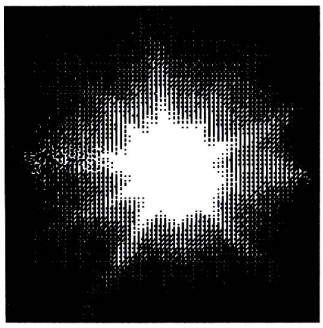

# WORKSHOP ON COLD FUSION PHENOMENA

MAY 23-25, 1989
SANTA FE, NEW MEXICO

## AGENDA

Sponsored by Los Alamos National Laboratory
and the U.S. Department of Energy

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The Welch Foundation
Houston, TX

Dr. J. Robert Schrieffer
Director, Institute for
Theoretical Physics
University of California
Santa Barbara, CA

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Dr. Reed J. Jensen
Los Alamos National Laboratory

**PROGRAM SUPPORT COORDINATOR**

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**AGENDA**

**WORKSHOP ON COLD FUSION PHENOMENA**

**May 22–25, 1989**

**SWEENEY CENTER, SANTA FE, NM**

## MONDAY, MAY 22

Workshop participants arrive in Santa Fe

| | | |
|---|---|---|
| 4:00 – 8:00 | Registration and badge issue at Eldorado Hotel—Hospitality room available at Eldorado Hotel | |

## TUESDAY, MAY 23

| | | |
|---|---|---|
| 7:30 – 8:00 | Arrival at Sweeney Center | |
| 8:00 – 8:30 | Late Registration | |
| 8:30 – 9:00 | Preliminary Remarks | Reed J. Jensen |
| – | Welcome | Sig Hecker |
| – | Introduction of Workshop | Norman Hackerman |
| 9:00 – 12:00 | First Plenary Session (A)— **Integrated Experiments** | |
| | Moderator: **Reed J. Jensen** Los Alamos National Laboratory | |
| 9:00 – 9:30 | Evidence for Excess Heat Generation Rates During Electrolysis of $D_2O$ in LiOD Using a Palladium Cathode – A Microcalorimetric Study (Invited Talk) | A.J. Appleby, S. Srinivasan, O.J. Murphy, C.R. Martin Texas A&M |
| 9:30 – 9:50 | Neutron Emission and the Tritium Content Associated with Deuterium Loaded Palladium and Tritium Metals | K.L. Wolf, N. Packham, J. Shoemaker, F. Cheng, D. Lawson Texas A&M |
| 9:50 – 10:20 | BREAK – Refreshments Available | |

| | | |
|---|---|---|
| 10:20 – | Electrochemical "Cold Nuclear Fusion" Attempts at IPP | G.A. Wurden<br>LANL<br>H.S. Bosch, J. Gernhardt, G. Janeschitz<br>F. Karger, J. Perchermeier<br>Max Planck Institut für Plasma Physic<br>FR Germany |
| 10:40 – | Measurements of Neutron and Gamma Ray Emission Rates and Calorimetry in Electrochemical Cells Having Pd Cathodes | D. Albagli, V. Cammarata, M. Schloh, M.S. Wrighton<br>X. Chen, C. Fiore<br>M. Gaudreau, D. Gwinn, P. Linsay, S.C. Luckhardt, R. Parker, R. Petrasso<br>K. Wenzel, R. Ballinger<br>I. Hwang<br>MIT |
| 11:00 – | In Search of Nuclear Fusion in Electrolytic Cells and Metal/Gas Systems | D.R. McCracken, J. Paquette, R.E. Johnson, N.A. Briden<br>W.G. Cross, A. Arjena, A.M. Lone, D.C. Tennant, W.J.L. Buyers<br>Chalk River Labs<br>Ontario, Canada |
| 11:20 – | LUNCH/POSTER SESSION | |
| 1:30 – 5:00 | Second Plenary Session (B)—**Integrated Experiments** (Cont'd)<br>Moderator: **Fred Morse**<br>Los Alamos National Laboratory | |
| 1:30 – | Search for Neutrons from Cold Fusion in Pd-D | R.S. Raghavan, L.C. Feldman M.M. Broer, J.S.Kraus, A.C. James, D.W. Murphy<br>AT&T Bell Labs |
| 1:50 – | Calorimetry, Neutron Flux, Gamma Flux, and Tritium Yield from Electrochemically Charged Palladium in $D_2O$ | Nathan S. Lewis, Charles A. Barnes<br>Cal Tech |
| 2:10 – | Search for Fusion in Deuterated Transition Metals: Dynamical Pressures Above 1 Megabar | F.M. Mueller, K.A. Johnson, W.J. Medina, A.R. Mantheia, C.L. Talcott, E.K. Storms<br>J.W. Shaner, B.L. Freeman<br>J.E. Vorthman, M.M. Fowler<br>LANL |

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|---|---|---|
| 2:30 – | Tests for "Cold Fusion" in the Pd-$D_2$ and Ti-$D_2$ Systems at 350 MPa and 195-300 K | J.G. Blencoe, M.T. Naney, D.J. Wesolowski<br>ORNL |
| 2:50 – | Measurements of Heat, Neutron and $\gamma$ Flux Induced by $\mu$ Stopped in Deuterium Saturated Targets | M.Chen, S. Steadman, C.Fiore, M. Gaudreau, S. Luckhardt, R. Parker, R. Crooks, M. Schloh, D. Albagli, V. Cammarata, M. Wrighton<br>MIT<br>R. Debbe, D. Lowenstein<br>BNL |
| 3:10 – | Electrochemical Experiments in Cold Nuclear Fusion | J.F. Ziegler, T.H. Zabel, J.J. Cuomo, V.A. Brusic, G.S. Gargill III, E.J. O'Sullivan, A.D. Marwick<br>IBM Rsch. Div., Thomas J. Watson Research Center |
| 3:30 – | BREAK – Refreshments Available | |
| | **Physics of Fusion Reaction** | |
| 4:00 – | Nuclear Reactions and Screened-Coulomb Fusion Rates | G.M. Hale, R.D. Smith, T.L. Talley<br>LANL |
| 4:20 – | Molecular Dynamics Simulation of $PD_{1.1}$: How Close Can Deuterons Get? | Peter M. Richards<br>SNL |
| 4:40 | Conditions Leading to the Production of Cold Fusion Neutrons | M. Gajda, G. Harley, J. Rafelski<br>Univ. of Arizona |
| 5:00 – 5:30 | BREAK – Walk to Eldorado Hotel | |
| 5:30 – 7:00 | Reception at Eldorado Hotel | |
| 7:00 – 7:30 | Return to Sweeney Center | |
| 7:30 – 9:30 | Discussion Period with Presenters | J. O'M. Bockris |

## WEDNESDAY, MAY 24

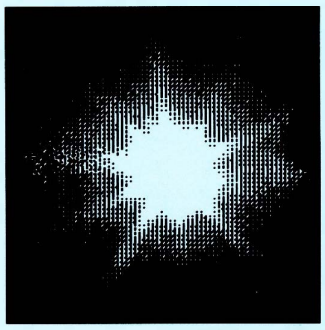
| | | |
|---|---|---|
| 7:30 – 8:00 | Arrival at Sweeney Center | |
| 8:00 – 12:00 | Third Plenary Session (C)—<br>**Neutron- & Gamma-Ray Spectroscopy**<br>Moderator: **C. A. Barnes**<br>Cal Tech | |
| 8:00 – | Cold Nuclear Fusion in Condensed Matter: Recent Results and Open Questions (Invited Talk) | S.E. Jones<br>BYU |

| | | |
|---|---|---|
| 8:30 – | Experimental Evidence for Cold Nuclear Fusion in a Measurement Under the Gran Sasso Massif | A. Bertin, M. Bruschi, M. Capponi, S. DeCastro, U. Marconi C. Moroni, M. Piccinini, N. Semprni-Cesari, A. Trombini, A. Vitale, A. Zoccoli<br>Instituto Nazionale Di Fisica Nucleare<br>Italy<br>J.B. Czirr, G.L. Jensen S.E. Jones, E.P. Palmer<br>BYU |
| 8:50 – | The Measurement of Neutron Emission from Ti Plus $D_2$ Gas | H.O. Menlove, M.M. Fowler E. Garcia, A. Mayer, M.C. Miller, R.R. Ryan<br>LANL<br>S.E. Jones<br>BYU |
| 9:10 – | Neutron Emission from a Titanium-Deuterium System (Invited Talk) | A.De Ninno, A. Frattolillo, G. Lollobattista, L. Martinis, M. Martone, L. Mori S. Podda, F. Scaramuzzi<br>Centro Ricerche Energia Frascati<br>Italy |
| 9:40 – | Upper Limits on Emission Rates of Neutrons and Gamma-Rays from "Cold Fusion" in Deuterided Metals<br>(Invited Talk) | M. Gai, S.L. Rugari, R.H. France, B.J. Lund, Z. Zhao<br>Yale<br>A.J. Davenport, H.S. Isaacs, K.G. Lynn<br>BNL |
| 10:10 – | BREAK – Refreshments Available | |
| 10:40 – | Lack of Neutron and Gamma Radiation from PPPL's Cold Fusion Experiments | H.Hsuan, D. Manos, S. Cowley, R. Motley, L. Roquemore, T. Saito, J. Timberlake, W. Ayeres, T. Bennett, M. Bitter E. Cecil, S.C.J. Cuthbertson, H.F. Dylla, H. Furth, L. Grisham, H. Hendel, K. Hill, R. Kulsrud, D. Meade, S. Medley, D. Mueller, E. Nieschmidt, R. Shoemaker, J. Thomas<br>Princeton University |
| 11:00 – | An Attempt to Measure Characteristic X-Rays from Cold Fusion | R. Fleming,F. Donahue, S. Mancini,G. Knoll, B. Heuser<br>Univ. of Michigan |

| | | |
|---|---|---|
| 11:20 – | LUNCH/POSTER SESSION | |
| 1:30 – 5:00 | Fourth Plenary Session (D)—<br>**Calorimetry**<br>Moderator: **Anthony Turkevich**<br>University of Chicago | |
| 1:30 – | Title Unknown at Printing (Invited Talk) | R.A. Huggins<br>Stanford University |
| 2:00 – | Calorimetric and Thermodynamic Analysis of Palladium-Deuterium Electrochemical Cells | N.A. Godshall, E.P. Roth, M.J. Kelly, T.R. Guilinger, R.I. Ewing<br>SNL |
| 2:20 – | The Possibility of Evaporation Dominating "Cold Fusion" Power Balance Calculations | A.E. Pontau<br>SNLL |
| 2:40 – | Calorimetric Measurements on Electrochemical Cells with Pd-D and Pd-H Cathodes | L. Redey, K.M. Myles, D. Dees, M. Krumpelt, D.R. Vissers<br>ANL |
| 3:00 – | Electrochemical Calorimetric Studies on Water and Deuterium Oxide Electrolysis | D.E. Stilwell, M.H. Miles<br>Naval Wpns. Cntr. |
| 3:20 – | BREAK – Refreshments Available | |
| | **Physics of Fusion Reactions–II** | |
| 4:00 – | Seven Chemical Explanations of the Fleischmann-Pons Effect | J.O'M. Bockris, N. Packham, O. Velev, G. Lin, M. Szklarzcyck, R. Kainthla<br>Texas A&M |
| 4:20 | Evidence Against Condensed Matter Fusion Induced by Cosmic-Ray Muons | K. Nagamine, T. Matsuzaki, K. Ishida, S. Sakamoto, Y. Watanabe, M. Iwasaki, H. Miyake, K. Nishiyama, H. Kurihara, E. Torikai, T. Suzuki, S. Isagawa, K. Kondo<br>University of Tokyo |
| 4:40 – | DINNER/POSTER SESSION | |
| 5:30 – 7:00 | Optional, No-Host Buffet at Eldorado Hotel | |
| 7:00 – 7:30 | Return to Sweeney Center | |
| 7:30 – 9:30 | Discussion Period with Presenters | M. Broer |

## THURSDAY, MAY 25, 1989

| | | |
|---|---|---|
| 7:30 – 8:00 | Arrival at Sweeney Center | |
| 8:00 – 12:00 | Fifth Plenary Session (E)— **Applicable Condensed-Matter Physics, Applicable Electrochemistry, Analytical Chemistry of Appropriate Products**<br>Moderator: **Johann Rafelski**<br>University of Arizona | |
| 8:00 – | PAC Studies of Electrolytically Charged Metal Cathodes | G.S. Collins, S.L. Shropshire, Jiawen Fan<br>Washington State Univ. |
| 8:20 – | Interaction of Deuterium with Lattice Defects in Palladium | F. Besenbacher,B.B. Nielsen, S.M. Myers,P. Nordlander, J.K. Norskov<br>University of Aarhus<br>Denmark |
| 8:40 – | Search for Cold Fusion in Superstoichiometric Palladium Deuteride Using Ion Implantation | S.M. Myers,D.M. Follstaedt, J.E. Schirber,P.M. Richards<br>SNL |
| 9:00 – | Tritium Enrichment in the Electrolysis of $D_2O$ | J. Bigeleisen<br>State Univ. of NY<br>Stony Brook, NY |
| 9:20 – | Nuclear Fusion from Crack-Generated Particle Acceleration | F.J. Mayer,J.S. King, J.R. Reitz<br>FJM Assoc.,<br>Univ. of Michigan<br>Ford Motor Rsch. Lab |
| 9:40 – | Search for 0.8 MeV $^3$He Nuclei Emitted from Pd and Ti Exposed to High Pressure $D_2$ | S.W. Barwick,P.B. Price, W.T. Williams<br>UC–Berkeley |
| 10:00 – | BREAK – Refreshments Available | |
| 10:30 – | Workshop Summary/Wrap-Up | R. Schrieffer, N. Hackerman |
| 12:00 – | Workshop Concludes | |



# WORKSHOP ON COLD FUSION PHENOMENA

MAY 23-25, 1989
SANTA FE, NEW MEXICO

## MEETING ABSTRACTS
## Session A

Sponsored by Los Alamos National Laboratory
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# EVIDENCE FOR EXCESS HEAT GENERATION RATES DURING ELECTROLYSIS OF $D_2O$ IN LiOD USING A PALLADIUM CATHODE - A MICROCALORIMETRIC STUDY

Supramaniam Srinivasan*, Young Jin Kim*,
Oliver J. Murphy*, Charles R. Martin** and A. John Appleby *

*Center for Electrochemical Systems and Hydrogen Research
Texas Engineering Experiment Station
and
**Department of Chemistry
Texas A&M University
College Station, Texas 77843

The "cold fusion" announcement by Professors Martin Fleishmann and Stanley Pons on March 23, 1989, evoked great excitement and was a stimulation for scientists all over the world to reproduce their results. Microcalorimetric investigations were commenced in our laboratory with the objective of measurement of the excess heat generation rates reported by these scientists. The rationale for selection of the microcalorimetric techniques were: (1), the high sensitivity of microcalorimeters using thermoelectric measuring principles; (2), the successful use of microcalorimeters for measurement of heat generation rates in the 1μW to 8W range to predict self discharge rates of, for example, pacemaker batteries with predicted lifetimes of over ten years; and the rates of slow corrosion processes; and (3), the possibility of using small Pd electrodes (short, thin wires, small spheres) to minimize (i) the time required for maximum absorption of deuterium by electrochemical charging; (ii) the charging input power; and (iii) the consequent low input power requirements at the high current densities at which anomalous heating was observed.

A Tronac(Model 350) Microcalorimeter, refurbished by Hart Scientific Instruments, was used in this work. The basic components of this equipment are (1) stainless steel test and control cells (5 x 5 x 1 $cm^3$) which are snugly fitted into an aluminum block sink; (2) water reservoir, external to the aluminum block maintained at a constant temperature; and (3) thermoelectric sensors surrounding the test and control cells. The measurements are based on the Seebeck effect: A voltage develops between the hot (test) and cold (control) junctions, which is a measure of the heat flux.

Several tests and control experiments were carried out to determine the excess heat generation rates. These experiments consisted of:

1. Control Experiment - charging of Pd wire (0.5 mm diameter, 1 cm length) in 0.1M LiOH at 60 $mA/cm^2$ for two days and then increasing the current density for $D_2O$ electrolysis to 600 $mA/cm^2$ for four days, continuously recording the heat generation rate;

2. Control Experiment - Recording of heat generation rates during electrolysis of $D_2O$ in 0.1M LiOD on a Pt cathode (wire with same dimensions as in Experiment 1).

3. Test Experiment - similar to Experiment 1, but conducted in 0.1M LiOD. In this equipment, the heat generation rates were also recorded when the current density was increased from 0.6 A/cm$^2$ to 1.0 A/cm$^2$ and then decreased to 0.3 A/cm$^2$.

The results of these experiments may be summarized as follows:

1. Excess heat generation rates were observed only in the test experiment (Experiment #3) and not in the control experiments (Experiments #1 and #2).

2. The rate of excess heat generation was 19 W/ml of Pd, close to the value (26 W/ml of Pd) reported by Fleischmann and Pons. The observed heat generation rate showed no increase when the current density for electrolysis was increased from 0.6 to 1 A/cm$^2$ but decreased to 14 W/ml of Pd when the current density was lowered to 0.3 A/cm$^2$.

3. The results of the two control experiments confirm that the rates of recombination of $H_2$ or $D_2$ with $O_2$ are negligible and cannot account for the excess heat generation rate in the test experiment.

# NEUTRON EMISSION AND TUE TRITIUM CONTENT ASSOCIATED WITH DEUTERIUM LOADED PALLADIUM AND TRITIUM METALS*

K. L. Wolf, K. Packham, J. Shoemaker, F. Cheng and D. Lawson
Cyclotron Institute and the Department of Chemistry
Texas A&M University, College Station, TX 77843-3366

An experimental investigation has been conducted on samples of Pd and Ti which were loaded with deuterium through the electrolysis of $D_2O$ and by absorption of $D_2$ gas. In approximately 200 experiments on 25 samples, statistically significant evidence for neutron emission was obtained in two separate experiments from one Pd-Ni electrolysis cell. Observed rates of 3-4 times the background rate of 0.8 neutrons/min (0.4-2.5 MeV) correspond to a 2.5 MeV neutron source strength of 50 neutrons/min over a period of 1-2 hours.

A 3" x 5" NE213 liquid scintillator coupled to a 5"-diameter RCA 8854 phototube was used for an overall efficiency of 5% for 2.5 MeV neutrons. Pulse shape discrimination (PSD) was used for n/γ discrimination. Cosmic ray rejection was provided by the PSD and by 2' x 4' x 1/4" plastic scintillator paddles. Antennas and the PSD were used for external noise rejection. The neutron detector was shielded from the heat produced by electrolytic cells and the temperature was monitored. Data were acquired with a CAMAC-based LeCroy 2280 system interfaced to an 80386 computer.

The presence of 5 x $10^{12}$ tritium atoms in the solution of the electrolysis cell was determined several days after the neutron production runs. Tritium detection was accomplished with a pair of low-noise EMI 9954 phototubes coupled to a 1 cm x 1 cm x 3 cm ceil. Neutralized samples were mixed with a water soluble liquid scintillator for an efficiency of 30%, in coincidence mode. Energy spectra were compared to tritium standards for the efficiency and for identification through slope and end point determinations. Tritium content of the cell before neutron production is not known.

*This work supported by the U. S. Department of Energy under Grants DE-FG05-86ER40255 and DE-FG05-88ER40437 and by The Robert A. Welch Foundation.

# Electrochemical "Cold Nuclear Fusion" Attempts at IPP

G. A. Wurden*, H. S. Bosch, J. Gernhardt, G. Janeschitz, F. Karger, J. Perchermeier

Max Planck Institut für Plasma Physik
8046 Garching, Federal Republic of Germany

**Abstract**

Following the report of Pons and Fleischmann, we (The Bavarian Bubble Bottle Team) have attempted to reproduce their claims of cold nuclear fusion, and failed. We note that our measurements would not be able to detect neutrons at the level of Jones *et al.* Three experiments were conducted without any signs of neutrons, tritium or gammas above backgrounds, and within ±5% accuracy calorimetry, no excess heating. Intrinsic tritium, differing from each $D_2O$ bottle tested, was however observed.

The third, and most significant attempt used a 22 gram, 10 $cm^2$, cast (vacuum melted by an e-beam) palladium piece, which was electrolytically loaded with deuterium (99.75% purity $D_2O$, 0.11 M LiD, Pt mesh anode) at current densities of 200-250 $mA/cm^2$ for a period of 21 days. Current, voltage, water bath (well-stirred) and air temperature were monitored continuously with a strip chart recorder. The fully covered 170 ml central cell did not partition the electrolysis products, all calorimetry was done in steady state, (bath time constant 100 minutes), and air flow across the 1 liter water bath was kept constant. No isolation Dewar was used. Measurements of the actual temperature(s) directly in the center cell showed strong thermal gradients ($3-4°C$), so calorimetric measurements are only relevant for the well-stirred water bath/air temperatures (typically 45 and 26°C, respectively). An absolute resolution of better than 200 mW, out of 20 Watts typical input power, was obtained. The equilibrium temperature rise of the water bath was strictly linear with input power, calculated from $P_{in} = I * (V - 1.54v)$. A Kapton encapsulated 40 Ohm strip resistor was used in the water bath for reference ohmic input measurements. Fast reductions in current density, after waiting for a new thermal equilibrium, yielded nothing unusual. A $BF_3$ thermal neutron counter, (calibrated efficiency of 1 count/370 neutrons from the same location as the cell, backgrounds of 0.05 counts/sec, with 12 cm polyethylene moderator and a Cd shield), as well as a moderated $Li^6I$ neutron detector, a large high-resolution, high efficiency (170 $cm^3$) GeLi gamma detector, a 2" NaI detector, and a proportional counter were used to look for radiation. Gamma backgrounds from $K^{40}$, $Bi^{214}$ and $Tl^{208}$ (Thorium decay in concrete), were easily seen in pulse height spectra. Backgrounds at our second floor location were 120 mrem/year gammas, and 10 mrem/year thermal neutrons, as measured by a Berthold LB1026 Radiation Monitoring system. No special shielding precautions against cosmic rays were used. A 4 Megawatt swimming pool nuclear reactor, 600 meters away from our building, was one of our additional background considerations! Tritium was measured in the electrolyte, $D_2O$ samples, and $H_2O$ (both with and without the LiD solute). A model 2260XL Tri-Carb Liquid Scintillation Analyzer by Canberra-Packard was used, with the old ($\geq$ 15 years) Merck heavy water yielding 210 dpm/ml from one vial, and 9.9 dpm/ml from another used for refilling. By contrast the LiD dissolved in pure $H_2O$ (unneutralized) gave 6.6 dpm/ml. The cell was replenished with $D_2O$ at a rate averaging 16 ml/day. The electrolyte after 19 days of operation measured 150 dpm/ml. In comparison, the $D_2O$ from another bottle (with same Merck #, and purchased at the same time!) used in our first 14 hour experiment had 750 dpm/ml. Pulse height analysis suggests that true Tritium decay signals are present, and chemical fluorescence in the "cocktail" was not important (although measurable). Tritium can reasonably be explained from that originally present in the various $D_2O$ flasks.

The experiment was terminated on April 28, by throwing the loaded palladium sample directly into liquid Nitrogen, immediately next to the bare $BF_3$ counter (backed by 25 cm of moderator), in order to attempt one of the Italian ENEA neutron production variants. No neutrons (sensitivity of 5 n/sec equivalent source strength) above backgrounds were seen, while counting for one hour, and also none while the piece warmed to room temperature over the next hour. Postmortem analysis of the darkened, hardened Pd piece showed large crystal grains (up to 2mm×2mm), and continuing evolution of gas bubbles at the grain boundaries even four days after the experiment was ended.

# Measurements of Neutron and Gamma Ray Emission Rates and Calorimetry in Electrochemical Cells Having Pd Cathodes.

Massachusetts Institute of Technology

| | |
|---|---|
| Department of Chemistry | D. Albagli, V.Cammarata, R. Crooks, M. Schloh, and M.S. Wrighton. |
| Plasma Fusion Center | X. Chen, C. Fiore, M. Gaudreau, D. Gwinn, P. Linsay, S.C. Luckhardt, R. Parker, R. Petrasso, K. Wenzel. |
| Departments of Nuclear Engineering and Materials Science and Engineering | R. Ballinger, I. Hwang. |


---

Results of experiments intended to reproduce the excess heat and neutron emission from electrochemical cells[1] are presented. Radiation emission and power balance measurements were carried out on a set of electrochemical cells consisting of Pd cathodes, Pt anodes, and $D_2O$/LiOD or $H_2O$/LiOH electrolytes. The first phase of this experiment was aimed at determining gross excess heating effects (> 30% of applied power, calorimetry based on observation of temperature fluctuations for constant power input), or unusual neutron or X-ray emission, from cells with 6.4 mm diameter Pd rods operated for >45 days. The second phase of the experiment featured improved accuracy and data aquisition in experiments with 1 and 3 mm diameter Pd rods. Results of calorimetry (power balance measured in a constant temperature calorimeter), controlled to ± 15 mW, and calibrated neutron and X-ray measurements will be presented. In addition, we have measured $^3T$ levels in all cell electrolyte solutions before and after electrolysis, and we have analyzed for $^4He$ in effluent gas from cells containing 1 mm diameter Pd cathodes. We anticipate presentation of results regarding the presence of $^4He$ which may be present (trapped) within the Pd lattice.

