huge amounts of things are being produced and being produced on a regular fashion. Now, what he didn't say is that the experiments which claim to see tritium don't see gamma rays, or those that see heat don't see one of the other things. **[This statement is no longer valid. Several papers report the combination of nuclear byproducts.]** The way that science works is, you do an experiment, you see heat supposedly. You also must see some evidence to back up the origins of that heat, whether it's a chemical or a nuclear reaction. Now, they [Pons and Fleischmann] looked for neutrons, didn't find any. ... [Omitted comments about Oak Ridge work.] And I think one also has to bear in mind how can it be that the professional labs and professional scientists in large amounts are saying that they have done experiments exactly [no exact formula has been published] attempting to reproduce the experiments as originally purported and have failed to find anything, with much more sophisticated apparatus? ... [Deleted comments about Pons-Fleischmann apparatus being relatively primitive.] Gene mentioned that 50 or 100 people around the world claim this thing or that thing but nobody claimed all of the phenomena that would be needed. **[Dr. Close either doesn't read or else doesn't believe the peer-reviewed published literature on cold fusion.]** He doesn't mention the fact that there are many places that have not found anything at all. Many of these do not publish their results because what is the point in some sense. In fact I wish more people would do so. ... [Deleted remarks on difficulty one has to properly make a judgement.] The only way one can explain away some of the things that are being asserted -- the editor of *Nature* suppressing information and such outrageous things are happening, to quote Gene -- is to accept that there is some conspiracy in the scientific establishment to suppress genuine discovery. Now if I had found the slightest evidence for that [a conspiracy] I would have written a different story. It is very easy to claim that there is some conspiracy in terms of the political angle like the hot fusion people would be undermined if this new route were found, therefore they are trying to suppress it. ...

**Moderator:** Let me ask you about the politics of science. I think we have come to the point where we are talking about precisely that. You've suggested, Dr. Close, that it's not likely or even possible that editors of respectable scientific journals would suppress the truth or accurate findings. To what extent is it possible that because

certain ideas are current, editors are perhaps unintentionally blinded to the potential of certain new ideas? I think for example about my own conversations with Nobel Laureate Howard Temin [1975, Physiology and Medicine.] who talks about the early days before the Nobel prize. He said he never had to take off time from his work to go to conferences because, of course, no one was at all interested in what he was doing. Everyone thought it was silly and yet of course, he was absolutely right. He was not supporting the party line. To what extent is science blinded by its own fads?

**Frank Close:** This is a very subtle area to think about. ... [Deleted comments about scientific paradigms.] And this is one that fascinates me. This cold fusion story is a particularly extreme example. [a scientist being deluded by his own work]. I think this is an episode that illustrates that scientists are indeed humans. They are real people and they have the same desires for power and glory that everyone else does. And scientific research has to be played out within very strict rules. Sometimes, as in many parts of society, the pressures are too great and one's judgement can indeed be disturbed. As Gene is saying my judgement is disturbed because he describes me as a skeptic. I'm a theoretical physicist and nothing would have given me more joy than if some really clear cut evidence had come out that here was an utterly new phenomena that would overthrow science as I knew it. Because we all want to be in there to staff a new revolution and be part of the excitement of it.

**Moderator:** Dr. Mallove, I want to hear from you.

**Eugene Mallove:** ... First of all, I will say that I am in more of a position to judge this issue than Dr. Close says "as just an excellent science journalist". I have a PhD in engineering from Harvard and I have advanced degrees in engineering from MIT. I have studied these technical papers quite deeply by myself and I have watched very carefully what is going on and I say if Frank Close claims to be a theoretical physicist, then I would like to know why the theory of Peter Hagenstein ... the theory of the Nobel Laureate Julian Schwinger, ... was not discussed? [In Frank's book.] Now the next thing that I would like to say is this: To tell you what certain scientists have said about the blindness of other scientists. I will first read from Arthur C. Clarke, Profiles of the Future, c1963. I begin my book with this: He said, "It is really quite amazing by what margins competent but conservative scientists and engineers can miss the mark when they start with a preconceived idea that what they are investigating is impossible. When this happens the most well informed men become blinded by their prejudices and are unable to see what lies directly ahead of them." ... I'll say another thing about some of Frank Close's illusions about some very important laboratories that got negative results. **Science is not done by vote.** It cannot be done by voting. Ultimately a consensus does emerge. We have not had a

consensus emerge clearly in the case of cold fusion. Particularly when you consider the enormous number of publications that are continuing to occur in this field. ... all kinds of reports are still coming in. It is impossible to say that all these [positive findings] are mistakes or are systematic errors. I just do not believe that. In order for cold fusion to die completely: what one is going to have to kill off, as it were, everyone of these disturbing (or optimistic) depending on how you look at it, channels of information.