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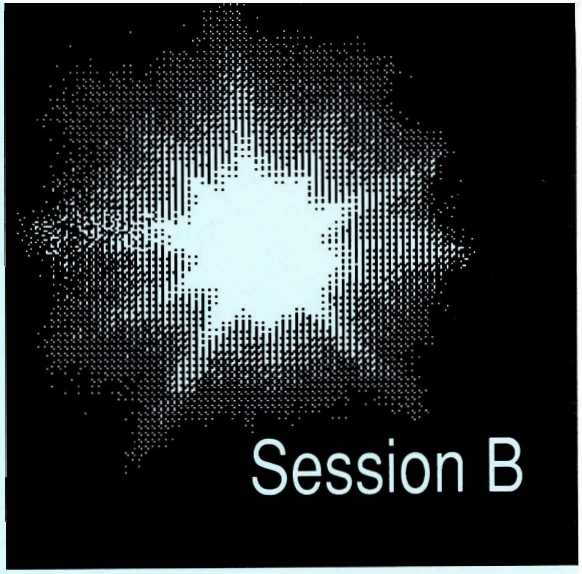
1. Fleischmann, M.; Pons, S.; Hawkins, M. *J. Electroanal. Chem.* **1989**, 261, 301.

# IN SEARCH OF NUCLEAR FUSION IN ELECTROLYTIC CELLS AND METALS/GAS SYSTEMS

D.R. McCracken, J. Paquette, R.E. Johnson, N.A. Briden, V.G. Cross, A. Arjena, A.M. Lone, D.C. Tennant and V.J.L. Buyers, Chalk River Nuclear Laboratories, Atomic Energy of Canada Limited, Chalk River, Ont., Canada and K.W. Chambers, A.K. McIlwain, E.M. Attas and R. Dutton, Whiteshell Nuclear Research Establishment, Atomic Energy of Canada Limited, Pinawa, Man., Canada.

A variety of electrochemical ceils having palladium cathodes in the form of wires, tubes, foils and rods have been used to electrolyze heavy water containing 0.1 $mol.dm^{-3}$ LiOH, or 0.5 $mol.dm^{-3}$ LiOD or 0.50 $mol.dm^{-3}$ $D_2PO_4$. Current densities of up to 140 $mA.cm^2$ were used. The mass of the palladium cathodes covered the range from 1 to 40 grams and the surface area varied from 8 to 140 $cm^2$. Neutron detection systems with low constant backgrounds were used to search for the presence of a neutron flux during electrolysis. These included moderated $^3He$- and $^{10}BF_3$-based detectors. After running some of the cells for times up to 28 days no neutron flux above background could be detected. No enrichment of the electrolytes in tritium was evident after correction for evaporative losses. Chemical analysis of one of the cathodes after 25 days of near continuous electrolysis indicated that the average bulk composition was $Pd_{6.7}$ with the ratio of deuterium over palladium remaining constant to a depth of at least 20 $\mu$m. Experiments were also performed with the titanium metal/deuterium gas system. These consisted in exposing titanium metal to a deuterium gas pressure of 40 atm, lowering the temperature to -196°C, releasing the pressure and gradually warming the titanium to room temperature. No neutron flux above background was observed during these experiments.


Session B

Submitted to the Workshop on Cold Fusion Phenomena
May 23–25, 1989
Santa Fe, New Mexico

# Search for Neutrons from Cold Fusion in Pd–D

R.S. Raghavan, L.C. Feldman, M.M. Broer, J.S. Kraus, A.C. James and D.W. Murphy

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We report on a search for neutrons from dd fusion in Pd rods loaded electrolytically with deuterium. Three Pd rods were used: 1) 0.125 dia. x 9 cm long, drawn and cold worked; 2) 0.125 dia. x 9 cm long, drawn and annealed; 3) 0.41 dia. x 8 cm long, cast, drawn and annealed. The rods were held in two electrolytic cells ($D_2O$ (99.5% D)+ 0.1 M LiOD, current density 53 $mA/cm^2$) and placed before a 12.5 dia. x 12.5 cm NaI(Tl) detector with 5 cm of polyethylene (PE) moderator interposed. A pair of plastic scintillator plates above and below the NaI(Tl) vetoed cosmic muons. The apparatus was housed within 10 cm thick PE surrounded on the outside with Pb and borax. Fusion neutrons are moderated inside the PE housing, creating a slow neutron gas that can be detected by two $\gamma$–ray producing reaction signals: (1) n–capture by protons in the PE (2.224 MeV $\gamma$); (2) $^{23}Na$ and $^{127}I$ n–capture $\gamma$–rays in the range 3.5–7 MeV. The latter, produced inside the NaI(Tl), is the more sensitive signal. The background in this region, mostly due to cosmic rays, is far less than the background below 2.62 MeV, which is dominated by natural radioactivity. Therefore our results are insensitive to ambient natural radioactivity. From the overall n detection efficiency (measured with an Am–Be source immersed in $D_2O$(LiOD) at the counting position) and the observed background limit, we deduce that neutron production at the rate of $\sim$ 0.1 n/sec in the cells can be detected. In a four–week measurement we observe <0.007 n/sec/g Pd, (0.4 cm dia. rod) compared to $2.6 \times 10^3$ n/sec/g Pd, claimed in recent work[1] for a similar Pd rod. Our result implies $<2.2 \times 10^{-24}$ (ddn) fusions/dd pair/sec in our Pd electrode, as compared to $\sim 10^{-23}$ (ddn) fusions/dd pair/sec observed by Jones et al[2] in a Ti electrode.

1. M. Fleischmann and B.S. Pons, J. Electroanal. Chem. **261**, 301(1989).
2. S.E. Jones et al, Nature **338**, 737(1989).

# Calorimetry, Neutron Flux, Gamma Flux, and Tritium Yield from Electrochemically Charged Palladium in $D_2O$

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We report the results of our work on cold fusion using palladium. We have used extremely sensitive neutron, gamma ray, and photo counters, and can place strict upper limits on the flux of expected nuclear products emitted from charged Pd cathodes. Liquid scintillation counting has been used to measure tritium production, which was found at background levels for extended periods of time. However, a subtle chemical interference that generates chemiluminescence has been shown to yield tritium signals and lead to overestimates of the fusion yield based on tritium production. We have also performed accurate, calibrated calorimetry, and have identified several serious errors that can make the measurements appear to show excess power production. When these common errors are eliminated, a correct energy balance is obtained. We have used cold-worked Pd, recast Pd, Pd thimbles, and Pd wires over a variety of pH values and for a variety of activation times. We will also discuss the calorimetry experiments performed by the Utah researchers, will explain their calculations to the physics community,and will clearly state the assumptions and corrections implicit in the Utah calculations.

# SEARCH FOR FUSION IN DEUTERATED TRANSITION METALS: DYNAMICAL PRESSURES ABOVE 1 MEGABAR

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One can conceive a number of possible solid state or metallurgical mechanisms to produce enhanced fluctuation fusion rates in Deuterated Metals, such as Coulomb Screening, Crowdions, Dislocations, Crack Propagation, Shear Banding, Vacancy and Void Filling, Grain Interstices, Twinning, Tweeding and Surface Reconstruction, Dynamically Shrinking, through pressure, a transition metal lattice containing Deuterium probes all of these possible mechanisms simultaneously to some degree.

A Cylindrical Shock Experiment was performed on Deuterated Pd (0.3 gm) and Ti (0.1 gm) foils using a fully recoverable, high pressure, and well tested design. Four gm of Zn was also inserted in the experimental chamber as a post shot neutron radiochemical detector. The system was pressure tested and its free volume was measured. The system was then cleaned to remove gas contaminants, surface poisons or deuterium transfer inhibitors. The system was then back loaded with deuterium at room temperature initially at a pressure of 50 psi which dropped to a pressure of 30 psi of Deuterium gas. The observed uptake rates showed that both foils deuterated to about 0.7 D/M for Pd and about 0.7 for Ti. The sample container was removed from the loading system, maintaining gas tightness, and inserted into the high explosive configuration. The entire system was then subject to a Dynamical Shock Pressure of greater than 0.1 Tera Pascals. Prompt Neutron Detectors were placed behind protecting sandbags and Pb bricks in the close proximity of the experiment. Post Shot radiochemical analysis was also performed. The results showed that less than $10^4$ neutrons were generated. No increased neutron flux over background was detected during the several microseconds of Dynamical Pressure on the deuterated foils. We conclude that whatever mechanisms are possible to enhance fusion rates in deuterated transition metals, they were not present at the detection level and pressures of this experiment.

# Tests for "cold fusion" in the Pd-$D_2$ and Ti-$D_2$ systems at 350 KPa and 195-300K

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Experiments are in progress on the Pd-$D_2$ end Ti-$D_2$ systems at 350 MPa, 195-300K, to investigate the possibility that "cold fusion" occurs in high D/metal phases generated by pressurization with $D_2$ gas. Reactions between high-purity Pd or Ti and $D_2$ are being monitored using $BF_3$ neutron detectors end thermocouples. The neutron detector array has an efficiency of approximately 6%, as determined using a $^{252}Cf$ source. The pressure vessel and neutron detectors are immersed in a water bath thermostated at 300K. A type-K thermocouple in contact with the Pd or Ti sample is compared with a reference type-K thermocouple also housed in the vessel and located approximately 10 cm above the sample. The neutron flux, gas pressure, sample and reference thermocouples and bath temperature are continuously monitored at time intervals ranging from 6 seconds to 5 minutes.

Experiments completed to date in the Pd-$D_2$ system at 300K have shown no neutron flux significantly above background (9.5 ± 0.5 counts/min.), and no sustained heat production has been detected.

Research sponsored by the Division of Engineering and Geosciences, Office of Basic Energy Sciences, U.S. Dept. of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

**Measurements of Heat, Neutron and γ Flux Induced by $\mu$ stopped in Deuterium Saturated Target***

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**Abstract.** We use small scintillation hodoscopes to define a pencil-size 80 MeV/c $_{3\mu}$ beam at DNL to stop negatively charged $\mu$'s inside Td and Ti targets saturated with deuterium/hydrogen. Heat, neutron and γ flux produced from the targets as functions of the number of stopped muons are measured with calorimeters, $BF_3$/$He_3$ counters and NaI crystals respectively. The relative rates with/without stopping muons are measured using cast thin Pd rods in an ongoing electrochemical cell similar to that used by Pons and Fleishmann. The absolute rates are measured in targets made of thin foils. The background is calibrated both with targets in the beam but without deuterium/hydrogen and with targets saturated with deuterium but without muons stopped in them. We also search for any excess helium produced inside the target material. The results are compared with theories which claim cold fusion is induced by cosmic ray muons.

Abstract: 1) ELECTROCHEMICAL EXPERIMENTS IN COLD NUCLEAR FUSION, by J.F. Ziegler, T.H. Zabel, J.J. Cuomo, V.A. Brusic, G.S. Gargill III, E.J. O'Sullivan and A.D. Marwick, IBM Research Division, Thomas J. Watson Research Center, Yorktown Heights, NY 10598 USA. Recently, two scientific papers have reported positive detection of nuclear radiation from similar electro-chemical cells operating with deuterated water. Fleischmann and Pons have observed gamma rays at 2.2 MeV at a rate of about 4000/cc-s, and if the heat they observe is due to unobserved nuclear fusions, they have a fusion rate of about 10**12 fusions/cc-s (the subscript "cc" refers to the volume of Pd cathode used). In an independent work, Jones et al. have reported detecting 2.4 MeV neutrons at a rate of 0.7 neutrons/cc-s from an electrolytic cell.

We have experimented with similar electrolytic cells and have looked for energetic charged particles which are characteristic of nuclear fusion reactions. We report on six variations of cell, with an upper limit of 0.005 detected particles/cc-s. Within background statistics, we observe zero nuclear fusions. (Submitted to Physical Review Letters: 18 April, 1989)

2) Experimental reports of cold nuclear fusion continue to raise questions, e.g. in regard to details of stirring during calibration of the cells in which temperature rise is used to infer heat generation. Other possible problems include the assumption that power input is the product of time averages of voltage and current applied to the cell, whereas it is the time average of the instantaneous product. Monitoring the reaction cells for electromagnetic signals would help to determine whether "arcs and sparks" play a role in the generation of the nuclear particles observed in some experiments. Comments along these lines, updated to reflect experiments as of the time of presentation, may help in evaluation and to focus further experimental work.

# Nuclear Reactions and Screened-Coulomb Fusion Rates

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We discuss properties of nuclear reactions (branching ratios, reaction constants, etc.) between hydrogen isotopes from the standpoint of recent R-matrix calculations. These calculations predict, for example, quite different branching ratios for the d+d reactions when they are initiated by S-waves than when they are initiated by P-waves. We will also give a more speculative discussion of the constraints on possible non-radiative electromagnetic transitions that could occur for the d-d and p-d reactions in the metal lattice.

When R-matrix theory is used to include nuclear effects at small distances in the calculation of fusion rates, the rate expression exhibits a more complex interplay of the short-ranged (nuclear) and long-ranged (screened Coulomb) forces than does the familiar separable form,

$$\lambda = A_0 |\Psi(r=0)|^2 ,$$

to which the R-matrix expression reduces if the appropriate approximations are made. Using the latest nuclear R-matrix information for the d+d and d+t reactions in this more correct formulation, we have calculated rates for a variety of screened Coulomb potentials. The fusion rate calculations are presented as a function of the screening radius at fixed relative energy, and as a function of relative energy at fixed screening radius. They are compared with calculations made using the standard expression above.

# MOLECULAR DYNAMICS SIMULATION OF $PD_{1.1}$: HOW CLOSE CAN DEUTERONS GET?

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Crucial to whether cold fusion can occur in Pd or similar metals is how close deuterons can get to one another in the hydride lattice, particularly if the concentration is above stoichiometry and/or there is large thermal agitation. To investigate these questions a molecular dynamics (MD) simulation has been done of $PdD_{1.1}$ and the distribution of D-D distances examined.

Pd-D potentials were used similar to those in previous MD simulations of hydrogen diffusion. They were modified slightly to allow investigation of cases both where the tetrahedral (t) site was stable and unstable. The screening length was taken as $a_0/2$ ($a_0$ = Bohr radius) so as to be highly optimistic about a weakened repulsion allowing for close D-D distances. Simulations were done at temperatures of 300 K and 1300 K.

In no case were distances shorter than 0.7 Å found. Thus no evidence was found for D-D separations significantly less than in molecular $D_2$ (0.74 Å). The fact that a fair number of distances less than 1.5 Å, considerably shorter than the equilibrium 2.8 Å below stoichiometry, are seen may, however, have implications for other aspects of hydrogen in metals.

This work was supported by the U.S. Department of Energy under contract number DE-AC04-76DP00789.

# Conditions Leading to the Production of Cold Fusion Neutrons

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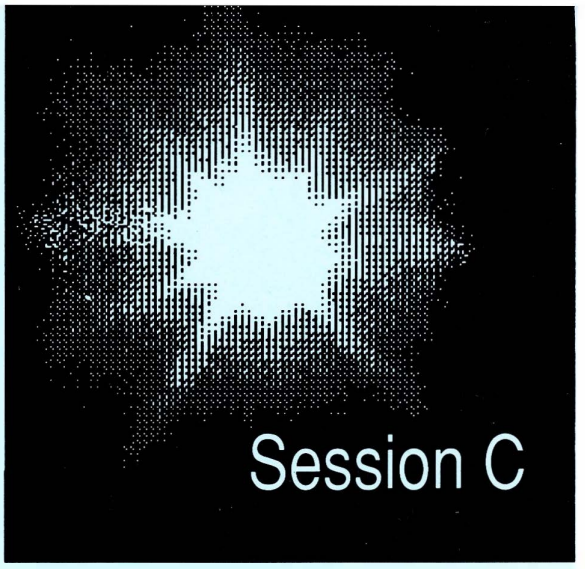
We have examined the conditions that must be attained within the metallic lattice in order to achieve $d + d \rightarrow {}^3\mathrm{He}+n$ thermonuclear fusion rates as observed by Jones *et al*, supposing that the so-called 'cold' fusion is occurring in small pockets of deuterium under plasma conditions. We establish i) the relevant time scales governing the plasma formation process, ii) the influence the conduction band electrons have on the fusion rate, and iii) the temperatures, densities and plasma lifetimes required to explain the reported neutron rates. The particular mechanism we are considering as being responsible for the formation of pockets of plasma is the catastrophic collapse of microscopic cavities between the metallic crystals, caused by the sudden expansion of crystals under stress. This process may lead to the formation of high density and temperature plasmas for brief periods of time. We note that the presence of the metal's conduction band electrons plays a significant role, firstly by screening the $d-d$ interaction and thereby reducing the temperature required for fusion, and secondly by absorbing the electronic component of the produced $d^+ + e^-$ plasma. The work is still in progress and at this time it is not established that the proposed model is a viable mechanism for neutron production. However, one can propose several experimental procedures whereby the creation of plasma pockets by the above mechanism may be tested. These include: i) the correlation of neutrons bursts with the application of mechanical stress or ultrasound to the material, and to the presence of micro-quakes which may be detected within the sample; ii) by initially preparing the metal sample in different ways so as to increase the amount of internal stress, such as by casting and cooling the metal very rapidly or by tempering; and iii) by combining the hydride with impurities that have different thermal expansion coefficients or which expand differently under hydridization. The plasma conditions that may exist could be probed by comparing different fusion reaction rates such as $p + d \rightarrow {}^3\mathrm{He}+\gamma$, $d + d \rightarrow {}^3\mathrm{He}+n$ and $d + t \rightarrow {}^4\mathrm{He}+n$.


Session C

# COLD NUCLEAR FUSION IN CONDENSED MATTER: RECENT RESULTS AND OPEN QUESTIONS

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We have observed clear signatures for neutron emission during deuteron infusion into metals, implying the occurrence at low rates of nuclear fusion in condensed matter near room temperature. The cold fusion phenomenon has been demonstrated in collaborative experiments at Brigham Young University <1>, at the Gran Sasso Laboratory in Italy, and at the Los Alamos National Laboratory. We have shown that cold fusion can be induced in metals using both electrochemical and variational temperature/pressure means to generate non-equilibrium conditions <1>. Observed average neutron emission rates are approximately 0.04-0.4 n/s.

Current efforts focus on trying to understand and control the cold fusion phenomenon. In particular, we wish to understand the correlation of fusion yields with parameters such as hydrogen/metal ion ratio, pressure (induced, for example, by electric fields or gas pressure or mechanical pressure), temperature variations, hydride phase changes, and surface conditions (e.g., a palladium coating on titanium). We want to know if the fusion arises due to confinement of the deuterons in the lattice (piezonuclear fusion), or rather from 'microscopic hot fusion' accompanying strong electric fields at propagating cracks in the hydride. The latter interpretation would imply neutron emission in bursts.<2> Our experiments show clear evidence for emission of neutrons in bursts of less than 200 μs, although random (continuous) neutron emissions were also observed. Experiments now underway to compare the d-d, p-d, and d-t fusion rates will be important to an accurate description of the new phenomenon.

We should also consider the implications of this discovery. Although energy applications now appear extremely unlikely, cold fusion at enhanced rates could serve as a useful source of monoenergetic neutrons. Certainly, condensed-matter fusion provides a novel probe of extreme conditions in metal-hydrogen systems. Careful scrutiny of the effect could also increase our understanding of heat and helium-3 generation in the earth and other planets, and even in cooler regions of the stars.<1> The discovery of cold fusion may significantly impact our view of nature.

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<1> S. E. Jones et al., "Observation of cold nuclear fusion in condensed matter," Nature, 338: 737-740 (April 27, 1989).

<2> J. S. Cohen and J. D. Davies, "The cold fusion family," Nature 338: 705-707 (April 27, 1989).

# EXPERIMENTAL EVIDENCE FOR COLD NUCLEAR FUSION

# IN A MEASUREMENT UNDER THE GRAN SASSO MASSIF

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We have observed the emission of 2.45 MeV neutrons following the electrolytic infusion of deuterons into titanium electrodes in a replication of experiments performed at Brigham Young University.<1> The present results were obtained using neutron-gamma discriminating proton-recoil detectors at the Gran Sasso Laboratory. The observed neutron emission rate is comparable to that reported by Jones and collaborators. The observation of cold nuclear fusion under the Gran Sasso Massif where cosmic-ray intensities are $\sim 10^{-6}$ of sea-level values rules out the possibility that the observed neutron signal could be due to cosmic-ray muons or to cosmic-ray-induced neutrons <2>.

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<1> S. E. Jones et al., "Observation of cold nuclear fusion in condensed matter," **Nature 338**: 737-740 (April 27, 1989).

<2> J. M. Carpenter; A. J. McCevoy and C. T. D. O'Sullivan, in "Cold fusion: what's going on?" **Nature 338**: 711-712 (April 27, 1989).

# THE MEASUREMENT OF NEUTRON EMISSION FROM Ti PLUS $D_2$ GAS

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We have measured neutron emissions from cylinders of pressurized $D_2$ gas mixed with various forms of Ti metal chips and sponge. For some of the cases, the Ti was coated with a surface layer of Pd. The gas pressure ranged from 20 atm to 50 atm, and the Ti loadings ranged from 30 g to 200 g.

The neutrons were measured using a high efficiency (34%) cavity-type detector containing 18 $^3$He tubes. Random neutron emissions were observed as well as time-correlated neutron bursts. The time spread in an individual burst was less than 200 μs.

The neutron emission was observed after the cylinder had cooled in liquid nitrogen temperature and was warming to room temperature. The bursts occurred about 40 minutes into the warm-up phase, and the random emission occurred for at least 12 hours after the sample reached room temperature. This cycle could only be repeated two or three times before neutron emission ceased.

The neutron emission rates were very low and the 12-hour random emission rate was 0.05-0.2 n/s. However, this yield was still 11σ above the background. The instantaneous neutron bursts were more dramatic with yields several orders of magnitude above the coincidence background rates.

# NEUTRON EMISSION FROM A TITANIUM-DEUTERIUM SYSTEM

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# UPPER LIMITS ON EMISSION RATES OF NEUTRONS AND GAMMA-RATS FROM "COLD FUSION" IN DEUTERIDED METALS*

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ABSTRACT

A search for neutrons and gamma-rays emitted in "cold fusion" in electrolytically deuterided metals was carried out with a very low background and a sensitive neutron detection system, composed of an array of six liquid-scintillator neutron counters operating in coincidence, with total efficiency of -1%. Pulse shape, pulse height and time of flight were measured for scattered neutrons. Gamma-rays were detected in two large (12.5 cm) NaI(Tl) detectors, with total efficiency of 0.1% at 5.5 MeV. The detection system was shielded from background radiation and two large area cosmic-ray veto counters were utilized. Up to four electrochemical cells, similar to the ones used by Fleischmann, Pons and Hawkins (FPH) and by Jones et al., ran concurrently, with Pd or cold worked Ti rods as cathodes. The Pd electrodes were cold worked or annealed in vacuum or argon, one electrode was predeuterided and various surface treatments were carried out. The metals were electrochemically charged with deuterium in heavy water (97.5% or 99.8% D2O) electrolytes containing LiOD or a variety of salts. TI alloy powder deuterided at room temperature and high pressure was also used for comparison. No statistically significant deviation from the background was observed in either gamma-ray or neutron detectors, over three weeks. Using our neutron detector system we estimate (with 98% confidence) the rate of "cold fusion" of d + d in our Pd and Ti samples to be smaller than the order of $10^{-25}$ fusions/atom pair/sec ($3\sigma$ limit), and the gamma ray data yield for (the faster) p + d fusion rate, a limit of the order of $10^{-22}$ fusions/atom pair/sec ($3\sigma$ limit). The estimated neutron flux in our experiment is a factor of 50-100 smaller than that reported by Jones et al. and some million times smaller than that reported by FPH. We suggest that the FPH quoted neutron flux is in error, and the rate of vetoed cosmic ray induced neutron events, in our data, suggests the observation of Jones et al. to be cosmic muon induced events. An attempt to initiate "cold fusion" with 5 MeV alpha particles produced no measurable effect.

Supported in part by U.S.D.O.E. contracts Numbers: DE-AC02-76ER03074, DE-AC02-76CH00C16.

# LACK OF NEUTRON AND GAMMA RADIATION FROM PPPL's COLD FUSION EXPERIMENTS†

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We have tried to reproduce the various 'cold fusion' experiments [1, 2] along with some variations to their basic schemes. To date, we have not seen evidence from any of our experiments for the production of either neutrons or gamma rays at rates above the background. Experiments performed include: (i) electrolysis in a pure $D_2O$ cell with 1 molar LiOD (or LiOH) solution and various palladium cathodes at current densities up to 0.6 amperes/$cm^2$; (ii) electrolysis in a 50-50% $D_2O$-$H_2O$ cell with a graded drawn Pd wire (or cast Pd sphere) cathode at current density up to 0.5 amperes/$cm^2$; (iii) thermal and pressure cycling of various high-pressure $D_2$ gas-loaded Ti turnings, and Ti powders, a Nb bar, alumina, quartz, and feldspar mixtures, etc..

For all the experiments, neutrons were measured with $BF_3$ proportional counters and gamma rays with NaI scintillation detectors, but at different times and with separate test stations. The neutron monitoring station was shielded with a polyethylene moderator and cadmium absorber, and the background count rate was found to be highly variable, ranging from 5 counts/hr to 30 counts/hr. The neutron detection efficiency was determined with a $^{252}Cf$ source to be 1% for experiments (i) and (ii) and 0.1% , 0.3% , or 1% for experiment (iii), depending on configuration. The gamma-ray station employed a NaI scintillator-photomulitplier closely coupled to the electrolysis cell. The detector was surrounded by a cylindrical annulus of NaI fitted with 6 photomultipliers. The central and surrounding detectors were operated in anti-coincidence mode to minimize spurious signals from external sources. The experiment was surrounded by lead shielding to further reduce background; the background rate was 5 - 15 counts/hr in a 1- MeV wide window around the 5.5 MeV region of interest. The gamma detector energy calibration was determined with $^{60}Co$ and $^{137}Ce$ sources. We thus claim that our neutron counting apparatus can continuously resolve a neutron source strength of 1 neutron/sec and our gamma counting apparatus is capable of resolving a gamma source strength of 1 photon/sec. However, our apparatus could not detect neutrons as low as the level of Jones et al. [3].

We have considered the possible proton- and deuteron-induced nuclear reactions with the various isotopes present in the electrolysis apparatus. We note that there are no bound excited states in $^4He$, and only 3 unbound excited states lie below the d + d reaction threshold. The width of the lowest lying excited state (at 19.8 MeV) is 0.27 MeV. the higher excited states are broader and overlap strongly, and thus, one would expect the nearly prompt ($10^{-20}$ sec) decay by particle emission from the compound $^4He$ nuclei rather than an electromagnetic mode of decay (see, for example Ref. 4). Therefore, in our theoretical efforts, only two mechanisms for 'cold fusion' arc considered: (i) tunneling through coulomb barrier by 'cold' deuterons, and (ii) cold target

bombardment by deuterons accelerated in bursts [5]. The fusion rates for tunneling in p-D, D-D, and D-T molecules have been computed. The dependence of fusion rates on electron mass and temperature will be presented. This suggests that if the experiments of Ref. 1, 2, 3, and 5 were repeated with mixtures of hydrides and deuterides, the relative importance of quantum-mechanical tunneling vs. simple cold target bombardment would be determined.

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† This work is Supported by the U.S. Dot contract No. DE-AC02-76-CIIO-3073.

1. Fleischmann, M. and Pons, S., J. Elcctroanalyt Chem. 261.301 (1989).
2. DeNinno, A. et al., submitted lo Europhysics Letters.
3. Jones, S.E. et al., Nature 338. 737 (1989).
4. Jackson, J.D., Phys. Rev., 106, 330 (1958).
5. Klyuev, V.A., et al., Sov. Tech. Phys. Leu. 12, 551 (1986).

# AN ATTEMPT TO MEASURE CHARACTERISTIC X-RAYS FROM COLD FUSION

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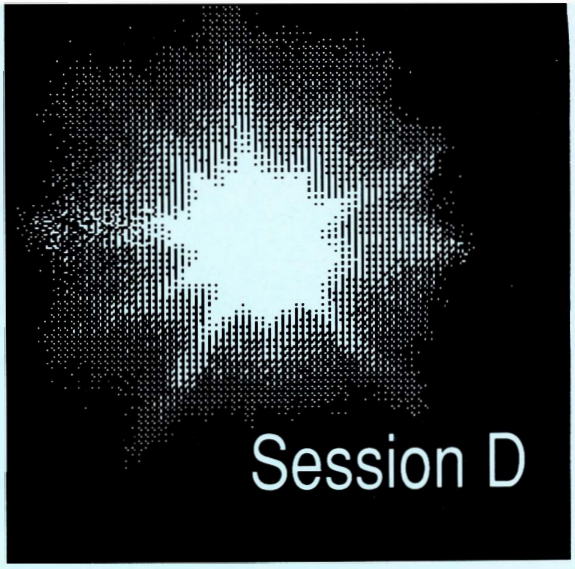
We have carried out tests using an electrolytic cell modeled after the Pons-Fleischmann descriptions, but with several modifications to allow the detection of characteristic X-rays emitted from the palladium electrode. In virtually any fusion reaction that could be postulated as taking place within the electrode, the energetic charged particles formed in the reaction would inevitably excite 21 keV characteristic K X-ray from palladium. If the structures and water of the cell do not absorb these X-rays before they emerge, then an external detector can have nearly 100% intrinsic efficiency for their detection.

A 1.5 by 1.5 cm palladium foil of 0.5 mm thickness was located within several millimeters of a thin nylon window fitted into the side of the glass cell. Two additional platinum electrodes were mounted at either side of the cell, and 0.1 M LiOD electrolyte in heavy water filled its internal volume. An electrolytic current ranging from 7 to 48 mA was sustained over a period of 7 days. The palladium electrode was observed to distort somewhat over this period, consistent with the hypothesis that substantial deuterium loading of the metal took place.

A germanium detector with thin endwindow was placed within several millimeters of the cell window outer surface throughout the experiment. Background data were obtained by inserting a 0.2 mm thick copper disk in front of the detector, of sufficient size to shadow the palladium sample. In separate measurements, a radioisotope source of X-rays was used to calibrate the detector energy scale and to verify the transmission properties of the cell components.

Over the period of time during which current was flowing in the cell, and for one day thereafter, no statistically significant differences were observed in data taken with and without the copper disk in place. We therefore conclude that no measurable characteristic X-rays were generated in the palladium over the period of the experiment.


Session D

# Calorimetric and Thermodynamic Analysis of Palladium-Deuterium Electrochemical Cells*

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A controversy exists concerning the analysis of the heat observed from palladium-deuterium electrochemical cells. This is partially due to the fact that calorimetry can only measure the enthalpy (heat) of the reaction; whereas, the energy supplied to the Pd-D electrochemical cells reflects a free energy of the reactions occurring within the cell. The fundamental interrelationships among the diverse concepts of 1) calorimetrically measured heat, 2) the cell potential, 3) the thermoneutral potential, 4) electrolytic and galvanic electrochemical reactions, 5) the endothermic cooling effect of the heavy water electrolysis, 6) the energy returned from any subsequent gas recombination, and 7) the internal pressure, fugacity, and thermodynamic activity of deuterium in the palladium will be presented.

The experimental effort at Sandia National Laboratories includes the calibration of a unique calorimeter, which operates on the principle of accurate measurements of the vaporization rate of liquid freon which completely surrounds the Pd-D cell. Unlike other recent calorimeter experiments on the Pd-D system, this calorimeter does not depend on the measurement of temperature within the cell and, therefore, avoids the present objections of possible temperature gradients (due to poor mixing within the cell) causing the reported excess heats.

The freon vaporization calorimeter has been assembled and initial electrical calibrations show a measured power resolution of 0.1 watts. Measurement of cell temperature will also be performed to give an independent measure of cell heat output. We installed $He^3$ neutron detectors around the cell to allow one of the first simultaneous sensitive radiation with calorimetry experiments. We will report on results of this combined calorimetry/radiation experiment at the time of the workshop presentation.

**The Possibility of Evaporation Dominating "Cold Fusion" Power Balance Calculations***

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The primary assertion of Profs. Fleischmann and Pons in their recent experiments with electrochemical loading of deuterium in palladium[1] is that more energy is produced than is consumed in the process. Their attribution of litis excess energy to nuclear fusion is derived from a power balance calculation based ultimately on Newton's Law of Cooling which may not be directly applicable in their experimental situation. They use a submerged resistor to heat the electrolyte solution and assume a constant heat transfer coefficient which in turn is used to calculate the energy loss rate, $k_T\Delta T$, to the surrounding environment.[2] Since the sum of this calculated loss rate and the chemical potential increase from electrolysis is greater than the electrical power input, they require the additional energy source. However, total heat loss (especially from evacuated Dewar cells) may be dominated by evaporation of electrolyte which increases exponentially with temperature. In many everyday situations, evaporation is limited to small amounts by vapor diffusion rates. In this experiment, the bubbles of electrolyzed $D_2O$ are saturated with water vapor and also serve to enhance convection of water vapor from the surface. Thus, during the calibration period at higher temperature, they may have overestimated the heat transfer coefficient applicable at the lower operating temperature. Even though the change in temperature for the calibration run described in ref. 2 was only 1.55 K, the corresponding water vapor partial pressure change, $\Delta P$, which drives evaporation, is large. The key to the difficulty is the nonlinearity of the heat loss process with temperature variation, i.e., $k_T$ is not constant Other nonlinear chemical reactions involving heat loss from the cell could also contribute to the perceived energy balance discrepancy. If evaporation dominates, energy loss can vary as $k_p\Delta P$, where $k_p$ is a constant. In this paper, calculations are presented to support the plausibility of this argument which negates the reason to postulate significant levels of fusion power.

1. Martin Fleischmann and B. Stanley Pons, J. Electroanal. Chem., 261 (1989) 301.
2. B. S. Pons, seminar at Los Alamos National Laboratory, April 18,1989.

* This work supported by the U. S. Department of Energy under contract DE-ACO4-76DP00789.

Abstract to be submitted to the Workshop on Cold Fusion Phenomena, May 23-23, 1969, Santa Fe, New Mexico

# CALORMETRIC MEASURMENTS ON ELECTROCHEMICAL CELLS WITH Pd-D AND Pd-H CATHODES

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## Introduction

The purpose of these experiments was to verify the results provided by M. Fleischmann and S. Pons, University of Utah [1]; they were not designed to verify the results of S.E. Jones [2]. The experiments sought to determine the presence of "excess heat"; experiments will also be undertaken to determine the presence of neutrons.

## Technical Approach

Two series of experiments have been performed: (1) differential comparison of temperature deviations between identical light- and heavy-water electrochemical cells and (2) calorimetric measurements of heavy-water cells under varying electrochemical conditions.
In the first series of experiments, the temperature difference of identically built and operated (current density and operational times) Pd-H/LiOH-saturated $H_2O$/Pt and Pd-D/LiOD-saturated $D_2O$/Pt cells was observed. We anticipated that both cells would operate at identical temperatures but that the $D_2O$ cell would become much hotter after the onset of cold fusion. However, we found it difficult to provide identical conditions in both cells. At identical current density, the operating cell voltage of the $D_2O$ cell (therefore, also the temperature) vas higher. When the current density and the voltage ware made identical, the $H_2O$ cell became warmer ($\Delta T$ = 0.8 K). We concluded that this type of experiment was too ambiguous and not suitable for evaluating the levels of heat and the special effects of deuterium new being reported.

In the second series of experiments, two Pd-D/LiOD-saturated $D_2O$/Pt cells in constant-heat-loss calorimeters ware operated to detect "excess heat" evolution. Excess heat is defined in this report as a heat output from the cell that is higher than the heat equivalent of the electrical Input [(cell voltage minus 1.53 V) multiplied by cell current]. The cathodes in both kinds of experiments were wrought palladium 5.0 cm in length and 6.3 mm in diameter. Under a series of well-defined electrochemical conditions (times and electrolyte additives) that were expected to increase the D/Pd ratio, we examined the various contributors of the electrical and heat inputs and outputs at various current densities (15-500 mA/cm$^2$). In addition, we calculated the mass and heat balances for the duration of the experiment to evaluate short- and long-range system transients. Thus far we have not found any excess heat within the sensitivity (0.13 W, 0.082 W/cm$^3$ of Pd or 0.013 W/cm$^2$ of Pd) and precision of the calorimeter. For now, the experiments are continuing. A detailed description of the experimental apparatus and of the analysis of the measured data will be presented.

References

1. M. Fleischmann and S. Pons, J. Electroanal. Chem., 261, 301 (1989).
2. S.E. Jones, E.P, Palmer, J.B. Czirr, D.L. Decker, G.L. Jensen, M.J. Thorne, S.F. Taylor, and J. Rafelsky, Nature, 338, 27 April 1989.

Acknowledgment
Work supported by the U.S. Department of Energy index contract W-31-109-Eng-38.

# Electrochemical Calorimetric Studies on Water and Deuterium Oxide Electrolysis.

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This talk will focus on our preliminary results on calorimetric studies on water and deuterium oxide electrolysis using Pt or Pd cathodes with LiOH(D) and NaF as the supporting electrolytes. In some cases, sulfur was added as an intentional poisoning agent. The Pt or Pd rods were 1 to 1.5 mm in diameter. Radiation levels were monitored by neutron activation of copper or silver metal. These studies were prompted by a recent note on electrochemically induced nuclear fusion (1).

A deuterium oxide solution, containing NaF and the Pd cathode poisoned by sulfur was electrolysed for 14 days. In terms of excess heat, the results appeared to be negative. Next, matched cells, with a Pd cathode in one and a Pt cathode in the other were tested for temperature differences in deuterium oxide containing 0.1M LiOD. After one week of electrolysis (100 $mA/cm^2$), no unexplained temperature differences between these cells were observed. However, this experiment is ongoing, and any future results will be given.

A comparison of the steady state heat evolution between water and deuterium oxide (LiOH(D) electrolyte, Pd cathode) indicated that the deuterium oxide cell was producing more heat than the water cell. The Newton cooling constants, 0.0538 J/s°C ($H_2O$ cell) and 0.0541 J/s°C ($D_2O$ cell) were determined by resistance heating in well stirred solutions. During the electrolysis (100 $mA/cm^2$), no temperature changes were noted as a function of the thermometer placement, and thus, the cells were not stirred mechanically. All trials resulted in an excess calculated heat, with the D20 always producing more excess than the water cells. For example, in one trial the excess heats were 0.201 and 0.223 J/s for the water and $D_2O$ cells, respectively. We attribute these observations, wholly or in part, to recombination of the gases (2). Further refinements on these cells are being made and the results will be shown and discussed.

Finally, remote monitoring of a scaled-up cell, in hopes of recording the Pd ignition event (1), is being planned. Progress towards this effort will be described.

1) M. Fleischmann and S. Pons, J. Electroanal. Chem., 261, 301-308 (1989).

2) O.M. Sherfy and A. Brenner, J. Electrochem. Soc., 105, 665-672 (1958)

ABSTRACT

SEVEN CHEMICAL EXPLANATIONS OF THE FLEISCHMANN-PONS EFFECT

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Seven chemical explanations are stated and quantitatively analyzed. (a) The $D_2O$ solution drops below the top of the electrode, and it pumps H out to an O contact at the Pd - gas interphase. (b) The same, but the situation described occurs inside the electrolyte with $O_2$ in bubble form from the anode, impelled sporadically against the cathode.

(c) $D_2 + O_2$ recombination in the gas phase.

(d) The $\alpha \rightarrow \beta$ transition is incomplete and continues for > 100 hours.

(e) The H/Pd ratio grows 0.7 - 1.25 over ~100 hours.

(f) Pd $D_2$ forms and dissociates sometimes explosively.

(g) Li alloys with Pd and this provides a heat of reaction.

The watts provided by these effects are compared with the heat reported from the Pd-$D_2$ system at high overpotential.

# EVIDENCE AGAINST CONDENSED MATTER FUSION INDUCED BY COSMIC-RAY MUONS

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b) Institute of Physical and Chemical Research (RIKEN), Wakoh, Saitama, Japan
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It has recently been proposed that the cosmic ray muons might catalyze d-d fusion in condensed matter /1/ offering a possible origin for claims of observations of fusion neutrons from deuterated Pd or Ti. In order to test this hypothesis, we have studied the behavior of accelerator-produced negative muons in Pd(D).

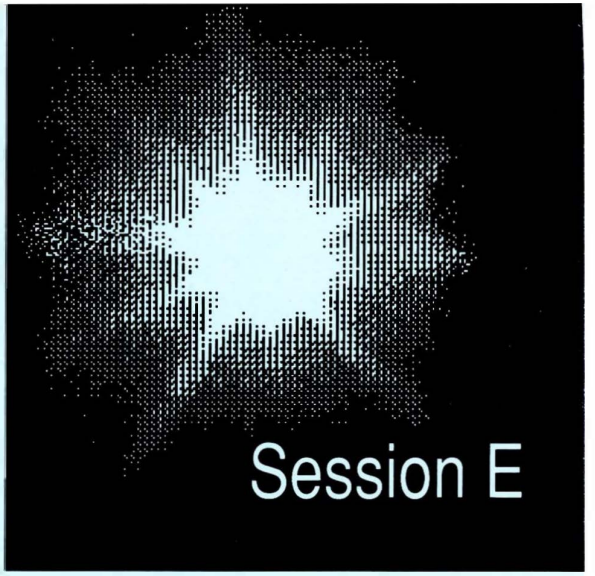
The experiment was carried out at the pulsed muon facility of UT-MSL/KEK by measuring the following muon-induced events ; a) timing of decay electrons to see the relative fraction of muons stopping in D versus Pd by a lifetime method; b) energy and timing of neutrons with n-$\gamma$ discrimination to see fusion neutrons ; c) energy and timing of X-rays to see ($\mu^3$He) events associated with (dd $\mu$) fusion if it exists. All the experimental arrangements employed here were the same as those used for the recent successful experiments on a direct observation of alpha-sticking phenomena in liquid and high $T_2$ concentration $D_2/T_2$ mixtures by the X-ray method /2/.

The Pd(D) samples used were a) a 5 mm diameter Pd rod with 10 days D loading ; b) a 3 mm thick Pd plate with 60% D loading; c) a 1 mm thick Pd plate in $D_2O$ with electrolysis in situ. As a control, we used Pd samples without D.

So far, no differences were observed between Pd and Pd(D) in all the above observables for these 3 systems, placing a limit on atomic capture ratio for D to Pd (below 5%) and on (dd$\mu$) fusion rates in Pd(D) (below $0.1/\mu^-$). The obtained result provides evidence against the extraordinarily enhanced fusion rates assumed in the proposal /1/.

/1/ M. I. Guinan et. Al., UCRL Preprint 10081 (1889)

/2/ K. Kagamine et. al., to be published (1989)


Session E

**PAC STUDIES OF ELECTROLYTICALLY CHARGED METAL CATHODES** *[1]*

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Cold nuclear fusion reactions might occur at special, "active" sites in the cathode, such as in lattice vacancies. We have investigated hydrogen (H) interactions with vacancies in metals on an atomic scale, using perturbed $\gamma$-$\gamma$ angular correlations (PAC) of $^{111}$In probes.*[2,3]* Our approach has been to trap diffusing H atoms in pre-existing probe-vacancy complexes. H trapping is detected microscopically by changes in the hyperfine interactions signals. Binding enthalpies of ~0.5 eV and occupation numbers of H in the complexes have been deduced from changes of signal amplitudes during charging and annealing. Some results are as follows:
(1) Divacancy and trivacancy complexes in Ni*[2]* and Pt*[3]* are rapidly decorated by H atoms after charging for a few minutes at 20 mA/cm$^2$ in 0.1 M $H_2SO_4$.
(2) NiH can be formed by charging Ni at ~200 mA/cm$^2$, whereas it is only formed under gas pressures in excess of 6 kbar.
(3) Li was the only common cation in electrolytes used by Fleischmann and Pons and by Jones et al. Because its radius is small, Li may diffuse interstitially in the cathode, like H. Using a Pt cathode and 1.0 M LiOH electrolyte, the pH was observed to drop from 13.3 to 9.4 after 24 hours at ~20 mA/cm$^2$, demonstrating that most Li deposited onto and/or diffused into the electrode. Experiments are in progress to detect Li diffusion in the lattice by observation of new signals corresponding to Li-decorated vacancy complexes.

*[1] Supported in part by NSF grant DMR 86-19688 (Metallurgy Program).*
*[2] G.S. Collins and R.B. Schuhmann, Phys. Rev. B34 (1986) 502.*
*[3] G.S. Collins, S.L. Shropshire and H.-J. Jang, proceedings, DIMETA-88.*

# INTERACTION OF DEUTERIUM WITH LATTICE DEFECTS IN PALLADIUM

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## ABSTRACT

The interaction of ion-implanted deuterium (D) with lattice defects and He bubbles/voids in single crystals of palladium (Pd) was investigated by ion-beam-analysis techniques. Experimental data for the amount of D retained during linear-ramp annealing were analyzed using transport theory to obtain trap strengths. Small He bubbles/voids were found to trap D with e binding enthalpy of 0.31 eV relative to the solution site, whereas implantation damage trapped D with three different binding enthalpies, 0.31 eV, 0.23 eV, and 0.15 eV, attributed respectively to vacancy clusters, monovacancies with low D occupancy, and monovacancies with high D occupancy. Each Pd vacancy can accomodate up to six D atoms. The lattice location of D trapped to monovacancies is obtained by the channeling technique, following anneals at various temperatures. At low temperatures, T~25 K, D occupies the octahedral ($O_h$) interstitial site which is the solution site for D in fcc metals. At T~100 K, D becomes trapped by vacancies, and at 200 K, just before the depopulation from the vacancy is initiated, 60% of the D is at a near-tetrahedral site, in which the remaining 40% is deposited 0.3 Å from the $O_h$ site towards the vacancy. The experimental results are compared with the theoretical prediction of the effective-medium theory.

# SEARCH FOR COLD FUSION IN SUPERSTOICHIOMETRIC PALLADIUM DEUTERIDE USING ION IMPLANTATION

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Deuterium-deuterium distances in D-charged Pd are expected to be reduced for D-to-metal atom ratios above one, since excess D remains after filling of the octahedral interstitial solution sites. Such atom ratios are usually not achieved by electrochemical or gas-phase charging, but D ion-implantation at a temperature of 35 K was previously found to yield compositions up to D/Pd = 1.3. We have implanted similar high fluences of D into Pd at 40 K and an energy of 10 keV, and have used a solid-state detector to search for high-energy D and T particles from the D-D nuclear reaction. Copious charged particles of the appropriate energies were produced by the impinging D beam, thereby verifying the operation of the detection system and permitting the buildup of the D concentration to be monitored. After the beam was turned off, however, fusion events were not detected during about 9 hours of counting at 40 K. We estimate an upper bound on the reaction rate of $10^{-21}$ events/D/s. Similarly negative results were obtained for D-implanted Zr.

During warmup of D-implanted Pd, the D/Pd atom ratio was monitored by measuring the yields of energetic H and T induced by bombardment with 30-keV D. The D concentration decreased in distinct stages at 120 and 220 K. The first stage is attributed to rapid diffusion of the excess D in the superstoichiometric hydride, and its occurrence supports the existence of a D/Pd ratio above one; the second stage is then ascribed to D release by conventional diffusion in the normal hydride phase. Theoretical consideration of the respective diffusion processes yields relative rates consistent with the temperature separation of the two stages.

This work was supported by the U. S. Dept. of Energy under Contract. No. DE-AC04-76DP00789.

# Tritium Enrichment in the Electrolysis of $D_2O$

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The tritium content of heavy water manufactured by the GS process ($H_2S$ – $H_2O$ dual temperature exchange) is calculated as a function of the tritium content of the feed to the heavy water plant. Fresh heavy water has a tritium activity of 68 dpm (cc $D_2O$)$^{-1}$ (TU)$^{-1}$. The gross tritium enrichment into heavy water during electrolysis is calculated from the theory of relative enrichment [1] and the experimental data of Ostlund and Werner [2] as a function of the T/D separation factor. For separation factors in the range $1.6 < k_D/k_T < 2.2$, the overall enrichment increases from 1.4 to 5.1 as the fraction of water electrolyzed increases from 0.6 to 0.95. Implications with respect to cold fusion experiments will be discussed.

1. Bigeleisen, "Tritium in the Physical and Biological Sciences" IAEA (Vienna, 1962) pg. 161.
2. H.G. Ostlund and E. Werner, Ibid, pg. 95.