**Moderator:** Well Dr. Mallove, I guess what I hear you saying is that the cold fusion debate is not over; that these publications are still carrying articles that do explore the possibilities of cold fusion and that, in other words, the system works. That maybe Pons and Fleischmann's work was defective in some ways, but the whole notion of cold fusion is still being explored by reputable scientists and their results are being published in reputable peer-reviewed journals.

**Eugene Mallove:** Two things are happening. Indeed science is working. People who really take this seriously are many: literally hundreds of scientists still [do]. For example there is the forthcoming conference in Como, Italy, where the second annual cold fusion conference will be held. **They** are taking it seriously. They are doing experiments. However, what is happening is that the community of skeptics, largely from the physics community and certainly the hot fusion community, have tried to sweep the whole matter under the rug as though it doesn't exist. Now this is actually a natural phenomenon in the history of science where you have a possible paradigm shift and the established viewpoint gets very upset, refuses to believe it and, in fact, many of them go to their graves without ever believing it. The history of science is full of this. Maybe faced with that you are seeing, the skeptical people using various types of names such as "pathological science", that's a favorite one, to describe the cold fusion people. You are having a very top man at the head of the American Physical Society say that the several hundred people [about 200] meeting in Utah at the First Annual Cold Fusion Conference were "a seance of true believers". You are having various disparaging remarks coming from the skeptics' point of view. ... [Deleted an interruption.]

Let's talk about the blockage at various journals. For example, Howard Menlove, of the Los Alamos National Laboratory. His paper went to *Nature*. Four of the five reviewers said, "Publish it". The fifth reviewer said, "No". He had a certain request that he wanted filled. The request was filled. Howard Menlove went back to *Nature* and they would not publish it. They said you have to go through the whole review cycle all over again. ... Fortunately, many journals that are taking the subject seriously are publishing positive and interesting articles.

**Moderator:** Okay, Frank Close, it is your turn ...

**Frank Close:** Well the skeptics as described are being put in the position of being accused of trying to kill off cold fusion, but to kill something off, first of all it has to be born. And regrettably the evidence that was presented at the original press conference which has not been added to was by no means complete and was of very poor quality and did not constitute evidence that anyone would take seriously [except hundreds of scientists in various part of the world]. Had there not been a claim that fusion was present, I don't think that any of us would be having this conversation today. If Pons & Fleischmann had claimed that they had found a new way of producing heat with a storage battery [no threat to hot fusion research], which is what they may have, at best, that would be an interesting thing for science as maybe will some of these things that have come out like these neutron bursts. ... [Deleted comments about what public might think.] And as Gene said earlier on, it is not sufficient just to find heat. You have to find a product somewhere and to date nobody has found any product commensurate with the quantity of heat that has been claimed. [True at time of debate, but now reported by Bush et al.] You must find things systematically in different experiments and all of these papers asserting here are being published in papers that I have not yet been able to see. [Most papers have been in published conference proceedings! It is unusual for a science writer not to read about his subject.] ... The moment that there is something to work at, I can guarantee that we will work at it. But the onus is on the people who claim to have got the new discovery and to provide the evidence to back it up. [The fact that many -- other than Pons and Fleischmann -- have given the evidence seems to have been missed by Dr. Close.]

**Moderator:** How can you find a common thread if the articles cannot be published if it is politically a hot potato and I don't want to carry it? [Most of the papers not accepted for publication were given at conferences later.]