# Nuclear Fusion from Crack-Generated Particle Acceleration

Frederick J. Mayer [a], John S. King [b], and John R. Reitz [c]

We propose a conventional interpretation for the neutron production in electrochemical ("cold" fusion) experiments [1,2]. We suggest that electrostatic acceleration of deuterons results from internal cracks in the highly-stressed/ deuterium-loaded metal lattices. After sufficient internal stresses have accumulated, cracks may propagate through the metal. The lattice surfaces, on either side of the crack, are left with unbalanced electrical charge. As the crack grows, the charged surfaces separate while maintaining constant charge, thereby increasing the voltage across the crack gap, as $V = 10^9 \eta d$ eV, here $\eta$ is the number of imbalanced charges per square lattice constant (16 square angstroms for palladium), and d is the gap separation. With $\eta = 0.1$, and $d = 10^{-5}$ cm, $V = 10^3$ eV, or with $d = 10^{-4}$ cm, $V = 10^4$ eV. Stray deuterons falling across the gap may then acquire energy sufficient to produce conventional d-d nuclear reactions at rates comparable to those apparently observed in some cold fusion experiments [1, 2]. The surface charge must be maintained for at least the deuteron transit time across the gap, roughly a few picoseconds. A number of effects, near the tip, may allow for this relatively long relaxation time.

The electrostatic stored energy in the crack electrostatic fields is easily calculated to be about $E = 10^5 \eta^2 d/2$ joules/cm$^2$. If the cracks are created and then electrostatic energy is discharged from tens of square centimeters per second, then watts of electrical power may be released and appear as excess heat.

Finally, lattice fracture, in strongly shocked, lithium deuteride, has recently been proposed by Klyuev [3], et. al., as the mechanism responsible for their observed d-d neutron generation at low levels.

REFERENCES:

1) M. Fleischmann and S. Pons, J. Electroanal. Chem., 261, pg. 301 (1989).
2) S. E. Jones, E. P. Palmer, J. B. Czirr, D. L. Decker, G. L. Jensen, T. M. Thorne, S. F. Taylor, and J. Rafelski, Nature, 338, pg. 737 (1989).
3) V. A. Klyuev, A. G. Lipson, Yu. p. Toporov, B. V. Deryagin, V. I. Lushchikov, A. V. Strelkov, and E. P. Shabalin, Sov. Tech. Phys. Lett., 12, pg. 551 (1986)

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# Search for 0.8 MeV $^3$He Nuclei Emitted from Pd and Ti Exposed to High Pressure $D_2$

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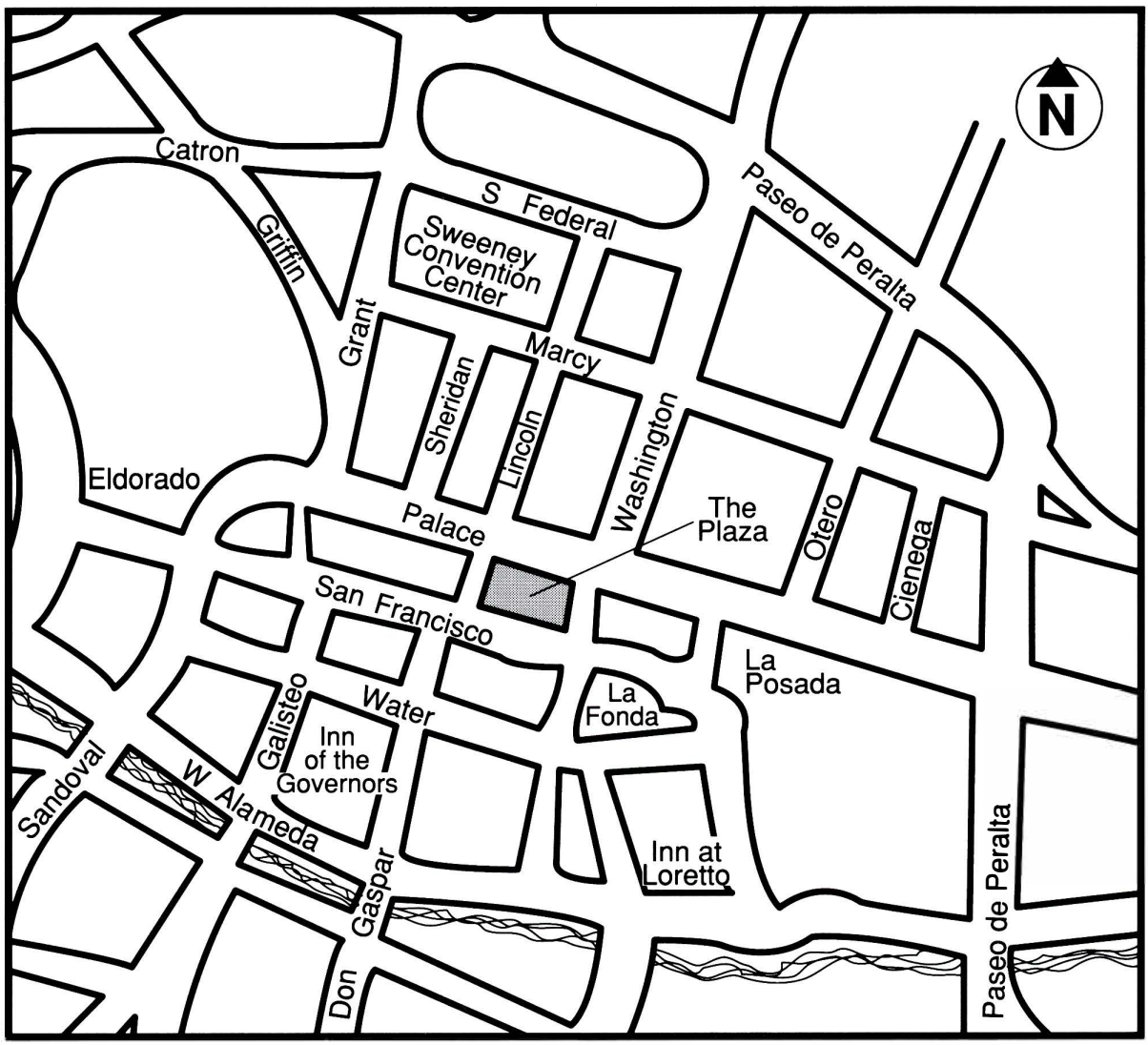
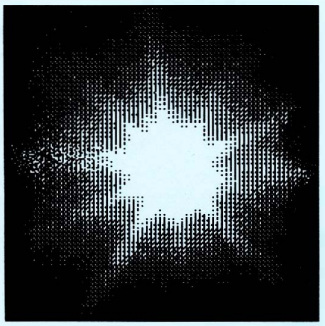
To look for evidence of cold fusion leading to n + $^3$He, we have exposed track-recording plastic films in direct contact with Pd and Ti sheets inside a cell containing $D_2$ at pressures up to ~15 bars. A portion of each film not in contact with metal served to measure backgrounds due to alpha decay of radon and to cosmic ray-induced spallation of C and O in the plastic films. We have cycled between 77 K and 300 K and between 1 and 15 bars, and also reduced the pressure with a forepump as done at Frascati. For a Pd sample with atom fraction D/Pd = 0.5 (measured by weight gain) the track density due to $^3$He ions emerging from the surface was <20 cm$^{-2}$; results for Pd loaded to D/Pd = 0.8 by electrolysis and for Ti loaded with D will be reported. The corresponding limit on the number of neutrons, ~4 x $10^4$ per gm, is far lower than the numbers reported in the two Frascati experiments with Ti (~3 x $10^5$ per gm and ~3 x $10^6$ per gm) and in the Genoa experiment with Pd (~6 x $10^7$ per gm). We calculate that lattice damage cannot explain the non-reproducibility of the Italian experiments.

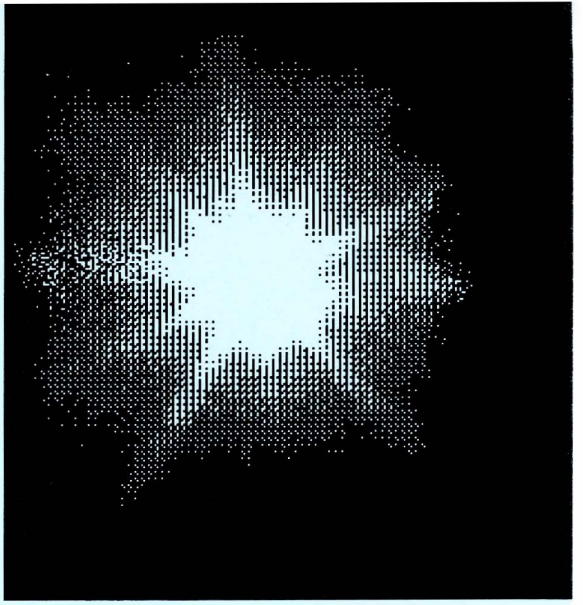
# Downtown Santa Fe





# WORKSHOP ON COLD FUSION PHENOMENA

## ABSTRACTS SELECTED FOR POSTER SESSIONS



# INTEGRATED EXPERIMENTS

# On the observation of charged particles in cold fusion.

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## Abstract

With the aim to confirm or reject the recent claim of observation of cold d-d fusion, an experimental effort has been made to try to observe MeV protons which should be emitted as a result of d-d fusion. Pd foils, thin enough to allow all protons produced to escape the foil, were electrolytically charged with deuterium. A Si(SB) detector was placed close to the Pd foil during charging in order to detect any protons emitted. The deuterium content was measured to be the expected 0.7 D per Pd. Monte Carlo simulations were made to estimate the detection efficiency of 3.02 MeV protons produced in the Pd foil.
The background in the experiment was so low that fusion rates considerably lower than those reported on by Jones et al could be detected. A number of experiments have been performed where the charging conditions were varied. In spite of that and the good sensitivity of the experiment no evidence for cold fusion has been found.

# Search for $\mu^-$ Catalyzed $d-d$ Fusion in $PdD_x$ *

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Jones *et al.*[1] recently claimed to have observed neutrons from possible $d-d$ fusion reactions in Pd or Ti charged with D using simple electrochemical cells. Among other things, this led to the proposition[2] that negative cosmic ray muons stopping in $PdD_x$ samples could produce such neutrons via muon catalyzed fusion ($\mu CF$) of $d\mu d$ mesomolecular ions: $d\mu d \rightarrow {}^3\mathrm{He} + n + \mu$, a process known to occur in pure $D_2$ but never observed in condensed matter due to the enhanced probability of $\mu^-$ capture on heavier elements and the rapid transfer of the $\mu^-$ from $\mu^-$d to heavier nuclei once formed. In order to test this proposition, we have made a preliminary study of the time distributions of electrons and neutrons relative to the time of arrival of stopped $\mu^-$ from a muon channel (M20B) at an accelerator (TRIUMF), thus increasing the hypothetical $\mu CF$ rate by a factor of more than $10^7$ relative to stopping cosmic ray muons. We stopped 1.5 to 2.8 $\times 10^4 \mu^-$/s in 15 g, $2.3 \times 2.0 \times 0.25$ cm$^3$ samples of 99.9% pure Pd in thin electrochemical cells and detected electrons and neutrons in a NE213-type BC501 liquid scintillator "N" counter with pulse shape discrimination. A thin NE102 plastic scintillator "E" between the target and the "N" counter was used in coincidence with the electron trigger and as a veto for neutrons. Similar plastic scintillators were used to generate the $\mu^-$ stop trigger. A fast time digitizer was used to measure the time interval between a $\mu^-$ stop and an $e^-$ or $n$ event; these time intervals were histogrammed to form the above-mentioned time spectra. All Pd samples were initially degassed in vacuum at high temperature. One was kept free of H or D and used as a control. The second was charged for 5 days in a 0.1M solution of LiOD in $D_2O$ so that the stoichiometry (measured by weight change) was $PdD_{0.88(1)}$ at the start of the run. The third was charged for 5 days in a 0.1M solution of LiOH in $H_2O$ to make $PdH_{0.87(1)}$. During the run the samples were maintained in the same solutions with electrolysis currents of 10 mA at voltages of 2.69 V (PdD) and 2.36 V (PdH) to prevent loss of D or H. The uncharged Pd was held in the same cell at 8.7 mA and 2.67 V during the run to preserve identical systematics. Comparing results for Pd, $PdD_{0.88(1)}$ and $PdH_{0.87(1)}$, we find no evidence for any efficient $\mu CF$ in $PdD_x$, which effectively negates the original hypothesis; we have not ruled out the possibility of more subtle effects with a small minority of the stopped muons, but the data are consistent with a complete absence of any $\mu CF$ in $PdD_x$. It is important to note that almost every $\mu^-$ captured by Pd liberates one or more neutrons in the nuclear capture process ($\mu^- + p \rightarrow n\nu_\mu$); this produces a significant background of neutrons associated with stopping muons. It is not inconceivable that such $\mu$–capture neutrons are generated in detectable numbers by cosmic ray muons, but such events have nothing whatsoever to do with fusion.

* Work supported by NRC and NSERC.

[1] S.E. Jones, E.P. Palmer, J.B. Czir, D.L. Decker, G.L. Jensen, S.F. Taylor and J. Rafelski, "Observation of Cold Nuclear Fusion In Condensed Matter", to be published in Nature (1989).

[2] M.W. Guinan, G.F. Chapline, and R.W. Moir, "Catalysis of Deuterium Fusion in Metal Hydrides by Cosmic Ray Muons", UCRL Preprint 100881, April 7, 1989.

*Abstract for Cold Fusion Workshop, Santa Fe, NM, May 1989.*

# ELECTROCHEMICAL AND MATERIAL PROPERTY FACTORS IN COLD FUSION EXPERIMENTS

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ABSTRACT

An overall description of the electrochemical processes occurring in cold fusion cells with Palladium cathodes is presented. Energy/power deposition distributions, deuterium activity/overvoltage relationships, uniformity of current density and symmetry of the cell design, the effect of palladium microstructure and void/inclusion distribution and the possible role of poisons are discussed. Correlation with ongoing experiments are discussed.

# AN INVESTIGATION OF COLD FUSION IN THIN PALLADIUM FILMS

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The source of heat in the cold fusion experiments of Pons and Fleischmann has been hypothesized to arise from an as yet unidentified nuclear reaction. If this is the case, it must involve the emission of massive energetic particles (such as alpha particles), since the traditional reaction paths would all produce great amounts of easily detectable neutrons, tritons, and gamma rays. With this in mind, an effort has been made to create cold fusion in thin films of palladium under low energy bombardment with high currents of deuterium ions in a vacuum chamber. The sample is monitored with a silicon surface barrier detector in order to detect any massive energetic reaction products. The films are deposited by sputtering onto smooth silicon substrates, and consist of approximately 170 Å of palladium sandwiched by thin layers of high chrome stainless steel. These films are bombarded with deuterium ions at an energy of 1.5 keV with a current density of about 0.5 mA/cm$^2$. The sample temperature is monitored during implantation, and is subject to control within a range from about 570 K to 20 K using a combination of beam heating and cooling with a cryostat. Full spectra will be presented, including background and control experiments, along with an analysis of possible causes of both real and spurious counts.

* NRC Postdoctoral Associate

# Evaluation of Cold Fusion in Single and Cast Polycrystalline Pd*

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The potential of electrochemically driven cold fusion has excited the imagination of scientists around the world. Preliminary reports have indicated that there are enhanced effects in cast versus extruded Pd electrodes. To investigate this we have examined a number of Pd electrodes including single crystal (20 gm) and cast ingot (40gm). No discernable differences in deuterium uptake are observed due to the sample morphology, rather it appears that the condition of the surface dominates the uptake kinetics. Surfaces etched in hot aqua regia before placement in the electrochemical cell show considerably enhanced D uptake.

The electrodes above as well as polycrystalline Ti rods have been run in a 0.1M LiOD/$D_2O$ electrochemical cell with Pt counter electrodes for 10 to 30 days while monitoring temperature, neutron fluence, voltage and current at 10 min. intervals. The neutron detector consisted of an array of $He^3$ tubes with a polyethylene moderator and Cd thermal neutron shield. The detector is capable of sensing the generation of as few as 5 neutrons/sec. The cell volume was carefully controlled and the Pd and Ti electrodes exposed only to the electrolyte. No excess neutrons or heat have been observed to date.

*This work performed at Sandia National Laboratories was supported by the U. S. Department of Energy under contract #DE-AC04-76DP00789.

Experiments in Search of Cold-Fusion Processes. S. Gottesfeld, T. E. Springer, F. H. Garzon, D. A. Baker, R. E. Anderson, E. M. Leonard, and M. W. Johnson, Los Alamos National Laboratory, Los Alamos, NM 87545. Since the announcement by Utah and Brigham Young Universities that "cold fusion" might be occurring in relatively simple electrochemical systems, there has been an intense effort at the Los Alamos National Laboratory, as well as at other institutions, to verify these results. One collaboration at Los Alamos has involved members of the Electronics Research Group, the Advanced Nuclear Technology Group, and the Controlled Thermonuclear Research Division. Four electrochemical cells similar to those described by the Utah scientists have been constructed and operated for three to five weeks under various geometrical and electrical current conditions. A number of diagnostic measurements have been performed, including total and spectrometric neutron measurements, high- resolution gamma measurements, and Pd electrode resistivity. No evidence has been obtained for production of neutrons or 2.223-MeV gammas above levels consistent with background. The temperatures of three of the cells were monitored, either directly in the cell or by monitoring the cooling bath. No evidence for excess heat generation has been obtained. In addition to the electrochemical cells, attempts are underway to reproduce the Frascati results; the first attempt produced negative results. Further measurements of this type are planned and results will be available at the conference.

# Nuclear and thermal effects during electrolytic reduction of deuterium at a palladium cathode

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ABSTRACT

An experiment was carried out in LiOD 0.1 M $D_2O$ electrolyte solution with a three electrodes arrangement . Palladium- a parallelepiped of 5 X 6 X 20 mm- was used as cathode. After 150 hours at a current density of 200 mA/ $cm^2$ a simultaneous neutron emission and sharp increase of the electrode temperature was observed. The evaluation of the neutron emission was about 150 times the background level and estimated thermal energy release of about 200 J was delivered in about four minutes. A predisposed security current cut off device driven by the data acquisition system was found to be activated during the event. Details concerning the experimental apparatus and procedure adopted for the evaluation of the experimental data will be presented.

# Investigation of Fusion Reactions in Palladium Using Galvanostatic, Coulometric, and Membrane Permeation Techniques*

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T. M. Christensen and W. H. Casey

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## Abstract

We describe a variety of electrochemical methods and our results in applying them to investigate cold fusion phenomena. Our initial cells used galvanostatic techniques with no reference electrode in an attempt to duplicate the particle fluxes (neutron and proton) observed in the University of Utah experiments. In these cells we used extruded Pd wire, both as received and after annealing at 1050°C in $10^{-6}$ torr vacuum for 12 hours cleaned using anodic/cathodic cycling, in 0.1 M LiOD with Pt cage counter electrodes. Using proton and neutron detectors thousands of times more sensitive than those described by Utah, we were unable to detect particle fluxes above background in any of 5 cells operated up to 35 days at current densities as high as 80 $mA/cm^2$. In agreement with the particle detection experiments, periodic sampling and analysis of the electrolyte in the cells failed to show tritium above background levels.

We are also utilizing coulometric and Devanathan-Stachurski electrochemical permeation techniques to analyze the loading of Pd with D/H. We determine the D content of Pd electrodes quantitative coulometry of a loaded Pd electrode on discharge. Using the Devanathan-Starchurski method, we determined the effective charging flux of Pd foils as a function of surface treatment. This method allows us to determine the fraction of D atoms from the discharge of $D_2O$ that enter the lattice as a function of applied current density. We can then better estimate which surface treatments allow us to fully load a Pd electrode to a Pd:D ratio of 1:1. We show that surface treatments such as palladizing, anodic/cathodic cleaning cycles, and flame washing are superior to ex situ solvent cleaning in increasing the effective charging flux of Pd foils.

**Search for Cold Fusion Using Pd-D; Cells and Ti-D Mixtures.***

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Ames Laboratory. Iowa State U.

We have searched for cold fusion produced in an electrolytic cell with Pd cathode and Pt anode. The electrolyte was 0.1 molar LiOD in 99.8% $D_2O$. Experiments using a 2 mm rod of polycrystalline Pd and a 4 mm rod of single crystal Pd ran for 10 and 6 days, respectively. The cell current was 0.95A. No radiation was detected above background by a $BF_3$ neutron and Ce γ-x detector. The $D_2$ loading of the Pd was measured to be 0.8 D per Pd atom and reached saturation after 4 hours. We also attempted to duplicate the work of Scaramuzzi and coworkers[1] on the Ti-D system. Both powder and pieces of Ti were used. The material was cycled several times between 1100 K and 77 K. No neutron emission above background was observed. The results of a barrier penetration calculation for H-like atoms will be presented and discussed in light of results of recent experiments.

* Work supported by DOE

1. Submitted to Euro. Phys. Lett

# AN INVESTIGATION ON NUCLEAR FUSION AT ROOM TEMPERATURE

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GUYIN FAN, DACHUN WANG AND YAHONG QIAN. ET. Al.

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## ABSTRACT

RECENTLY M. FLEISCHMANN AND S. PONS IN UTAH ANNOUNCED THAT THEY HAD SUSTAINED A FUSION REACTION IN A BOTTLE AT ROOM TEMPERATURE. IN ORDER TO CONFIRM THEIR RESULTS WE UNDERTOOK PRESENT WORK. NOW WE HAVE FINISHED FIVE RUNS OF EXPERIMENTS AND DETECTED NEUTRONS AMD TRITIUM IN A CERTAIN PERIOD DURING EACH EXPERIMENT AND FOUND AN UNKNOWN FEATURE OF THIS PROCESS: INTERMITTENCE OF PRODUCTION OF NEUTRONS.

# LARGE-CATHODE COLD FUSION EXPERIMENTS

by Scott R. Little, David B. Clifton, John C. Harlan, Noel B. Brinkley, and John S. Schindler, AUSTIN COLD FUSION, Austin, TX.

## ABSTRACT

A variety of experiments cover a range of materials and parameters. Several are attempts to duplicate the work of Fleischmann and Pons, including large, cast cathodes and high current densities. Gamma emissions from Ø.5 to 7.4 Mev are monitored with a 2x2 NaI multichannel spectrometer. Neutrons are counted with a LiI scintillator. Water-flow calorimetry provides an absolute measure of heat production with a precision of +/- 1Ø mW.

To date, one cell with a 1 cm diameter spherical Pd cathode has shown indications of slight excess heat production. If this is verified we will try to keep it running until the total heat energy exceeds the total integrated input of electrical energy. A complete presentation of all experimental conditions and results will be made. Measurement errors will be discussed and quantified.

# COLD NUCLEAR FUSION: SOME EXPERIMENTS AND ANALYSIS

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## ABSTRACT

Results of experiments on the electrolysis of $LiOD/D_2O$ solutions using Pd electrodes as a function of current density and time will be presented. Neutron and gamma levels during cell operation as measured with scintillation detectors were not significantly above backgrounds of 0.6 cps and 1.8 cps, respectively. Tritium analysis of the catholyte solution during and after electrolysis showed the same concentration as blank samples, i.e., 70 cpm/ml. Pitfalls associated with the interpretation of cold fusion experiments will be discussed.

A critical analysis of the calorimetry results of Fleischmann and Pons will be made. We note that their measured excess rates of heating are of quite modest magnitude but that the large values quoted at 512 $mA/cm^2$ are projections of highly questionable validity. The total heat output was generally less and at best about equal to the energy supplied. We calculate the ratio of measured excess heating rate to the equivalent $D_2$-$O_2$ recombination heat to be generally less than one. It appears that the data published do not warrant an interpretation based on nuclear fusion. In the absence of a complete accounting of excess heat from chemical and electrochemical sources, (e.g., $D_2$-$O_2$ reaction, Pd deuteride formation, anode depolarization, impurities), their conclusion of electrochemically induced nuclear fusion is largely a speculation.

# INTEGRATED CALORIMETRIC/NUCLEAR EXPERIMENT ON Pd-HYDROGEN INTERACTIONS

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K. H. Pool, J. F. Wacker

Pacific Northwest Laboratory

## ABSTRACT

We will describe an experiment designed to confirm conclusions reported by Fleishmann and Pons. We designed the experiment to simultaneously measure possible excess heat and neutron and gamma radiation that could be generated during electrolysis of $D_2O$ and deposition of deuterium in a palladium cathode. The aqueous electrolytic cell consists of a Pt anode, $D_2O$, 0.1 M $^6LiOD$ electrolyte, and Pd cathode. Simultaneous measurements are made in a nearly identical cell, except the electrolysis is of $H_2O$ in a 0.1 M $^6LiOH$ electrolyte. The $D_2O$ and $H_2O$ cells are connected in series to run with identical currents and nearly equal current densities.

The entire experiment is assembled inside a sensitive neutron counter with a 13% counting efficiency. The cathodes, cylindrical rods measuring 0.5 cm in dia x 5 cm in length, are vacuum/arc melted, annealed and conditioned at low electrical currents. Cathodic overpotentials, current, cell voltages, temperatures, and heat generation are recorded as a function of time by a computerized data logging system. Excess heat is calculated by considering integrated electrical energy input, electrolysis, and enthalpy lost from the system by evaporation and through recirculating water from a water bath surrounding the electrolytic cell. Conditions are maintained near isothermal. Energy input is calculated from $\int E(t)I(t)dt$, where t is the time ranging from the start of conditioning of the Pd electrode to the end of the experiment.

M. A. Prelas , F. P. Boody, W. Gallaher, E. Leal-Quiros, David Mencin, and Scott Taylor, **"Experiments to Produce Cold Fusion in Maxwellian Plasmas",** Fusion Research Laboratory, Nuclear Engineering Prog., University of Missouri-Columbia, 65211 USA-----
We are exposing samples of palladium, titanium, nickle, and tantalum to deuterium ions produced in a mirror machine. The ion temperature and current can be varied by changing the magnetic field strength, microwave power, and background deuterium density. We have incorporated a wide variety of diagnostics including: a $BF_3$ probe (neutrons), a gold foil (neutrons), a newly developed charged particle counter (p,T, $He^3$, and $He^4$), calorimeter, an ion energy analyzer ($D^+$ density and temperature), a residual gas analyzer, a He leak detector, a sodium iodide detector with multichannel analyzer (gamma ray spectroscopy), and Geiger counters (bulk gamma ray detectors). To date we have had interesting but non-conclusive results. This paper will describe the experimental set-up and provide up to date results on this potential method of initiating the cold fusion process.

# Limits on Emissions from Palladium-$D_2O$ Electrolytic Cells[#]

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J.M. Nitschke, S.G. Prussin, F.J. Echegaray, and M.A. Stoyer

*University of California, Berkeley, and Lawrence Berkeley Lab*

We are carrying out a series of experiments to attempt to verify the recent claimed observations of cold fusion. Our first experiments used a simple undivided electrochemical cell with an outer Pt helical wire electrode concentric with a 1.9440 g Pd inner tightly-wound coil electrode of 0.0100" dia. wire. The electrolyte was 1.0 M LiOD in $D_2O$ (99.9%). During the experiment the current was maintained between .250 A and 1.25 A. The cell was placed within a shielded enclosure filled with water and paraffin and equipped with an intrinsic Ge detector to monitor the 2224 keV neutron proton capture photons. The cell was run in a charging mode for two weeks, followed by a purging mode at reversed current for one week. From these measurements we are able to set an upper limit for the average D-D fusion neutron rate of $< 1 \times 10^{-22}$ per DD $s^{-1}$. The deuterium content was titrated to be ~0.62 D/Pd.

In a new experiment two vacuum-cast Pd disks are the cathodes in "twin" cells, one with $H_2O$, the other with $D_2O$. The two cells are shuttled every 24 hours between two similar detector setups, equipped with intrinsic Ge X-ray and $\gamma$-ray detectors, liquid scintillator and $^3He$ neutron detectors. Another experiment under way is designed to measure the production of charged particles, using a Si(Au) detector. The cell is of a simple "chimney" design with a 0.003" Pd electrode foil. Results from these experiments will be reported at the workshop.

* On leave from Kuwait Institute for Scientific Research, Kuwait.
# Supported by U.S.D.O.E. under Contract DE-AC03-76SF00098.

# PRELIMINARY INVESTIGATION OF POSSIBLE LOW TEMPERATURE FUSION

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## ABSTRACT

Preliminary tests have been made with an electrolytic cell utilizing 0.15 N LiOD in $D_2O$ as the electrolyte and a palladium cathode surrounded by a wire-wound platinum anode operating at a cathode current density of 100 $mA/cm^2$. The cathodes was freshly cast into a cold mold under argon and then swaged to a nominal diameter of 3-mm or 6-mm with 8 1/2- to 9-cm of active length in the electrolyte. The electrolyte temperature was controlled and heat was removed by flowing water in a cooling jacket, and the cell was insulated with 2 in. of fiber glass or foam insulation. Cooling water and electrolyte temperatures were measured by thermocouples, and neutron and gamma-ray spectra were measured and recorded. The electrolyte was periodically monitored and replenished and the tritium content was determined.

Tests up to 2 weeks in duration were made with no unaccountable heat generation. Neutron and gamma-ray count rates will be presented and discussed.

# Attempts to Understand and Reproduce Cold Fusion*

by
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The assumption will be made that some fusion can occur within a metal lattice if the conditions are right. However, in order to verify the claims of Pons and Fleischmann, three questions must be answered. First, what are the conditions that exist within the Pd electrode when fusion occurs; second, is excess energy actually produced in the cell; and, third, what is the source of this energy? An experimental approach will be described that can answer each of these questions.

In order for there to be a possibility of fusion, the deuterium content of the Pd lattice must approach a D/Pd ratio of unity. Such a high deuterium content can not be achieved in palladium unless the surface is poisoned. Without a surface poison, a cell can be electrolyzed forever without the deuterium content rising above a D/Pd ratio of 0.67 at 1atm and 25°C. Unless the D/Pd ratio is known to be near 1.0, failure to see heat can not be considered a refutation of the Pons-Fleischmann claim. Methods to achieve a suitable D/Pd ratio and its measurement will be described.

Once a proper electrode is available, all energy entering and leaving the cell must be measured. A cell will be described that allows the gasses, heat and electrical energy, and emitted radiation to be measured. Preliminary results will be described.

A proper study of the nuclear reaction is difficult to do using an electrolytic cell because of the difficulty in detecting possible reaction products such as $^{3}He$, $^{4}He$ and weak radiation. Therefore, a cell has been constructed using plasma loading of Pd directly from the gas phase. This cell will be used to study the nuclear reaction if fusion can be produced without an electrolyte and it will be used to study the d-d, d-p and d-t reactions.

# COLD FUSION EXPERIMENT AT THE SAVANNAH RIVER SITE

by

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## ABSTRACT

An experimental investigation of cold fusion is in progress at the Savannah River Site. Precise measurements are being made of energy balance, mass balance, gamma radiation, neutron radiation and tritium, and helium generation. An argon purged $D_20$ electrolysis cell is mounted inside a dry calorimeter which measures heat output with an accuracy of ±0.2% at 10 watts thermal. Constant-flow argon sweep gas is dried for water measurement and analyzed by an online quadrapole mass spectrometer to measure off gas species and amounts. Electrolysis power is measured at 10-second intervals, integrated, and compared with the sum of calorimeter heat, electrolytic product heat of formation, evaporation heat, and argon heating. Gamma radiation is measured by (high sensitivity) sodium iodide detectors at the cell and 6 meters away for background. Additional gamma monitoring at the cell is done by a high-resolution intrinsic germanium detector. Neutron measurements at the cell and 6 meters away are done by moderated helium through detectors. All measurement devices are calibrated against NIST traceable standards. Details of the experimental arrangement and results to date will be discussed.

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# Neutron and Thermal Measurements of a Solid State Palladium Cell

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A unique solid state "cold fusion" cell was constructed to test the idea of non equilibrium or "heavy electron" aided fusion. The concept behind this design was to inject electrons into deuterium loaded palladium so that the electron concentration in the metal would be in a non-equilibrium state for a short time. A time correlated neutron detector was then used to detect any anomalous neutrons produced during or shortly after the electrical excitation. Cells were constructed from alternating layers of palladium and silicon powder pressed into a ceramic form and exposed to deuterium gas at 110 psia resulting in a D/M ratio of 0.7. Cells with deuterium and cells with hydrogen or vacuum were used in the experiments. One deuterium cell showed anomalous heating, for a short time, above the rate found for the vacuum cell. No time correlated neutron events were observed, although the general level of the neutron background was slightly higher with the deuterium cell than with dummy samples. We attribute the increased neutron background to noise pickup from the pulsing electronics and the modest heating to an electrically driven chemical reaction of unknown origin.

# AN ATTEMPT TO DETECT CATALYTIC NUCLEAR FUSION IN Pd Dx LATTICE

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We searched for nuclear radiation during the electrolysis of 0.1 M LiOH heavy water in a three compartment electrochemical cell. Palladium electrodes of different shapes and area to volume ratios were used. The experiments wore performed in various sorption-desorption regimes. For neutron detection a $^{6}$Li glass scintillator <NE912> of two different diameters <6.12 cm 12.0 cm> was used with the efficiencies of 1% and 2% respectively. The efficiency of the detecting systems was measured by using the $^{252}$Cf neutron source. The $^{6}$Lil(Eu) crystal was used as a control monitor. The experiments were carried out in an underground laboratory having 0.2 m concrete deck covered by 3 meters of soil. The background neutron counting rate for the smaller detector was less than 0.01 count/s. The analysis of several experiments, which lasted from five to eight days, showed that no more than 0.01 neutron/s per one gram of palladium was produced.

# Measurements of Nuclear Radiation Due to Pd-Deuterium Interactions

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Battelle Pacific Northwest Laboratories, PO Box 999, Richland, WA 99352

Experiments have been run to verify the claim of Pons-Fleischmann that "cold" fusion occurs in the Pd-deuterium system. Pd cathodes were electrochemically charged with deuterium from a 0.1M LiOD electrolyte. The Pd was 99.9% pure and consisted of 3 to 5 mm wide strips cut from 25 by 25 mm wide by 1 mm thick foil piece. A Pt lead was spot-welded onto each Pd strip. Pt wire (0.68mm diameter) was used as the anode in most experiments. The LiOD solution was made by dissolving either $^{7}Li$ metal or $^{6}Li_2O$ in 99.8% $D_2O$. Cells were run at constant current, with current densities on the Pd ranging from 16 to 320 $mA/cm^2$; both cell voltages and currents were periodically measured, however, no temperature measurements were made. In one experimental setup, an electrochemical cell was placed inside a high sensitivity neutron counter and neutron counts were taken at 10 min intervals. In addition, temporal multiplicity events, characteristic of bursts postulated to be produced by muon catalysis, were measured by connecting the output of the neutron counter to a multiplicity counter. In a second setup, a cell was placed inside a germanium gamma-ray spectrometer to measure Pd x-rays generated by high energy fusion products (*e.g.*, protons) and secondary gammas produced by $(n,\gamma)$ reactions on Cd foil placed around the electrolysis cell. Gamma-ray spectra were collected over 1 to 2 day intervals.

Approximately 10 experiments have been run to date, with the longest continuous charging time being 20 days. No positive results have been observed; upper limits to the D-D fusion reaction rate are $\sim 2 \times 10^{-21}$ and $\sim 3 \times 10^{-16}$ fusions/sec per D-D pair for neutron and x-ray measurements, respectively. Experiments are continuing and plans have been made to analyze the abundance and isotopic composition of helium in our Pd electrodes.

# ATTEMPT TO REPRODUCE COLD FUSION IN PEKING UNIVERSITY

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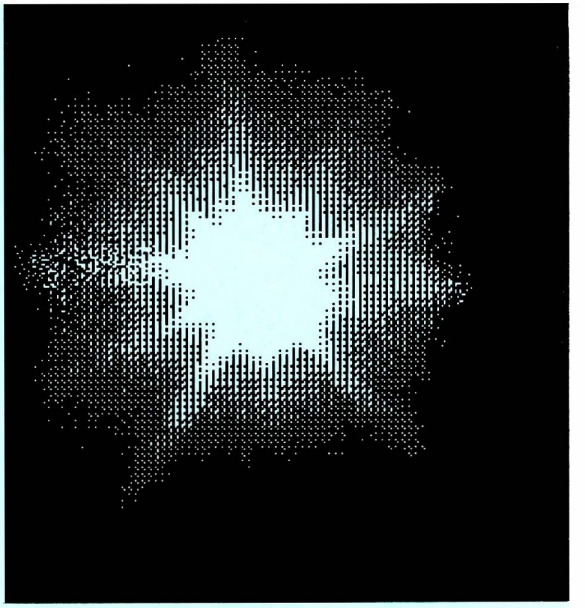
XL Wu, ZS Fu, XH Zhou, WJ Zhou, TW Wang, YH Wu,
VH Zong, and CC Wu

Peking university. Beijing 100871 PRC

A multidisciplinary research croup was set up at the beginning of April. 18 electrolytic cells with different conditions were tested. The cathode materials are Pd rods, foils, and bars in different sizes, and Ti rods, with or without pretreatment. Both high voltage-low current and low voltage-high current Modes were examined. 4 cells filled with light water were used as control. Electrolyses were usually lasted more than 100 hours in most test runs. The cells were detected with BF3 counters, liquid scintillation counters, NaI(TI) scintillation counters and thermometers. Tritium activities were also Measured in few oases. A BPS counting system was placed nearby to monitor the natural background. Following the claims of Italian Frascati research group, several runs on the system on Ti powder absorbing deuterium gas of 30 atm at 94 K have also been made. However, no conclusion has been drawn so far.

The rates of generation and accumulation of tritium in gas end liquid phases were measured. The T/D separation factor measured was 2.6 for Pd sheet electrode with bright surface and 2.0 for electrode of Pd black.



# APPLICABLE ELECTROCHEMISTRY

# Cold Fusion - The Heat Mechanism

Ali F. AbuTaha, Reston, VA

## ABSTRACT

A fundamental, and classically explainable, mechanism of heat generation was neglected in the recently reported experiments of Professors Martin Fleischmann and Stanley Pons. This is the release of stored strain energy which can be discharged during the propagation of ~~fractures~~ cracks in the palladium bulk. Hydrogen and deuterium are known to induce and propagate cracks in metals and alloys, including Pd. The maximum amount of heat possible from a typical Pd electrode is shown to be of the order of magnitude of the reported excess heat content.

## INTRODUCTION

Experiments by Stanley Pons and Martin Fleischmann (1) demonstrated that excess heat can be generated from Pd-D cells at room temperature. Some centers in the United States and abroad, were able to reproduce the excess heat, while other centers were not. While the heat generation appears to be real, the proposed fusion reaction is not so clear. Neutron counts, tritium, helium, and other fusion by-products were variable, inconsistent with theory, or non-existent. Anyway, the mechanism responsible for the heat generation has not yet been identified.

This matter may be resolved by classical means, recognizing that the "system" used in the Pons-Fleischmann experiments was not a truly closed system. Interaction with the external environment was hidden, albeit accidentally; and this was the source of the paradox. The

# AN EXPLANATION OF APPARENT HEAT GENERATION IN COLD FUSION EXPERIMENTS

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In recently publicized results of cold fusion experiments exceptionally high heating was reported that was attributed to nuclear reactions. To investigate mechanisms that may contribute to that observation, a series of experiments similar to ones conducted at the University of Utah was performed at the Idaho National Engineering Laboratory (INEL). Ordinary water, heavy water, and a mixture of the two were used in the INEL experiments. Cathodes used included a 51-$\mu$m Pd foil and 1-mm diameter Pd rods in various configurations. Energy balances in these experiments revealed that although some of the required voltage for cell operation is due to back-emf associated with reversible processes, irreversibilities associated with dissipation in the electrolyte are not negligible. Phenomena observed include activation energy and concentration polarization effects, the electrical resistivity of the electrolyte, and the sensitivity of that resistivity to temperature. Water addition requirements imply that effectively none of the gases produced in electrolysis recombine inside the test cell. Comparison of the manifestations of these effects in the INEL experiments with available excess heat data from the University of Utah experiments shows that the irreversibilities present are adequate to explain the observation of excess heating reported.

Work supported in part by U.S. Department of Energy, Director of Energy Research, Office of Fusion Energy under DOE Contract No. DE-AC07-76ID01570.

# ENHANCEMENT OF COLD FUSION REACTION RATES

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Although major controversy still remains as to the source of the majority of the thermal energy reported from cold fusion experiments, considerable evidence does exist that low-level hydrogen isotope fusion reactions are occurring based upon neutron and gamma ray emission observations. This paper will investigate those potential methodologies which might enhance these low fusion reaction rates and increase specific thermal energy output.

The principal component of primary interest in an electrolytic cold fusion cell is the cathode where the isotopic hydrogen is loaded via electrolysis of the electrolyte into the electrode for volumetric diffusion into the lattice. Cathode surface characteristics such a purity and lattice cell orientation are known to be essential for maximum hydrogen loading. The geometrical size and configuration of the cathode and the crystalline grain size and conditioning are important. Other cathode metals (besides palladium) and their alloys may be of interest. The composition of the electrolyte and possibly pulsed electrolysis as well as very high pressure and temperature (above the critical point for the electrolyte) operation may also enhance energy output.

# THE PREPARATION OF PALLADIUM FOR COLD FUSION EXPERIMENTS

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## ABSTRACT

Techniques have been established to prepare palladium specimens for cold fusion experiments using an ultra-high-vacuum, all-metal, high-temperature furnace to melt palladium metal in high purity alumina molds having a test tube shape. To date 6-mm and 15-mm cylinders have been fabricated, the latter being used to fabricate a sphere 12.5-mm in diameter. Techniques and facilities used for palladium-hydrogen isotope pressure-volume-temperature measurements[1-4] have been used to anneal these palladium specimens after machining and, in some cases, to charge these specimens with deuterium to $PdD_{0.6}$ stoichiometry prior to their use in electrochemical cells. The modeling of palladium-hydrogen isotope pressure-composition-temperature curves is described wherein existing data[5,6] is used to derive models that accurately describe the existing data and that extrapolate to high compositions.

## References

1. Lasser R. and Powell G. L., Phys. Rev. B 34, 578 (1986).
2. Lasser R. and Powell G. L., in "Hydrogen in Disordered and Amorphous Solids", edited by G. Bambakis and R. C. Bowman, Plenum, New York, 387 (1986).
3. Lasser R. and Powell G. L., J. Less-Common Met. 130, 387 (1987).
4. Lasser R. and Powell G. L., Fusion Technology, 14, 695 (1988).
5. Lasser, R., Meuffels, P. and Feenstra, R., "Databank der Loslichkeiten der Wasserstoffisotope Protium (H), Deuterium (D), und Tritium (T) in den Metallen V, Nb, Ta, Pd und den Legierungen $V_{1-x}Nb_x$, $V_{1-x}Ta_x$, $Nb_{1-x}Mo_x$, $Pd_{1-x}Ag_x$", Kernforschungsanlage, Jülich, Jül-2183, 1988.
6. Powell, G. L. and Lasser, R., "Solubility of Hydrogen, Deuterium, and Tritium in Palladium Metal, Oak Ridge Y-12 Plant, Oak Ridge, Y-2395, (1988)

# Properties of Heavy Water and Hydrogen Isotopes Relative to Cold Fusion

by

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Heavy water ($D_2O$) is a substance not normally used by most chemists and physicists. Since it is very hygroscopic, $D_2O$ must be handled very carefully if high purity is to be maintained. Data will be presented shewing the rate of exchange with normal water. Properties of $D_2O$ will be presented as well as a discussion of analytical techniques. Also presented will be information on H-D-T mixtures, isotopic equilibria, analytical techniques, etc. Radiological properties of tritium will be discussed.

# IN SITU EXAFS INVESTIGATION OF THE ELECTROCHEMICAL FORMATION OF $PdH_x$ and $PdD_x$

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We have conducted the Fleischmann and Pons (1) experiment in an x-ray transparent cell with a Pt anode and a 12.5 um thick x 3 $cm^2$ Pd cathode in 0.1 N LiOH electrolyte. Rapid scans (1 min.) of the Pd K-edge EXAFS were obtained during electrolysis on the ROMO 1 beam line at HASYLAB. The intent of the experiment was to determine the effect of electrochemical overvoltage on the Pd lattice in $H_2O$ and $D_2O$. The well-known progressive expansion of the Pd lattice (2) during charging with H or D is graphically evident in the overplots of the EXAFS shown in Fig. 1. Our estimate of the final H content of the Pd was $PdH_x$ where x = 0.77 from the lattice constant (2) and x = 0.80 by weight. $PdD_{0.72}$ was determined from the lattice constant (2) only because the sample lost weight so quickly on the balance pan that it was impossible to get an accurate weight. Electrolytic charging of H and D was done by applying 3 V at 7 $ma/cm^2$. Increasing the voltage progressively to 8 V and 100 $ma/cm^2$ did not change the lattice parameter although the lattice disorder decreased at the higher voltages. This can be interpreted as a stiffening of the lattice. Actual overvoltages at the Pd electrode were estimated by shutting off the cell and measuring the back emf, e. g., 0.7 V at 8 V applied.

Research supported in part by ONR for Greegor and Lytle.

1. M. Fleischmann and S. Pons, J. Electroanalyt. Chem. 261, 301 (1989).
2. J. Schirber and B. Morosin, Phys. Rev. B12, 117 (1975).

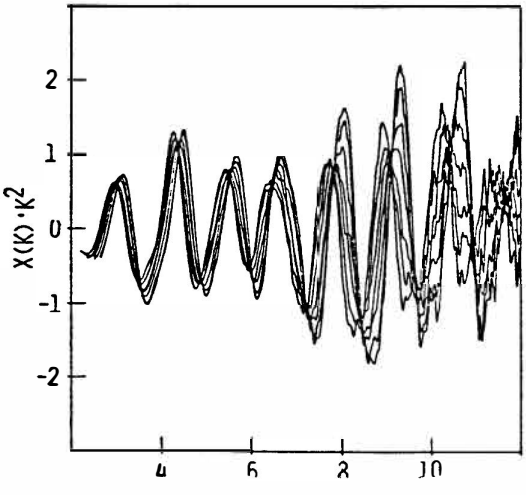
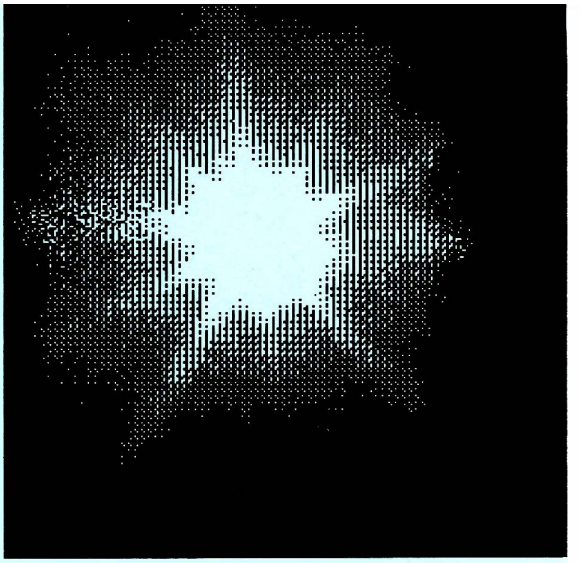



Fig. 1. Overplots of Pd EXAFS during electrolysis of $D_2O$.



# APPLICABLE CONDENSED-MATTER PHYSICS

# On the Determination of Fusion Rates of Light Nuclei Imbedded in Solids*

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The suggestion of the possibility of measurable fusion rates of deuterium and/or other light nuclei in a lattice of a material such as palladium and titanium has dramatically pointed out an area in fusion physics that needs further exploration; a credible means is needed for predicting fusion rates when fusible nuclei are packed at high density in solid-state materials. This current lack of understanding stems from a past lack of motivation for studying non-catalyzed cold fusion, from the difficulties in solving the relevant quantum mechanical many body problem, as well as from the modern trend of specialization of scientists since the questions of cold fusion cut across several disciplines-particularly condensed matter physics, nuclear physics, chemistry, and materials science. An important goal is the obtaining of quantitative values for the quantum mechanical tunneling probabilities for fusion reactions, which are strong functions of the spacing of the nuclei and the electronic screening of their coulomb fields the condensed matter environment.

The purpose of this paper is to assist in the solution of the problems at hand by (1) summarizing the status of some methods which can be used to attack the problem of obtaining theoretical predictions of nuclear fusion rates when the relevant nuclei are located in solid lattices, (2) discussing some present and possible future experiments which have the potential of obtaining the values of the parameters controlling such fusion rates.

We collect and delineate the fundamental assumptions and limitations associated with current related theoretical calculational techniques which may be used, in conjunction with experiments, for any future studies whose goal is the quantitative determination of the nuclear fusion rates of light nuclei imbedded in matter other than hot plasma.

# Design Consideration For Cold Nuclear Fusion Palladium Electrodes as Suggested by the Bush - Eagleton Theory for the Explanation of Cold Nuclear Fusion

by

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ABSTRACT: According to our theoretical model one of the essential elements for the occurrence of COLD NUCLEAR FUSION within palladium is the formation of sufficiently large deuteron globules within the octahedral lattice sites. There are several factors which affect the size, density, and rate of this deuteron globule formation. These factors are as follows: (1) Direction and magnitude of the electric field relative to crystalline lattice structure at the electrode surface and also within the interior, (2) the effect of diffusion barriers at all upstream palladium surfaces that are not immersed in the electrolyte and which are not exposed to a sufficiently large electric field, (3) local crystalline temperature excursions that are associated with the fusion events, and (4) the various deuterium diffusion mechanisms within the crystal which are associated with thermal gradients, deuterium concentration gradients, and externally generated potential field gradients that can enhance interstitial quantum mechanical tunneling along the direction of the associated internal electric field.