**Frank Close:** Well that is something that I cannot easily comment upon. Gene is making a statement and all I can do is assume that the statement he is making is true and is a fair representation of the referring processes that took place. I do not know if that was the case. I am astonished to hear it described the way he has. I should say many people who are believers in this phenomenon are claiming that "the establishment" for some unnamed reason has risen to stamp this thing down. I have searched very hard for it [conspiracy]. If I had done so [found evidence], I would say that I would have been horrified and would have explained this fact very clearly. **[Dr. Close comments in *New Scientist*, 19 January 1991, pp 46ff, "The funding of billions of dollars of research into hot fusion was in the balance; if the claims of cold fusion**

**turned out to be true, the DOE would have to reallocate funding."]** Dr. Close writes: "But that political fact of life does not imply that the DoE has conspired to kill cold fusion. My statement is that I found no proof of any "plot".

**Moderator:** I guess that as I have listened to this debate, [as a lay person] ... I am wondering if part of the problem may be that Pons and Fleischmann got so much bad press that any kind of science that might be in any way associated with them is too hot to touch, by journal editors, or too hot to touch by the scientists in the community. And regardless of what potential merits there may be in finding new ways of garnering energy from, conceivably, cold fusion that those ways will not be explored because of the bad press.

**Eugene Mallove:** Well this is exactly what has happened. The attacks that have occurred in the field have simple been outrageous. For example, *Nature* magazine published several editorials in which they said, "Would it not have been better, in the beginning, if we had used unqualified vituperation against them." - Pons and Fleischmann. In other words to kill it off in the beginning and get rid of it. They talked about the "embarrassment of cold fusion". The only embarrassment in this affair is going to be ultimately the embarrassment of those who consistently and unexplainably decided that this subject is too much nonsense to deal with and must be killed off. And I must say also, there is a curious thread that is running through the entire affair. All the experiments that have been done with heavy water got the strange effects occasionally. And it is an erratic process. The process does not occur repeatably at will, but it does occur and the central thread through the entire affair if you look at all of the experiments: They [cold fusion experiments] don't work with ordinary hydrogen and they do work with deuterium isotopes. ... [Deleted an interruption.]

**Moderator:** Gentlemen, may I ask you where do we go from here? What is the future of research in cold fusion? Is it dead and killed off with Pons and Fleischmann or this an area that scientists might in a creative new way continue to explore?

**Eugene Mallove:** Scientists will eventually get to the bottom of this. That is how science works. I am not claiming myself that cold fusion has been verified conclusively. I personally believe that the evidence is quite compelling, that something exists there. I certainly feel that the neutron bursts have been essentially verified. This is a physical phenomena that is brand new and still unexplained and that it would behoove the world of physics, of chemistry, and of other fields, to look into very carefully. This is in itself very new and extraordinary. Also the tritium, that is still unexplained. It is not uniformly contamination. It cannot be explained by contamination. In fact, some of those who withdrew their papers due to possible contamination-- those very

individuals have not done their **own** analysis properly. So there is a tritium question too. And as to the heat, I think we will get an answer as to what Frank Close and others want. They want to find evidence of nuclear reaction products. And if it is fusion of some kind or some nuclear process of some kind working within the palladium lattice somewhere, we may find certain changes that have not been observed, because it would be very difficult to observe them, nonstandard changes that will give us the signature of some new nuclear process. I have every confidence that this will eventually happen. ...

**Moderator:** Frank Close?

**Frank Close:** I think I would endorse some of the remarks that Gene has made. There are people who have made fun of this and I think that whether they are right or wrong that making fun of it is not the way things should proceed. Certainly, when people get to read my book that is not what they will see. ... [Deleted comments about his book.] Coincidentally, in time, we've now got the first well researched books on this [cold fusion] coming out and assessing the early days of cold fusion and coming to somewhat different conclusions: this will enable the public and the future historians of science to study two books assessing the whole spectrum of possibilities. It has great basis for scholarship and I am, at least, prepared to await the test of time to see how it will all work out. My personal suspicions are that the "Too hot to handle" thesis will eventually prove that cold fusion is "too cold to hold". **But I would like to see the opposite come true! It would be a great thing to have something new and exciting to work on.!**

## G. ITALY CONFERENCE & CALL FOR PAPERS

### II ANNUAL CONF. ON COLD FUSION June 29 through July 4, 1991 Villa Olmo, Como, Italy

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After two years, the puzzle of **NUCLEAR PHENOMENA IN METAL LATTICES (COLD FUSION)** is still with us. The aim of the conference is to promote the broadest discussion and confrontation on all scientific aspects of this phenomenon. Participation is open to all interested scientists.

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