# Nuclear Fusion in Host Lattices Discussed by the Model of a Nondegenerate Positive Hydrogen Isotope Ion Gas

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The reported results of the cold nuclear fusion in electrolytic cells with palladium and similar cathodes is explained by a model of the states of electrons and ions of the hydrogen isotopes in the host lattice using the following concepts: the electrons are more locally bound to states of unfilled shells with stronger energetic levels while the positive ions consist in a nearly ideal non-degenerate gas of plasma of very high density but relatively low temperature. Arguments for this model are the quantum theory of compressibility, including the electrostatic atom model, and measured electric conductivities. Such a model is of basic interest independently of whether or not fusion reactions are produced. It is based - contrary to the very numerous chemistry papers about hydrogen incorporation - on basic solid state and plasma physics concepts. The fact that disappointingly low levels of fusion energy released have been reported in the measurements (other than the unexplained heat producing reaction) is discussed and conditions that may permit a drastic increase of energy production (up to a level of about a kW per liter) at other temperatures as long as the conditions of the host lattice or liquid are maintained. Fusion reactions then occur in a fashion analogous to the volume ignition model for ICF, and should provide a modest bootstrapping effect. Even if this is very difficult to achieve, some increase in reaction rate would be realised. However, only small scale energy generation can be expected, on the scale of solar energy densities compared with more concentrated power production from other fusion concepts.

# Equilibrium Atomic Structure of Hydrogen in Ti Lattice: Pseudopotential Density-Functional Total-Energy Approach

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The atomic configuration of a pair of H atoms in a hcp Ti lattice is investigated by means of first-principles pseudo-potential total-energy calculations based on a local-density approximation for density functional theory. The *s* and *d* valence-electron wavefunctions in this system are expanded in a recently derived *optimized* mixed-basis set which allows self-consistent state-of-the-art pseudopotential calculations on the 3*d* transition metals. In the present study, we consider two different atomic geometries: (1) a pair of H atoms occupying an octahedral interstitial site, and (2) two H atoms occupying a pair of neighboring tetrahedral sites with one H per site. In both cases, the given unit cell structure is assumed to repeat over the crystal (i.e., we study a pair of H atoms in a limit of Ti-hydride). We find the equilibrium H-H distance is 1.6 Å(case 1) and 1.4 Å(case 2), both of which are much larger than that of the $H_2$ molecule (0.7 Å).

# Limits of Chemical Effects on Cold Fusion

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Tunneling-induced cold fusion—enhanced by chemical confinement of deuterons—has been widely touted as an explanation of recent reports of the production of neutrons and excess heat in electrochemically-generated metal deuterides. We have carried out an extensive set of model calculations to determine the effective interaction between deuterons in palladium, using a broad range of established techniques. Embedded-atom method calculations on bulk systems were used to study the interaction between two deuterons in the neighborhood of the octahedral and tetrahedral interstitial sites in the palladium lattice. Accurate first-principles local-density-functional and *ab initio* quantum chemical techniques were used to study the energetics of deuterons in model palladium clusters up to $Pd_6D_2$. At scales ranging from 0.1 to 1.0 Å no effects are found to suggest that the effective interaction between deuterons in palladium is significantly reduced from that of gas-phase $D_2$. Our results show that molecular $D_2$ in palladium should dissociate to distances of the order of 1.0 Å or greater even in lattices with $PdD_2$ stoichiometry. Implications of these results to possible models of cold fusion in metal lattices will be discussed.

# Chemical Forces Associated with Deuterium Confinement in Palladium

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## Abstract

First-principles and empirical methods are used to study the effective interaction between two deuterons in a palladium lattice. No effects are found to suggest confinement of deuterons at distances much smaller than the gas-phase $D_2$ separation.

# COLD NUCLEAR FUSION: EXOTIC QUASIATOMS ?

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It appears that solid-state effects cannot enhance the cold nuclear fusion rate enough in order to account for the experimental observations as reported by Jones et al. and by Scaramuzzi et al. Therefore, we search for an alternative explanation in the possible formation of a quasiatom of deuterons orbiting a metal (Ti, Pd) nucleus. The calculations are performed in the framework of the phenomenological quantum-statistical Thomas-Fermi models for the screening. This model appears attractive since it does not require (i) the presence of a crystalline metal lattice (the mechanism should work just as well in a powder as in a metal) or (ii) invoking any heavy electrons from the conduction band to bind to the deuterons. (iii) Semiclassical considerations of the deuteron orbitals suggest that orientational effects within this model may cause significant deviations between different channels of the usual d + d fusion reaction rates. Finally, (iv) the exotic quasiatom structure should constitute a metastable state, thus possibly explaining the transient, nonequilibrium situation suggested for cold nuclear fusion catalyzed by quasiatom formation, rather than by condensed matter.

The relevance of the present quasiatom model could in principle be tested experimentally with help of electron-scattering experiments.

Hydrogen-Hydrogen Separation and Stability of the Palladium-Hydrogen System. A. C. SWITENDICK, Sandia National Laboratories*, Albuquerque, NM 871875--

I have calculated the total energy of the palladium-hydrogen ~~system as a~~ function of lattice constant. Occupying the octahedral site gives normally occuring PdH and the tetrahedral site gives hypothetical $PdH_2$. Both curves exhibit a minumum. PdH is more stable than $PdH_2$ by over 2.65eV relative to palladium metal and $H_2$ gas. The H-H separation is 2.88Å in PdH at a 5% palladium lattice expansion and 2.30Å in $PdH_2$ with a 13% further expansion of the palladium lattice. This is to be compared with a H-H spacing of 0.74Å in the hydrogen molecule.

Occupying both sites in the $BiF_3$ structure gives an increased H-H spacing at a further increase in energy. We see no evidence for the violation of the rule of a minimum H-H spacing of 2.1Å in stable hydride systems.[1]

[1] A. C. Switendick, Zeits. für Physicalische Chemie N. F. Bd117, 89-112(1979).

# PREDICTED INSTABILITY OF OCTAHEDRALLY-CENTERED DIATOMIC HYDROGEN IN PALLADIUM

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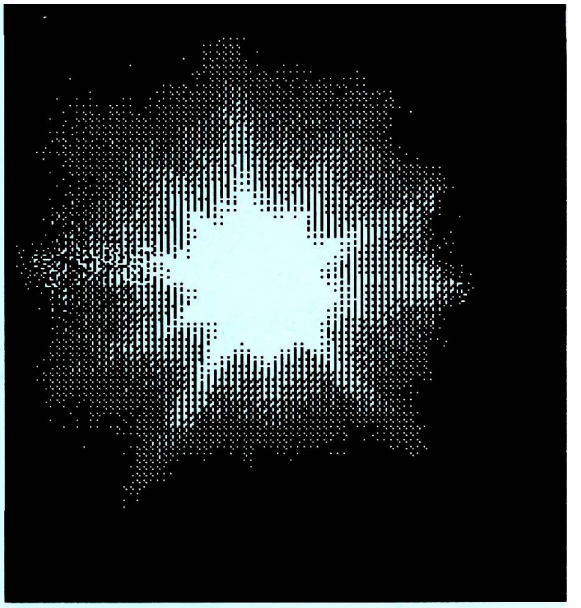
Both the vibrational wavefunction $\psi(R)$ of two hydrogens at a distance R [determining the fusion rate $A = A|\psi(R_c)|^2$] and the penetration factor B of their mutual barrier depend on the energy surface E(R) for diatomic hydrogen in Palladium. Current estimates for A and B have used the free-space form of E(R) of an isolated $H_2$ molecule. In an attempt to clarify some of the solid state aspects of the problem, we have used the first-principles self-consistent total energy method within the local density formalism (as implemented by the LAPW method) to predict the stability of various forms of hydrogen in fcc palladium. We find that: (1) the solution enthalpy of dilute octahedral H atom in Pd is negative [i.e., stable w.r.t. $Pd^{(s)} + 1/2\ H_2^{(g)}$], (2) likewise, octahedral H atom long-range-ordered phases of 1:1 and 1:0.5 Pd-H (in the NaCl and $I4_1/amd$ structures) are also stable (even stabler than the gas-phase PdH molecule), but (3) the octahedrally-centered $H_2$ molecule is unstable with respect to dissociation in the solid in either the (111), (001), or the (110) orientation. The basic picture that emerges is that such an $H_2$ molecule will spontaneously re-orient along (111) (the lowest energy of the three orientations), then separate into two hydrogens, each at a tetrahedral interstitial site (lower in energy by 1.88 eV/pair). This separated pair will subsequently drop into the yet lower energy octahedral sites (after surmounting an ~0.2 eV barrier for tetrahedral-to-octahedral displacement). Since bringing two isolated hydrogen atoms inside palladium to R=0.74 Å costs~ 2 eV (it releases ~ 4.5 eV in free-space), such molecules will not fuse under equilibrium condition.



# PHYSICS OF FUSION REACTIONS

# Cold Nuclear Fusion: A Hypothetical Model to Probe an Elusive Phenomenon

by

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ABSTRACT: A semi-empirical power law, which is based upon a "symmetry force catalyzation" of cold nuclear fusion, is presented. While it does not prove that Fleischmann and Pons, or others, have observed cold nuclear fusion in metals, it is very suggestive in accounting for the power yields of Fleischmann and Pons, and of Jones. Nuclear reaction and "anomalous" yields of tritium, He3, neutrons, and x-rays are accounted for in terms of the time evolution of the number of deuterons in a fusion center. Heat production is associated with the reaction of two d's to give He4. The production of heat and all nuclear products is predicted to be "pulsed". Finally, additional hypotheses for the role of the symmetry force in physics are set forth.

**DEUTERON TUNNELING AT ELECTRON-VOLT ENERGIES**

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A new mechanism is proposed to explain how d-d fusion reactions might take place at electron-volt energies.*[1]* We examine the spin dependence of the tunneling process, and specifically the possibility that the two deuterons form a $0^+$ combined state. It is shown that fusion should then occur principally via an electron-conversion process such that the combined d+d state becomes an energy level of $^4$He, with the excess energy transferred to an atomic or conduction electron. There would be two reactions: (1) $d + d + e^- \rightarrow {}^4He$(ground state)$+ e^-$ (K= 23.8 MeV), and (2) $d + d + e^- \rightarrow {}^4He$(20.1 MeV state)$+ e^-$(K= 3.7 MeV). The second reaction is followed only by (3) $^4$He(20.1 MeV state) $\rightarrow {}^3H$(K= 0.08 MeV)+ $^1$H(K= 0.23 MeV) since the 20.1 MeV level is below the threshold for neutron emission. Assuming the same energy dependence applies here as for internal conversion, reactions (1) and (2) will have branching probabilities of 1% and 99%, respectively. Consequences of this theory are that cold $d + d + e^-$ fusion would lead to copious production of tritium, protium and energetic electrons, lesser quantities of $^4$He and $\gamma$-rays, and no neutrons.

*[1] G. S. Collins, J. W. Norbury, G. E. Tripard and J. S. Walker (submitted).*

Coulomb Assisted Cold Fusion, M. Danos, NIST. — Of the two possible lowest order Feynman tree graphs, the graph of Fig. 1(a) requires the fusing nuclei $m_2$ and $m_3$ to penetrate the Coulomb barrier utilizing only the small ($A^{-1}$) momenta $|\vec{t}|$ contained in the wave function $\psi_0(t)$ (thus Furry representation propagators required), while in Fig. 1(b) $m_2$ has already acquired the recoil momentum $|\vec{q}|$ (1 - 2 $fm^{-1}$) by Coulomb exchange with recoiling (lattice) nucleus $m_1$, which eliminates the penetration factor (plane wave propagators adequate).

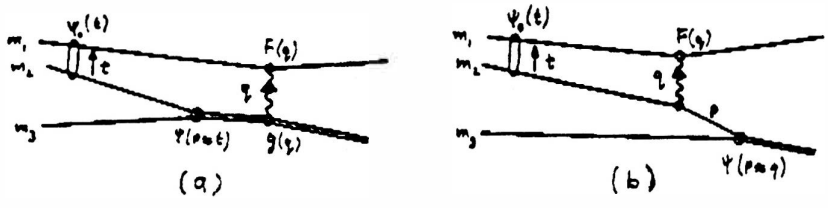


Fig. 1

In both cases $\psi_0(t)$ is the momentum space wave function for the (trapped) nucleus $m_2$; F(q), f(q), and g(q) are Coulomb form factors and $\psi(p)$ is the (half off-the-mass-shell) wave function of the final nucleus in the fusion channel. The matrix element (b) is about $10^{30}$ times larger than that of the usually assumed reaction graph (a), yielding a correspondingly larger fusion rate. Within a factor ~ $10^{\pm 3}$, reflecting the uncertainties associated primarily with estimating the effect of the unknown trapping wave function $\psi_0(t)$ the resulting dd fusion rates are for a fully loaded hydride ~ $10^{-10}$ (sec trap)$^{-1}$ and for HDO ~ $10^{-22}$ (sec molecule)$^{-1}$. The pd rates are $\gtrsim 10^3$ times faster than the dd rates.

# Can Cold Fusion of Deuterium in Palladium be Triggered by Muon Catalysis?

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According to Jones et al. fusion of deuterium occurs in palladium at a very low level. This may be muon-catalyzed fusion initiated by cosmic ray muons. A question arises whether muon-catalyzed fusion may under some circumstances be able to trigger much larger amounts of additional fusion. Several candidate mechanisms are considered. The only possibility appears to be cold fusion from implosion of an acoustic wave generated by the energy deposited near the ends of decay particle tracks. Some implications are discussed.

**Neutrons, Tritium, Heat and Metallurgy in The Fleischmann-Pons Effect**

by
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The neutron production at palladium electrodes heavily loaded with deuterium is related to the current density of deuterium evolution.

Tritium, produced in the solution surrounding such electrodes, is related to the potential production and to time.

It is found that heat produced is much more difficult to measure and its observation depends on the precise metallurgical background of the specimen. In some cases, heat in the order of 10 watts/cc can be measured.

A discussion is given of the effect of the stress near dislocations upon the internal concentration of D in Pd. The stress increases the local concentration by orders of magnitude. Edge dislocations are the likely locals of the reactions producing the affects concerned. Insofar as these are occupied by hydrogen, or other impurities, the electrodes concern will be inactive.

Super-pure palladium and electrodes which have been melted several times with attempts to allow H to escape may be the basis of observation of these effects.

# Dynamical Plasma Mechanisms for Enhancement of Fusion Rates in Metallic Hydrides and Deuterides.

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There exist several mechanisms for dynamical plasma enhancement of rates for fusion reactions such as $d + d \rightarrow t + p$ and $d + d \rightarrow {}^3He + n$ due to plasma oscillation wakes behind the recoiling nuclei: (1) Plasma wake potential: this can reach values of order 20 or 30 volts in a cylindrical region of radius ~10Å around the track[1], leading to fluctuation enhancement[2] of fusion rates. (2) Stimulated plasmon emission: Sequential fusions in the wake might lead to stimulated emission of subsequent wake plasmons. Enhanced population of these modes could lead to multiplasmon absorption by thermal deuterons in the wake region. Absorption of ~4 plasmons would lower the fusion barrier to ~0.125Å at which the fusion rate[3] is $\sim 10^{-23}$/sec. (3) Mechanism 2 might act in concert with statistical fluctuations or cosmic ray muon catalysis to produce fusion bursts, possibly explaining neutron bursts reported by the Frascatti group[4].

Preliminary estimates of enhancements due to these mechanisms will be presented.

1. Z. Vager and D. S. Gemmel, Phys. Rev. Lett. 37, 1352 5(1976).
2. S. E. Koonin, Phys. Rev. Lett, (submitted).
3. C. J. Horwitz, Phys. Rev. C (submitted).
4. De Ninno et al., Preprint, Centro Richerche Energia Frascatti.

# A POSSIBLE EXPLANATION OF THE ROOM TEMPERATURE NUCLEAR FUSION

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**ABSTRACT**

A POSSIBLE PHYSICAL MODEL WHJCH SEEMS TO CONFORM TO EXPERIMENTAL FACTS IS PROPOSED. DEUTERONS ABSORBED IN THE PALLADIUM LATTICE WOULD FORM A SUBLATTICE IN NON-EQUILIBRIUM STATE. THEY WOULD OSCILLATE VIGOROUSLY AND BE COUPLED NONLINEARLY THROUGH SEPARATE INTERACTIONS WITH THE PALLADIUM LATTICE. A COOPERATIVE EFFECT THUS INDUCED WOULD CAUSE DEUTERONS' ENERGIES TO CONCENTRATE ON A FEW OF THEM. THE LATTER WOULD BE ENERGETIC ENOUGH TO CAUSE APPRECIABLE NUCLEAR FUSIONS.

# BEYOND FUSION, ANNIHILATION REACTIONS OF CONFINED HYDROGEN

by
Prof. L. Carl Jensen
Assisted by
Dr. Kay S. Mortensen

A mechanism of how antineutrons can enter a region of confined hydrogen or deuterium and decay into antiprotons is given. An annihilation reaction of a proton and antiproton releases energy. This starts a series of deuterium fissions that increase the probability of annihilation reactions. The gamma rays produced lose momentum via radiation pressure vibrations of the surrounding confinement lattice. This constitutes a change of radiation energy to kinetic energy, exhibited as heating of the lattice material.

The deuterium fusions produce some 2.2 Mev gamma ray leakage. The gamma rays in the lattice dissipates energy within the lattice. The dissipation continues until the ray is lengthened to a wavelength that nearly matches the lattice size and can exit the material. This is 4.1 Å for Palladium and corresponds to a 3 Kev x-ray emission. Copyrights and patents applied for.

# LATTICE ALLOWED 4He FORMATION IN DEUTERIUM FUSION.

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**ABSTRACT.**

In condensed matter boundary conditions the possibility of nuclear reactions which could not be allowed in free space, for example 2D + 2D --- 4He, have a finite probability due to the recoil momentum of the lattice making up for overall momentum conservation. The theory parallels that of recoiless photo-emission in the Moessbauer effect from the point of view of the solid state effects. On the other hand the number of allowed final states is much larger than in the case of the standard free space reactions yielding 3He or 3H, as in fact we have a continuum of final states, therefore this reaction will be much more probable if the electronic structure of the solid allows it. It will also explain the difference of the observed reaction products when the cathode is either changed in chemical nature or in preparation procedure.

# New Cold Nuclear Fusion Theory and Experimental Tests*

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## ABSTRACT

A theory[1] of neutron-induced tritium-deuterium fusion at room temperatures is developed, based entirely on previously measured cross-sections of known nuclear reactions. The cold fusion process[2] involves self-sustaining chain reactions: (1) $n + {}^6Li \rightarrow {}^4He + T$, and (2) $T + D \rightarrow {}^4He + n$, in Li salts dissolved in a $D_2O/DTO/T_2O$ mixture. The theory predicts that the self-sustaining chain reaction, (1) $\rightarrow$ (2), can be achieved with and without the use of electrolysis[3,4]. The recent results of cold deuterium fusion reported by Fleischmann and Pons[3] are explained in terms of this process.[1] Theoretical fusion-rate estimates, experimental tests of the process, and basic designs of cold nuclear fusion reactors[2] for power generation, are described.

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1. Y.E. Kim, "Neutron-induced tritium-deuterium fusion in metal hydrides", Purdue Nuclear Theory Group Report PNTG-89-4 (April 14, 1989) submitted to Physics Letters B; Y.E. Kim, G.S. Chulick, and A. Tubis "Theoretical estimates of rates of controlled cold t-d fusion induced by neutrons", in preparation.

2. Patent application and claims filed on April 25, 1989.

3. M. Fleischmann and S. Pons, Journal of Electroanalytic Chemistry **261**, 301 (1989).

4. S.E. Jones, E.P. Palmer, J.B. Czirr, D.L. Decker, G.L. Jensen, J.M. Thorne, S.F. Taylor and J. Rafelski, Nature, April 1989.

# D-T COLD FUSION REACTION IN METAL HYDRIDES

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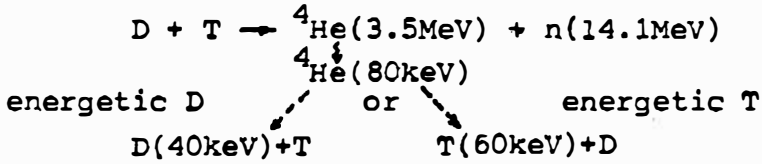
May 4, 1989

The DD reaction is initiated by muon capture or highly energetic charged particles. As discussed in a previous paper, it proceeds along one of the main channels: 1) D+D → T+p, T+D → $^4$He+n, 2) D+D → $^3$He+n, $^3$He+D → $^4$He+p. The energetic charged particles are slowed down by the atoms in the lattice to the Bohr orbital velocity, which corresponds to energies in the 20-80 keV range. The alpha particles can transfer momentum to the stationary D nuclei by elastic scattering. These D nuclei at energies in the range of 40 keV can fuse with the cold D in the lattice and in the absence of losses can result in a chain reaction. In practice, the loss is due to DD Rutherford scattering with a cross section exceeding 1 barn. It dominates the reaction cross section by 3 orders of magnitude. The D nuclei in the lattice effectively thermalize the energetic D nuclei. This may explain the extremely low neutron and energy output, as observed by Jones.

The picture changes dramatically in a D-T loaded metal hydride. Pd accepts T almost as well as D. The reaction chain is shown below.




The DT reaction cross section at 60 keV exceeds 1 barn and compares favorably with the Rutherford cross section in this energy range. The chances of sustaining a chain reaction in this case are much better.

An experiment with a DT loaded metal hydride is proposed. The loading can be done with gases at high pressures. The reaction can be initiated with a beam of fast deuterium nuclei.

The author is very grateful to Prof. H.Feshbach and Dr.S.Steadman for illuminating discussions and critical comments.

# DEUTERON DISINTEGRATION IN CONDENSED MEDIA

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## ABSTRACT

We discuss the Oppenheimer-Phillips process as a possible phenomenon leading to deuteron disintegration due to polarization in the Coulomb field of a target nucleus. This reaction may be possible in the context of electrochemichally compressed deuterons in a Palladium cathode. The process is highly exothermic and leads to neutron capture from deuterons into the Palladium isotopes, as well as between the deuterons themselves. In the last case, the equivalent of the proton branch of the D-D fusion reaction occurs in preference to the neutron branch. The process provides a possible explanation for the observed energy release, tritium production and neutron suppression in the Fleischmann and Pons experiment.

# Influence of Attractive Interaction between Deuterons in Pd on Nuclear Fusion

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It is shown that in a heavily deuterated palladium metal a pair of deuterons exhibit attractive interaction at short distance (≈ 0.1 Å - 0.7 Å) due to strong Coulomb correlations in the ion-sphere model and due to the screening action of localized 4d electrons. This mechanism leads to enhanced thermonuclear reactions at room temperatures some 50 orders of magnitude faster than that in a $D_2$ molecule. Characteristic signatures of predicted nuclear reactions are described.

# The Cold Fusion Rate of d-d in PdDx and the Branching Ratio of He-4 to the (p,n) Production Reaction

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The cold fusion rate of d-d in PdDx deuteride calculated by WKB approximation suggested that the value of the electron number piled up near the interstitial deutron multiplied by the effective mass of the electron should be about 5 and 10 for getting the fusion rates obtained in the experiments of Jones et al and Fleischmann et al.

The piling up this number of electrons from s and d conduction bands is impeded by the repulsive exchange coulomb interaction. To get a high fusion rate, the dynamical collective effect created by the stress accumulated by the presence of interstital deuterons might be required.

To obtain an appreciable rate of production of He-4 in the cold fusion condition (s wave incoming channel), a coherent auger-type ejection of electrons is required. Further, to get the extremely large branching ratio of He-4 production to p and n production, the energy of the electrons has to be dissipated by coherently exciting a large number of lattice vibration modes, eventhough PdDx deuteride itself has large electron phonon interaction in the large x value.

# Peregrinations on Cold Fusion*

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Over the past couple of months, it has become abundantly clear that the knowledge and paradigms acquired by several generations of physicists who have studied the interactions of accelerated particles are inadequate to account for the so-called "cold fusion" results claimed by the University of Utah researchers. Indeed, these results have engendered a high level of healthy skepticism in the physics community.

Now that the specter of cold fusion has again been raised,[1] I wish to list possible mechanisms worthy of investigation that might collectively substantiate what would otherwise seem to be such an ethereal prospect.

1. Screening of the deuteron Coulomb potential in a crystal lattice.

2. The tendency of bosons to condense in a crystal lattice.

3. The many-body aspects of an Avogadro number of room temperature deuterons fixed at interstitial lattice sites by a periodic potential.

4. Resonance effects in this periodic potential enhancing the transparency of the Coulomb barrier at certain deuteron energies leading to metastable states.

Although others, no doubt, have also been exploring mechanisms #1 and #2, I would like to emphasize that #4 is a mechanism that I have just stumbled upon and whose exploration I wish to encourage.

A serious research effort on cold fusion requires an interdisciplinary team of chemists and physicists (nuclear, solid-state, many-body, and plasma).

A properly hewn theory requires decent experimental data exhibiting the phenomenon of cold fusion.

1. F. Paneth and K. Peters, *Die Naturwissenschaften* **43**, 956 (1926).

# A (Slightly Revised) Simple Model for Coherent DD Fusion in the Presence of a Lattice

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## ABSTRACT

A highly speculative but simple model for $DD \longrightarrow^4 He$ fusion in the presence of a lattice is proposed. Within this model, neutron and tritium reactions are supressed due to coherence, and energy extraction occurs from virtual states in which many fusions have occured. The matrix element for the coherent process is derived from electromagnetic coupling in a three-body process, in which two of the bodies are initially deuterons, and the third body is an electron (or electron coupled to a lattice).

# Towards a Theoretical Understanding of Cold Fusion: Deuterium Bose Clusters in Lattice Defects.

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Our previous study of thermal equilibrium fusion rates with different parameters have lead us to conclusion that Jones-like cold fusion experiments can only be explained by non thermal equilibrium processes. Our opinion is that there are two different type of processes leading to the observed fusion rates: (i) the deuteron scattering on a deuterium Bose cluster, produced by steady state flow, leading to a steady neutron signal, (ii) the stress induced collapse of the cavity containing clustered deuterons leading to hot spots of microplasma and 'hot' fusion, giving as one of the products neutron bursts. Here we address the case (i).

We show that large 'metal like' aggregates of deuterons can exist in the lattice cavities or Schottky defects. Such droplets consist mostly of deuterons but we consider a possibility of a small number of protons to be present as well. In our model the electrons are treated statistically in a manner similar to the Thomas-Fermi description, while a deuteron condensate wave function is determined by the single particle Schrödinger equation. The deuteron-deuteron interaction (similarly deuteron-proton) is assumed to be screened by electron fluctuations. Our self-consistent calculations show that large deuteron densities can be reached within the droplet, and they are very dependent on the value of the screening parameter. Specific results of our work will be presented.

# Deviations from Maxwell Velocity Distributions in Equilibrated Inhomogeneous Fluids

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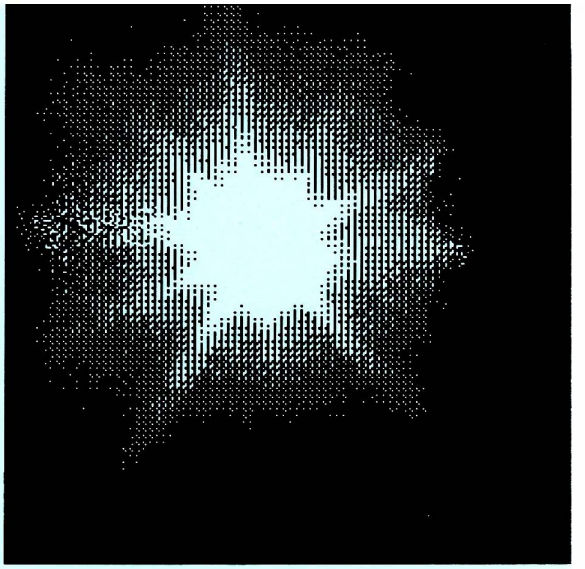
## Abstract

Determining velocity distribution functions for ensembles is one of the most fundamental problems in statistical mechanics. In this paper, using computer molecular dynamics (MD) methods, we demonstrate that the velocity distribution of a classical particle subjected to a strong time-independent force field in an inertial heat bath is generally noncanonical. When the system reaches equilibrium, a non-Maxwellian distribution persists for velocity components along the field direction.

**Fusion Rates for Hydrogen Isotopic Molecules of Relevance for Cold Fusion*** K. SZALEWICZ, J.D. MORGAN III: U. Delaware; H.J. MONKHORST: U. Florida. — In response to the recent announcements of evidence for room-temperature fusion in the electrolysis of $D_2O$, we have analyzed how the fusion rate depends on several factors, including the reduced mass of the fusing nuclei and the degree of vibrational excitation. Calculations have been performed within the adiabatic approximation employing an accurate Born-Oppenheimer potential energy curve and including the adiabatic and relativistic corrections. We have also used the WKB model which displays the essence of these factors. Our results predict fusion rates for the ground vibrational states up to 14 orders of magnitude larger than previously estimated and exhibit a strong dependence of the Coulomb barrier penetration factor on the reduced mass of the pair of nucleons. We have found that fusion out of vibrationally excited states is enhanced by several orders of magnitude, which may be of particular significance in light of the experimental evidence for the importance of non-equilibrium conditions. To assist in the investigation of whether a 'heavy' electron arising from complicated collective solid-state effects could play a role in the enhanced fusion rates seen in the experiments, we study how the Coulomb barrier penetration factor depends on the mass of a hypothetical particle (or quasi-particle) of charge -1. We examine the issue of whether the excess heat observed in one of the experiments could arise from the aneutronic fusion reaction $p + d = {}^3He + \gamma$. We find that under the conditions implied by the measurements of the neutron flux from the reaction $d + d = {}^3He + n$, it is unlikely that the excess heat observed by one of the groups could arise from $p + d$ fusion.

*Supported by the Division of Advanced Energy Projects, DOE.



# NEUTRON AND GAMMA-RAY SPECTROSCOPY

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We have performed an experiment similar to the one performed in Frascati by F. Scaramuzzi et al. with the intention of ascertaining their results relative to neutron emission from a Titanium-Deuterium system. Deuterium was absorbed into 2 g of Titanium dust placed in a 3 $cm^{-3}$ cylindrical inox receptacle which was then subjected to thermal shocks by dipping it in liquid Nitrogen, liquid Helium, and the application of heat pulses. Neutron emission detection was attempted.

Titanium dust treated in the usual manner, i.e. heating in vacuum for 14 hours at 900 C, was placed in the inox receptacle end air was evacuated before injecting Deuterium at an initial pressure of 150 bar. The receptacle was then heated to 500 C for 8 hours (in order to increase the absorption rate) and cooled down slowly to ambient temperature. About 0.08 g of Deuterium were absorbed (4%).

Several experiments using different methods to cool the receptacle were performed: a) sudden lowering of the temperature to 77 K; b) sudden lowering in two stages (to 77 k and then to 4.2 K) followed by application of heat pulses by means of an heating winding; and c) sudden lowering of the temperature to 77 K followed by an evacuation of the receptacle. All these runs were at least 20 hours long and in none of them any significant neutron emission above background (1-2 counts per hour) level was detected.

Nuclear Measurements for Cold-Fusion Experiments. R. E. Anderson, R. D. Bolton, K. B. Butterfield, C. A. Goulding, M. W. Johnson, and E. M. Leonard, Los Alamos National Laboratory, Los Alamos, NM 87545. A wide range of nuclear measurements have been performed in support of cold-fusion experiments at Los Alamos, including high- and low-resolution gamma-ray spectroscopy; integral neutron counting with well detectors and banks of $^3$He tubes; and neutron spectroscopy with NE-213 scintillators. Experiments included automated data acquisition for all measurement techniques. Results, including data both from electrochemical cells and background measurements, will be presented for all techniques. A discussion of sources of background neutron and gamma-ray events will also be presented, focusing on certain less usual sources of background (such as 2.223-MeV gamma rays resulting from interaction of background neutrons with hydrogen in the large neutron well counters), and on diurnal and other predictable variations in background counting rates.

# SEARCH FOR COLD FUSION IN PLASMA-CHARGED Pd-D AND Ti-D SYSTEMS

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**ABSTRACT**

To investigate whether cold fusion of deuterium (D) can occur in solid Pd and Ti as proposed recently, we have searched for the D-D fusion reaction in plasma-charged Pd-D and Ti-D. A DC glow-discharge was established in a deuterium gas (pressure 1-5 torr) between two water-cooled electrodes in a small reaction cell. The Pd or Ti sample was placed on the cathode, and the DC voltage across the plasma varied between 200 and 400 V. A thin (100 Å) Cu film was evaporated on the Pd samples to establish a barrier preventing the escape of D from the Pd samples. Various Pd samples were investigated, an evaporated 1 μm thick Pd foil, a commercial, cold-worked 25 μm thick Pd foil, and Pd single crystals.

Neutrons were detected with an NE213 liquid scintillator (5" diameter and 2" thick, intrinsic efficiency 20%). The conventional pulse-shape discrimination technique was employed to separate gamma counts from neutron counts. The detection efficiency for neutrons in the sample geometry was 3%, as determined with an AmBe neutron source. In the energy spectrum, the interest was focussed on the region where the 2.5 MeV neutrons from the D-D reaction was expected. In the laboratory two floors below ground level, the background counting rate in the neutron window was about 0.01 counts/sec.

The samples were charged with deuterium during the measurements, which continued for periods up to two weeks. No indication of a neutron count rate in excess of the natural background level was observed.

In parallel, we tried to reproduce the electrolytical-charging experiment of Pons and Fleischmann with a Pd single crystal (approximately 0.2 $cm^3$), a Pt anode, and a solution of 0.1 M LiOD in $D_2O$ (99.5% pure). Again, the observed neutron count rate did not deviate from the background level.

# Measurements of Gamma-Ray Spectra and Neutron Fluxes in Pons' Laboratory at the University of Utah

K. Crawford [1], W. Delaney [2], C. Henderson [1], M.H. Salamon [2], G. Sandquist [1], and M.E. Wrenn [3]

[1] Nuclear Engineering, [2] Physics Department, [3] Environmental Radiation and Toxicology Lab; University of Utah

We present results of gamma ray spectroscopy and flux measurements of fast and thermal neutrons performed near an operating Pd-D2O cell in Pons' laboratory at the University of Utah. Gamma ray spectra were collected with an 8" diam x 4" NaI:Tl crystal, of resolution ~ 10%/sqrt(E). Both fast and thermal neutron fluxes were measured using plastic nuclear track detectors (Cronar and Lexan) sandwiched around foils of enriched U-235 (the plastic films detect neutron-induced fission fragments); half of these were shielded by Cd to provide separate fast and thermal neutron data. An independent measure of the combined fast and thermal neutron flux has been obtained from an activation analysis using In-115 foils, counted on a 50 cc intrinsic Ge detector. Finally, we describe a neutron spectrometer (BC501 liquid scintillator with pulse shape discrimination) that will shortly be operating in Pons' lab.

# A Neutron Coincidence Calorimeter

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and Gary L. Jensen, Brigham Young Univ., Provo, Utah

Abstract: We have developed a spectrometer for MeV neutrons that relies upon total energy absorption to measure neutron energy. A coincidence signal is required from the capture of thermalized neutrons in Li-6 glass scintillators incorporated in the detector body. This dual signal from a single neutron provides a powerful means of discrimination against background events arising either from gamma rays or from ambient, low-energy neutrons. The spectrometer is particularly useful in situations in which the neutron source intensity is very low.

# A Search for Neutrons From Fusion in a Highly Deuterated Cooled Palladium Thin Film

by

Thomas G. Dignan, Mark C. Bruington, Robert T. Johnson, and Roger W. Bland

We have carried out an experiment to search for neutrons released from a thin film of Pd-10%Ir. A film of thickness ≈2000Å was prepared by sputtering. The film was then cooled to 77K, and was charged with deuterons by low-energy ion implantation, to a stochionietry of approximately $PdD_5$. Deuterium was incident on the film as neutral D and $D_2$ with a kinetic energy of 1000 eV. Paraffin was used as a neutron moderator and absorber, with a NaI detector to observe the 2.22-MeV γ-ray expected from neutron capture by hydrogen neuclei.

We observed fewer than 25 2.226-MeV gamma rays over a period of one hours, corresponding to a limit of fewer than 35 neutrons produced per second, from the $10^{21}$ deuterons in the film. We also place a limit during this period of fewer than ten 23.8-MeV γ-rays (from fusion producing $^4$He). Our limit on neutron production is well above the rate observed in electrolysis experiments. The high deuteron density and high implantation energy might however have produced an elevated rate of fusion in our sample. Evidently this did not occur.

# Neutrons from Cold Fusion?

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At the Niels Bohr Institute in Copenhagen we have set up sensitive neutron detection equipment to look at electrolysis cells after the prescription of Jones and of Pons and Fleischmann. The neutron detectors are two 3 l liquid scintillator detectors with pulse-shape discrimination. Our sensitivity is about a factor of 10 better than Jones but until now at this sensitivity our result is zero. We are now also investigating the titanium deuterium gas system described by the ENEA group at Frascati, Italy. Other experiments in Denmark will be mentioned.

## ABSTRACT

**High-Sensitivity Neutron Detectors Used at Sandia Laboratories to Monitor Cold Fusion Cells,** by Ronald I. Ewing, Sandia National Laboratories, Albuquerque, New Mexico.

High-sensitivity neutron detectors have been set up adjacent to several cold fusion experiments at Sandia since April 14, and none of the detectors has indicated any neutron emission above normal background levels. The detectors consist of eleven helium-3 thermal neutron detection tubes imbedded in a polyethylene moderator slab covered with cadmium. Each detector was calibrated in situ by placing a californium-252 neutron source of known intensity at the location of the test cells. The detectors are sufficiently sensitive that a source of fusion neutrons emitting 10 neutrons per second (corresponding to a fusion energy release rate of about $10^{-11}$ watts) would produce a 25 percent increase over the background counting rate, which is 2 counts per second. These detectors are several thousand times as sensitive to fusion neutrons as the "Bonner sphere" neutron dosimeters, and are capable of neutron energy discrimination using ratio techniques. The detectors indicate a small diurnal variation ($\pm$4%) due to the variation of the cosmic-ray induced background, and have detected the presence of people working around the cells due to the neutron attenuation of the human body. Several other detectors are also being considered for use in these studies.

# EXPERIMENTS IN INC DIVISION AT LOS ALAMOS RELATED TO COLD FUSION

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In INC-Division at Los Alamos, we have considered several experiments aimed mainly at verification that electrochemically induced nuclear processes can actually occur. We felt, from the onset, that the most convincing signal for nuclear processes would be the production of neutrons and have taken on the task of designing and executing several experiments to detect neutrons.

Several electrochemical experiments have been run using electrodes of Ti and Pd. Both normal and precharged electrodes have been investigated. To date these experiments have all yielded negative results for the emission of neutrons or Pd X-rays. No heat measurements have been made on these cells.

Since the fusion rate reported by Jones at BYU is very low, we felt one way to improve the chances for unambiguous detection would be to switch to the D-T fusion system and we have run one experiment in which we used a Ti cathode that was precharged with tritium. Again, there has been no emission of neutrons.

In view of the recent results from groups in Italy who have reported the emission of neutrons from systems containing Ti and deuterium, we have initiated a series of experiments to verify those results. In these experiments, we have observed a number of anomalous counting events and now feel that we have observed some emission of neutrons from these experiments.

# EXPLORATION OF THE POSSIBILITY OF STRAIN OR FRACTURING PROCESSES AS A MECHANISM FOR NUCLEAR FUSION IN METAL DEUTERIDES

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A series of experiments has been carried out with titanium metal in contact with various pressures of $D_2$ gas or prepared titanium deuteride in which the samples have been thermally cycled and observed for neutron emission. For the series of experiments with titanium metal in contact with $D_2$ gas, several forms of Ti were investigated including sponge, sponge crystals, metal turnings, porous Ti previously used as an electrode in a Jones-type electrochemical cell, and small pieces of sheet metal; gas pressures ranged between 6 and 100 atm. Thermal cycling was carried out between LN and room temperature, in most cases. Correlated neutron emission bursts have been observed on four occasions, during the warming cycle, for two different samples containing mixes of metal types. Experiments in which samples were heated above the phase boundary at 300° C have also been performed. Metal samples deuterided at 550 °C have been examined under similar conditions.

Experiments are currently underway at WSU in which predeuterided Ti samples are subjected to mechanical stress and examined for particle emission. To date, both negative and positive particle emission have been detected accompanying and following fracture, indicating non-metallic excitation of several eV energy and very likely the occurrence of charge separation across the fracture. A series of gas gun experiments, in which $TiD_x$ will be fractured and examined for tribo-luminescence and neutron emission, is in an early stage of development.

The nature of the neutron emission is consistent with a fracturing or strain mechanism that could conceivable result in either cold or hot fusion.

Cold Fusion Neutron Measurements at ORNL. D.P. HUTCHINSON, R.K. RICHARDS, C.A. BENNETT, C.C. HAVENER, C.H. MA, F.G. PEREY, R.R. SPENCER, J.K. DICKENS, B.D. ROONEY, ORNL,* J. BULLOCK IV, and G.L. POWELL, Y-12 Development–A number of experiments were begun on 29 March 1989 to look for neutron emission from a palladium cathode in an electrolytic cell using a deuterated electrolyte. Several different electrode configurations were tried. The fast neutron detector utilized a pair of NE213 scintillator/photomultiplier pairs in a shielded enclosure. This neutron detector has an efficiency of 13% and records a background count rate of 200 events per hour. At present no neutron counts above the background level have been detected.

*Operated by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy under contract No. DE-AC05-84OR21400.

# NEUTRON/GAMMA-RAY IMAGING OF FUSION SOURCES

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Established techniques for imaging intense nuclear fission and fusion sources via the emitted or related neutrons and gamma rays could be adapted for less intense (but longer temporal duration) fusion sources. The relaxation of temporal resolution requirements from the nanosecond or millisecond regime to the kilosecond regime may allow spatially-resolved imaging of a cold fusion source emitting ~$10^4$ n/s for one hour. Additionally, one would anticipate that d-t reactions at a comparable fusion rate as the reported[1] d-d rate would generate several orders of magnitude more neutrons so that smaller temporal and spatial samples could be utilized.

Key components of the system would be a thick pinslit aperture or a multi-channel collimator, a sensitive inorganic radiation converter screen, a peltier-cooled charge-coupled device (CCD) video camera, and a microcomputer-based data acquisition system. The newly developed camera has such low thermal noise that data can be integrated on the CCD sensor for up to 90 minutes. Directional information could confirm that the "cold fusion cell" is the source of the ionizing radiation. Also, if source strengths were sufficient, identification of the location within the cell or along the Pd rod axis might eventually be possible. Such information may be useful in monitoring larger-scale devices and for safety aspects. The imaging technique would be complemented by an energy-resolving neutron detector located just behind the converter screen. Lead and borated-paraffin absorbers could be used to strongly attenuate low-energy x rays and thermal neutrons, respectively, at the entrance of the aperture.

Samples of previous nuclear radiation source images and the scaling to less intense sources will be presented.

## Reference

1. M. Fleischmann, S. Pons, and M. Hawkins "Electrochemically Induced Nuclear Fusion of Deuterium," J. Electronanal. Chem. 261, p. 301-308, (1989).

# SEARCH FOR NEUTRONS, GAMMA-RAYS, PROTONS, BETA-PARTICLES, X-RAYS, TRITIUM ASSOCIATED WITH COLD FUSION IN DEUTERIDED METALS*

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In a search for cold fusion of hydrogen isotopes in electrolytically deuterided metals, no significant statistical deviation of either neutron, proton, beta-particle, x-ray, or gamma-ray emission above the background have been observed. By suppressing the background with shielding and cosmic ray veto counters, the rate of cold fusion of d+d has been measured to be less than that which would correspond to the measured background which is at a level of less than $10^{-25}$ fusions/atom pair/sec (1), a factor of approximately 100 below the yield reported by Jones et al. It has also been determined that the occurrence of cold fusion of p+d, which has recently been estimated to be eight orders of magnitude larger than the d+d reaction, does not exceed $10^{-22}$ fusions/atom pair/sec in our electrolytic cells.

The detection of fast neutrons was achieved with an array of six liquid scintillation counters (~1% efficient) (Yale-BNL collaboration), as well as an array of 24 $BF_3$ counters (~14% efficient) at BNL. All systems were well shielded from background and utilized cosmic ray veto detectors. Cosmic rays have been observed to produce neutrons. A Si surface barrier detector was used to detect energetic charged particles and x-rays. The gamma rays were detected with a 12.5 cm NaI(Tl) detectors. Electrolytic cells employing Pd or Ti cathodes in the form of thick rods or foils were used in electrolytes based on those used in previously reported experiments by Jones et al. and Fleischmann, Pons, and Hawkins. The Pd electrodes were cold worked or annealed in vacuum or argon, one electrode was predeuterided, and various surface treatments were carried out. The metals were electrochemically charged with deuterium from heavy water electrolytes (97.5% or 99.8% $D_2O$) containing LiOD or a variety of dissolved salts. The null results were obtained for specific individual runs utilizing various systems alternating between cells on and off during the period of more than a month. Other measurements of tritium, heat and surface conditions will be shown.

*Work performed in collaboration with H. S. Isaacs, A. J. Davenport, H. Wiesmann, M. Weber, J. Hurst, J. J. Reilly, and M. Zucker at Brookhaven National Laboratory, Upton, NY 11973 and M. Gai, S. L. Rugari, R. H. France, B. J. Lund, and Z. Zhao, A. W. Wright Nuclear Structure Laboratory, Yale University, New Haven, CT 06511.

Work supported in part by US DOE under Contract Nos. DE-AC02-76ER03074 and DE-AC02-76CH00016.

1. M. Gai, S. L. Rugari, R. H. France, B. J. Lund, and Z. Zhao, A. J. Davenport, H. S. Isaaca, and K. G. Lynn, presented at Am. Phys. Soc. Spring Meeting, Baltimore, May 1989.

**Search for neutron and gamma-ray emission from the cold fusion**

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and

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Raidation Laboratory, RIKEN

and

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Emission of neutrons and $\gamma$ rays was measured under the various electro-chemical conditions. A pair of 8" diameter liquid scintillators (NE213) were used for the detection. Pulse shape discrimination was applied to identify neutrons and $\gamma$ rays. Radiation shield of combination of poli-ethylene, iron, and lead combined with the veto counters made of plastic scintillators provided a very low backgorund condition. So far no sign of the neutron emission associated with cold fusion has been observed in $\sim 3 \times 10^{-3}$ /s. More accumulation of the data with different conditions is underway.

The measurement of the contents of d, $^{3}$He, and $^{4}$He in the paradium electrode after the electro-chemical reaction is also under way. The electrode is irradiated by 1.8 MeV/nucleon beam of Ar and recoil particles are detected by a solid state detector. The pulse height and the time of flight are used for identification of the particle.

More Searches for Cold Fusion * E. B. Norman, B. Sur, K. T. Lesko, R. A. Henderson, K.R. Czerwinski, H. L. Hall, and D. C. Hoffman, Lawrence Berkeley Laboratory – Following the reported observations of nuclear fusion reactions of deuterium nuclei loaded into metallic crystalline lattices[1,2], we have searched for neutrons and gamma rays that should be produced by such processes. Two types of $D_2O$ cells containing electrodes and electrolytes similar to those described in Refs. 1 and 2 have been operated over a period of five weeks. Fast neutrons have been searched for using liquid scintillators and dosimetry film. Prompt gamma rays have been searched for using NaI detectors; induced radioactivity in the electrodes was searched for using Ge detectors. Background measurements have been conducted with the $D_2O$ cells turned off and with an operating $H_2O$ cell. Measurements of the masses of palladium electrodes before and after electrolysis showed that the number of deuterium atoms loaded was greater than 0.5 per Pd atom. No excess of neutrons or gamma rays above background has been observed in any of our experiments. From the neutron measurements we have established an upper limit of $2.1 \times 10^{-24}$ [$d+d \rightarrow {}^3He + n$] reactions per second per deuteron occurring in our Pd electrode. Similarly the lack of 23.8-MeV gamma rays allows us to establish an upper limit of $2.7 \times 10^{-24}$ [$d+d \rightarrow {}^4He + \gamma$] reactions per second per deuteron in the same electrode. In some runs, a small (15%) amount of $H_2O$ was added to the $D_2O$ to allow us to search for the $d + p \rightarrow {}^3He + \gamma$ reaction. No excess of 5.5-MeV gamma rays above background was observed and an upper limit of $1.8 \times 10^{-23}$ such reactions per proton per second in our Pd electrode was established.

* Supported by the U.S. Dept. of Energy under Contract No. DE-AC03-76SF00098.

1. M. Fleischmann and S. Pons, preprint
2. S. E. Jones et. al., preprint

# NEUTRON SOURCES AND SPECTRA FROM COLD FUSION

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## ABSTRACT

Recent reports of heat and neutron production occurring in metal electrodes in a deuterium oxide bath have resulted in speculation that a fusion reaction is occurring at low temperatures. The candidates for the fusion reactions occurring are:

$$D + D = {}^4He,$$

$$D + D = T + H,$$

$$D + D = {}^3He + n,$$

and a possible secondary fusion reaction is:

$$T + D = {}^4He + n.$$

Each of these reactions produce neutrons and/or charged particles.

The primary neutrons form one of the many possible candidates for a signature for the fusion reaction. These neutrons themselves, as they thermalize, are captured in the surrounding material producing a gamma source, which will be transported throughout the reaction vessel. The gamma source if energetic enough, will undergo (gamma,n) reactions, primarily in the deuterium, resulting in a secondary neutron source. The charged particles may also undergo neutron-producing reactions. These neutron spectra may be used to indicate that a fusion reaction has indeed occurred.

This paper investigates these possible neutron producing reactions, and for those most likely occurring reactions, source strength and spectra are calculated. The charged-particle induced neutron spectra and source strengths are calculated with the SOURCES code. The (gamma,n) neutron source spectum is determined using the PHONEX code. The neutron flux spectrum is determined from transport calculations with ONEDANT.

Typical of the results is the neutron energy flux spectrum shown in Figure 1. These results represent the neutron energy flux found one centimeter from the edge of a 6.0 cm diameter flask with 0.5 cm glass wall. The neutron source is one neutron/cm-second distributed evenly within a 0.4 cm diameter titanium rod at the center of the cell. The source neutron energy is 2.45 MeV. Figure 1 thus represents the neutron flux spectrum from the familiar DD fusion neutron source.

# γ-Ray Spectra in the Fleischmann-Pons-Hawkins Experiment

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## Abstract

Fleischmann, Pons, and Hawkins (FPH)[1,2] recently announced that significant fusion heating was occurring in their cold fusion experiments. As compelling evidence of fusion processes, they reported the detection of 2.2 MeV γ rays that result from neutron-capture-on-hydrogen.

We have carefully analyzed the published γ-ray spectra of FPH. We have also performed detailed terrestrial γ background measurements and neutron-capture-on-hydrogen experiments. From our analyses we conclude that the FPH γ line is specious on the basis of three quantitative considerations: (1) it has a line width a factor of 2 smaller than the detector instrumental resolution would allow at 2.2 MeV; (2) there is no evidence of a Compton edge at 1.99 MeV (i.e., 2.22 MeV - 0.23 MeV), and this edge should be distinctly prominent; and (3) FPH's estimate of the neutron source rate, based on their purported γ signal, is a factor of 50 too large. Additionally, from terrestrial γ background considerations, we argue that FPH's γ "line" actually resides at 2.5 MeV rather than 2.2 MeV. Based on these arguments, we conclude that the γ signal of FPH cannot be the 2.2 MeV neutron-capture-on-hydrogen γ ray. We can offer no plausible explanation for the feature, other than it is possibly an instrumental artifact unrelated to a γ-ray interaction.

# COLD FUSION REACTION PRODUCTS AND THEIR MEASUREMENT

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## ABSTRACT

The major reaction products that have been associated with cold fusion reactions are: neutrons, protons, tritium, He-4, He-3, internal conversion electrons, and gamma radiation. The branching ratios and relative reaction rates for these products are examined for consistency with cold fusion experiments. Both theoretical calculations and experimental data are examined and will be presented. For example, the He-4 plus internal conversion has been proposed in order to explain the absence of neutrons or gamma radiation. This reaction is not favored, even in a deuterium-palladium system. In the event this reaction occurs, deexcitation of the excited He-4 nucleus would predominantly occur by gamma emission. Even if internal conversion dominates, considerable Bremmsstrahlung radiation would be generated. Either the Bremmsstrahlung or the gamma radiation would also create neutrons from the photodisintegration of deuterium. Measurement of these reaction products must be made carefully owing to their presence in background. For example, the 2.2 MeV gamma ray from Bi-214, background tritium in the heavy water, and neutrons from the photodisintegration of the deuterium from background radiation. These problems will be discussed and experimentally obtained examples will be presented.

# SEARCH FOR COLD-FUSION NEUTRONS IN HIGH PRESSURE $D_2$ LOADED Ti and Pd*

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Because of the reported observation by Prof. F. Scaramuzzi of Frascati of neutrons from cold fusion during the loading and unloading of Ti with $D_2$ as a function of temperature, we have subjected Ti and Pd powders to $D_2$ pressures up to 4 kbars while cycling temperature between room temperature and 77K. This process was continuously monitored with fast neutron detectors capable of detecting the generation of as few as 5 neutrons/sec. The detectors are $He^3$ tubes embedded in a polyethylene moderator and shielded by a Cd thermal neutron absorber. Thus, they are sensitive only to fast neutrons. Measurements were made in 10 minute intervals during all phases of the experiment. Previous work on pressure charging of $PdD_x$ under similar conditions resulted in x values in excess of 0.9. X-ray analysis of the recovered Ti powder indicated no discernible $TiD_x$ formation with this high pressure cycling. No neutrons in excess of background were detected during any of these experiments.

*This work performed at Sandia National Laboratories was supported by the U.S. Department of Energy under contract #DE-AC04-76DP00789.

# NEUTRON PRODUCTION BY PHOTODISINTEGRATION OF DEUTERIUM

by

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## ABSTRACT

Low-level neutron measurements require great care to account for variability in background sources. Measurements taken near deuterium for cold fusion studies must also consider another source. Photodisintegration of deuterium produces neutrons at significant rates if minerals near the measurement area contain high thorium levels.

The highest energy natural decay gamma-ray normally seen in a background spectrum is at 2614 keV. This line is from decay of Tl-208 in the Th-228 decay chain. Its energy is well above the 2223 keV threshold for the D($\gamma$,n)H reaction. Consider that:

- Uranium and Thorium are widely dispersed in nature.
- Uranium and Thorium are commonly found in the Mountain States.
- Some building materials in the Mountain States have incorporated old uranium mine tailings.

Although Pons and Fleischmann did not report their background at 2614 keV, the gamma-ray flux may be significant.

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**Cold Fusion Experiment at Department of Nuclear Engineering, National Tsing–Hua University**

Department of Nuclear Engineering ( Represented by Tsang–Lang Lin ), National Tsing–Hua University, Hsin–Chu, Taiwan 30043, ROC.

## ABSTRACT

We are repeating the so called cold fusion experiment by electrolysing heavy water with palladium rod as the cathode and platinum wire as the anode. The purpose of our experiment is to detect the neutrons that are produced from fusion process of deuterium if fusion does occur. We use one $^3He$ detector and one $BF_3$ detector to detect the thermal neutrons coming out of the 5 cm water bath that surrounds the heavy water cell. So far, we find that neutron counts are only slightly above background. Detail results will be presented in the workshop.

# Measurements of Nuclear Radiation Due to Pd-Deuterium Interactions

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Experiments have been run to verify the claim of Pons-Fleischmann that "cold" fusion occurs in the Pd-deuterium system. Pd cathodes were electrochemically charged with deuterium from a 0.1M LiOD electrolyte. The Pd was 99.9% pure and consisted of 3 to 5 mm wide strips cut from 25 by 25 mm wide by 1 mm thick foil piece. A Pt lead was spot-welded onto each Pd strip. Pt wire (0.68mm diameter) was used as the anode in most experiments. The LiOD solution was made by dissolving either $^{7}Li$ metal or $^{6}Li_2O$ in 99.8% $D_2O$. Cells were run at constant current, with current densities on the Pd ranging from 16 to 320 $mA/cm^2$; both cell voltages and currents were periodically measured, however, no temperature measurements were made. In one experimental setup, an electrochemical cell was placed inside a high sensitivity neutron counter and neutron counts were taken at 10 min intervals. In addition, temporal multiplicity events, characteristic of bursts postulated to be produced by muon catalysis, were measured by connecting the output of the neutron counter to a multiplicity counter. In a second setup, a cell was placed inside a germanium gamma-ray spectrometer to measure Pd x-rays generated by high energy fusion products (*e.g.*, protons) and secondary gammas produced by $(n,\gamma)$ reactions on Cd foil placed around the electrolysis cell. Gamma-ray spectra were collected over 1 to 2 day intervals.

Approximately 10 experiments have been run to date, with the longest continuous charging time being 20 days. No positive results have been observed; upper limits to the D-D fusion reaction rate are $\sim 2 \times 10^{-21}$ and $\sim 3 \times 10^{-16}$ fusions/sec per D-D pair for neutron and x-ray measurements, respectively. Experiments are continuing and plans have been made to analyze the abundance and isotopic composition of helium in our Pd electrodes.

# COLD NUCLEAR FUSION STUDIES WITH THE LAMPF BGO DETECTOR

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Provo, Utah, U. S. A. 84604

We are exploring cold nuclear fusion using a large solid-angle detector at the Los Alamos Meson Physics Facility. The detector consists of 26 segments of bismuth germanate (BGO). Each segment is 56 mm thick with a 3-mm-thick piece of plastic scintillator bonded to its front face in a reverse phoswich arrangement. This design allows both energy and $\Delta E$ information to be extracted from each crystal for charged-particle identification and for neutral-particle separation. The detector is well-suited for gamma identification; neutron detection is enhanced by placing a polyethylene moderator/absorber around the test cell. The detector covers about 80% of $4\pi$ and permits insertion of either an electrolytic cell or a test cylinder holding metal fragments in a pressurized hydrogen + deuterium environment for cold fusion studies <see Ref. 1>.

A principal goal of the experiments is to determine the yields of 5.4 MeV gamma rays from proton-deuteron fusion relative to 2.5 MeV neutron yields from deuteron-deuteron fusion. The relative yields will be of value in assessing whether the fusion occurs due to piezonuclear fusion <2> or to 'microscopic hot fusion' accompanying strong electric fields at propagating cracks in the hydride <3>. Early results will be presented at the workshop.

This research is supported in part by the Advanced Energy Projects Division of the U.S. Department of Energy.

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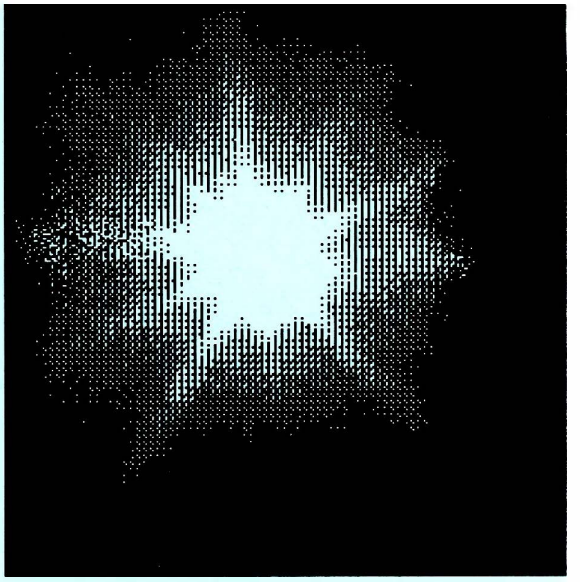
<1> S. E. Jones et al., "Observation of cold nuclear fusion in condensed matter," Nature, 338: 737-740 (April 27, 1989).

<2> C. DeW. Van Siclen and S. E. Jones, "Piezonuclear fusion in isotopic hydrogen molecules," J. Physics G12: 213-220 (March 1986).

<3> J. S. Cohen and J. D. Davies, "The cold fusion family," Nature 338: 705-707 (April 27, 1989).

SEARCH FOR D(P,GAMMA)$^3$HE COLD FUSION PROCESS. S.A. Wender, D.L. Wark, G.L. Morgan, C. Laymon and P.W. Lisowski, Los Alamos National Laboratory--It is now well established theoretically that at low temperatures the fusion rate in a plasma for the three primary fusion reactions is reversed from the order in the keV range. Koonin and Nauenberg in a recent paper submitted to "Nature" calculate a rate for the D(p,gamma)$^3$He reaction which is more than eight orders of magnitude larger than the rate for the D(d,n)$^3$He rate. If these enhancements should hold for the solid state, then even at the low level claimed for cold fusion by the BYU group, the effect would be readily detectable. A cell has been constructed containing 0.1 M LiOD and LiOH in a 3:1 ratio with Pt and Pd electrodes. The Pd was treated in a 3:1 D:H atmosphere prior to starting the electrochemistry. Detectors consisted of a 3" by 3" BGO gamma ray detector in an active cosmic ray shield and a 4" by 2" NE-213 liquid scintillator neutron detector with PSD gamma ray rejection. During the first week-long running period no neutrons or gamma rays were detected above background. Several changes in the experiment are under way which will significantly increase the sensitivity.



# CALORIMETRY

# Calorimetric, Neutron, Helium, and Impedance Measurements to Detect Electrochemically Induced Cold Fusion

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## ABSTRACT

Cast, and cast/drawn palladium samples from 1.0 to 6.25 mm diameter and 10 cm in length were electrochemically loaded with deuterium or hydrogen from solutions 1.0 M LIOD/D2O or LIOH/H2O at constant current densities up to 620 ma/cm^2 in an attempt to duplicate the Pons-Fleischmann experiments (1).
Calorimetric measurements of heavy and light water samples were performed as a function of time, current density, and sample preparation. The cell heat transfer coefficients were measured as well as calculated from Nusselt relations for convective heat transfer. These calculations demonstrate errors in the heat transfer analysis of the CalTech group. No continuous excess enthalpy was detected in the samples. Temperature transients in the samples will be discussed in terms of possible chemical sources including the formation of peroxides at the cathode.

Neutron measurements of the samples with a reaction pulse height analysis detectors is reported in a companion report (1). No neutron were detected beyond the background level which ranged from 3 to 30 counts/hr.

The palladium samples were analyzed for lithium and helium. Helium content was initially analyzed by spark gap spectroscopy. This technique could not resolve 4^He from 12^C^+3. Sample analysis by high resolution mass spectrometry is underway (3). Lithium was not detected below the roughened surface (~1 micron).

Impedance changes in the palladium samples during charging with hydrogen or deuterium provide clear indication of sample saturation and diffusion times. These data indicate that anomalous (non-equilibrium) hydrogen or deuterium concentrations are reached within the samples when the current is lowered or reversed. The impedance measurements detected no internal consumption of deuterium/deuteron species.

* Idaho National Laboratory, Idaho Falls, Idaho

1. Fleischmann,M. and Pons,S., J. Electroanal. Chem. 26, 301-308 (1989).
2. H. Hsuan et. al. Princeton University Plasma Physics Laboratory Abstract Santa Fe Workshop on Cold Fusion.
3. Analysis by Rockwell International Inc.

Calorimetry Cell Design for Cold Fusion Studies. D.P. HUTCHINSON, C.A. BENNETT, R.K. RICHARDS, ORNL* J. BULLOCK IV, and G.L. POWELL, Y-12 Development--Several calorimetry cells have been constructed for the measurement of heat output from electrolysis cells containing palladium rod cathodes. The cells have been calibrated using a resistance heater and a bank of independently calibrated thermistors. The cells are immersed in a 15°C constant temperature bath. Several cells are being operated with palladium cathodes prepared by extrusion and cast techniques. The minimum level of observable excess joule heating power for the cells is estimated to be 1.5% of the applied power to the cell. Data will be presented on the cell design and calibration and the results of the measurements to date will be given.

*Operated by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy under contract No. DE-AC05-84OR21400.

# CALORIMETRY OF "COLD FUSION" CELLS

This paper presents results of an investigation of "cold fusion". Test cells were assembled that are essentially identical, except that one has $H_2O$ and the other has $D_2O$. Each cell has both electrodes of nickel wire. These are connected to variable voltage, 60 Hz. power supplies. The water in each cell has a volume of 6 cc, to which is added one cc of LiCl having one gram of LiCl per $10^4$ cc of water. The temperature rise of each cell, cooled by ambient air, was measured for known amounts of electric power input. A difference in cell temperatures, for the same power input, would reveal a source of power originating in the cell having the higher temperature. A temperature increase of 2° C corresponds to 0.1 watt input. The thermometers are accurate within ±0.5°, and were calibrated in a water bath.

Two runs showed an "excess power" of 20%. Two subsequent runs showed no "excess power." Each run was started with completely new cells. Three runs with no LiCl present showed no "excess power."

RE: **Calorimetric and Thermodynamic Investigation of the Electrolysis of LiOD Solutions with Palladium Cathodes**

Bruce E. Gammon *, Charles R. Martin -, Kenneth N. Marsh *
Texas A&M University
* Thermodynamics Research Center
- Department of Chemistry
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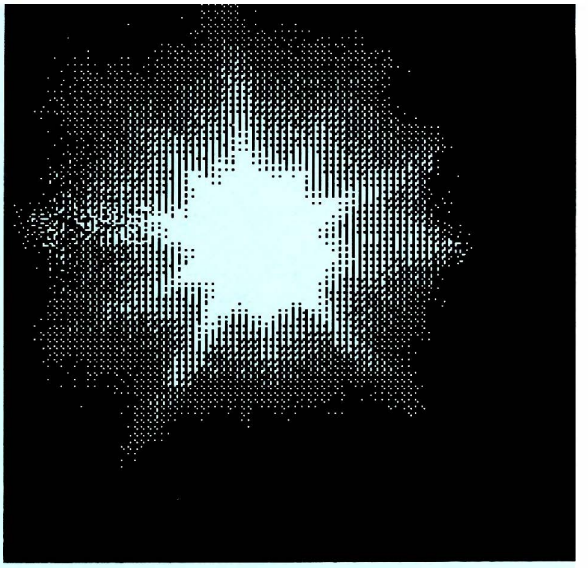
Possible sources of errors in calorimetric measurements will be described. The thermodynamic and thermophysical implications of charging a palladium electrode with isotopes of hydrogen will be discussed. A calorimetric measuring system devised at Texas A&M University for testing for excess power will be described. It employs a power-compensation heat-conduction principle and provides for stirring of the electrolyte. Provisions for metering and analysis of effluent gases and for replenishing their parent materials will be outlined. Provisions for analysis of the electrode materials and solutions will also be discussed. Results obtained will be discussed.



# ANALYTICAL CHEMISTRY OF APPROPRIATE PRODUCTS

# VISIBLE PHOTON YIELDS IN Pd/$D_2O$ ELECTROLYSIS*

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We have investigated the light emitted from the active side of a palladium cathode in an electrolytic cell. The experiment was designed to search for very low yields of light emission, expected to occur in any energy exchanges from a cold fusion process. The electrolyte is 1.5 M $HNO_3$ in $D_2O$. Experiments were also performed including LiOH in heavy and light water. The anode is platinum. The cell is contained in a light tight box and the cathode is viewed by a cooled photomultiplier. Observations were made in the wavelength range 3000 to 8500 Å.

Results to date are as follows:

Photon yields of 1 to 20 per second are obtained in observations covering the wavelength range of 3000 to 8500 Å.

The observed rates correspond to 1 to 20 photons per $10^{17}$ charge carriers in the cell. The yields vary with time, temperature, and current. Using different filters within the above wavelength range, we verify:

1) Infrared photon yields (above 7000 Å) depend partially on the electrolyte temperature
2) At wavelengths below 6000 Å, the major dependence is on power input to the cell.
3) No significant yield from the Balmer α, n = 2-3, transition in deuterium is observed.
4) Fluorescence continues at a reduced rate (1 to 3 photons per second observed) when current to the cell is reduced to zero.
5) Temporal dependence shows a large peak (up to 25 photons per second observed) when the current is turned on suddenly, after a current downtime. This yield depends on the downtime, and is increased for downtimes of an hour or more.

The above results can be understood in terms of standard (but unexpected) chemical models for the cell electrolysis, and diffusion of the deuterium atoms within the palladium. Further measurements are continuing.

Palladium electrodes in $H_2O$ also yield the residual light flux, observed after the current to the cell is reduced to zero.

* Work supported by the U. S. Dept. of Energy, Office of Basic Energy Sciences, under contract W-31-109-ENG-38.
† Graduate Student, University of Illinois, Chicago.

# Problems With the Mass Spectral Determination of Tritium from Cold Fusion*

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**Abstract**

Among the attempts to measure particles produced in the cold fusion of deuterium in palladium metal is the mass spectrometric observation of tritium. An experiment which has been reported in the popular press involves attaching a hollow Pd electrode to a vacuum chamber and measuring tritium produced during electrolysis using a mass spectrometer. We present data demonstrating that mass 5 and 6, which could be mistaken for the ions $DT^+$ or $T_2^+$, can arise from ion/molecule reactions in the ionizer of the mass spectrometer giving the ions $D_2H^+$ and $D_3^+$. With $H_2$ and $D_2$ present in the vacuum chamber, there are at least 9 reactions which lead to these triatomic species, and these may contribute to a complex time and pressure dependence of the signals. If during electrolysis, tritium were produced at the levels suggested by the Pons & Fleischmann experiment, the $DT^+$ signal would be insignificant compared to the background generated by ion-molecule reactions.

*This work performed at Sandia National Laboratories supported by the U.S. Department of Energy under contract number DE-AC04-76DP00789.

# COLD FUSION REACTION PRODUCTS AND THEIR MEASUREMENT

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## ABSTRACT

The major reaction products that have been associated with cold fusion reactions are: neutrons, protons, tritium, He-4, He-3, internal conversion electrons, and gamma radiation. The branching ratios and relative reaction rates for these products are examined for consistency with cold fusion experiments. Both theoretical calculations and experimental data are examined and will be presented. For example, the He-4 plus internal conversion has been proposed in order to explain the absence of neutrons or gamma radiation. This reaction is not favored, even in a deuterium-palladium system. In the event this reaction occurs, deexcitation of the excited He-4 nucleus would predominantly occur by gamma emission. Even if internal conversion dominates, considerable Bremmsstrahlung radiation would be generated. Either the Bremmsstrahlung or the gamma radiation would also create neutrons from the photodisintegration of deuterium. Measurement of these reaction products must be made carefully owing to their presence in background. For example, the 2.2 MeV gamma ray from Bi-214, background tritium in the heavy water, and neutrons from the photodisintegration of the deuterium from background radiation. These problems will be discussed and experimentally obtained examples will be presented.

# Detection Of "Cold Fusion" Helium Products by Mass Spectrometry

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Rocketdyne Division
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and

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## Abstract

The detection of helium products would be a most compelling piece of evidence that "cold fusion" is occurring in palladium electrochemical cells. In this paper we report on mass spectrometric measurements of helium ($^3$He and $^4$He) released from palladium samples through vaporization. Extensive measurements conducted by Sandia National Laboratories on helium-implanted metals and metal hydrides have conclusively demonstrated that helium is not released at ambient temperatures until a He/metal concentration ratio of ~ 0.4 is achieved. If we assume that "cold fusion" events are creating helium in the palladium electrode with Q = 23.84 MeV, then one watt of fusion power would correspond to a helium production rate of $2.5 \times 10^{11}$ $^4$He/s.

While this potential production rate is orders of magnitude below that required for spontaneous release, it can be detected by mass spectrometry of vaporized samples. In the Rockwell International measurements, 10-50 milligram size samples were vaporized under vacuum and all gases were passed through multiple getter stages to remove unwanted gases, including hydrogen isotopes. The helium concentrations were then measured using a precision mass spectrometer. Absolute calibration of die system was verified using palladium samples implanted with 700 keV $^4$He ions. The ultimate detection level of the system is ~ $1 \times 10^{10}$ helium atoms (either $^3$He or $^4$He or both) per gram of palladium. Results of helium measurements conducted for a number of U.S. laboratories are presented. In no case was there any "cold fusion" helium detected above system background for palladium electrodes used typically for 1-2 weeks, implying a maximum time-averaged "cold fusion" rate of less than 0.1 microwatts per gram of palladium.

* This work supported by the U.S. Dept. of Energy under contract DE-AC04 76DP00789.

# Ion Beam Analysis of Pd Electrodes after Electro-chemical Reactions in $D_2O$

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and
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Radiochemistry Laboratory, RIKEN
and
S. Nakabayashi, A. Kira
Chemical Dynamics Laboratory, RIKEN
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Ion beam analysis of the Pd electrodes was made after electrolysis of $D_2O$ with several electrolytes of different metal ion mixture. An Ar ion beam from heavy-ion LINAC at RIKEN was used at 61 MeV. Recoil proton, deuteron, and other light elements were detected by silicon solid state detector placed at 33 degree scattering angle. Particle identification was made by the measurements of total energy and the time-of-flight of a particle. Only a very small amount of deuteron was observed in most electrolytes. Instead considerable amount of proton was observed in all cases. It is considered, therefore, that the replacement speed of proton to deuteron in Pd metal is very slow. The slow replacement speed is also observed in other material such as Si.

If the cold fusion is occurring in Pd metal, a sufficient number of deuteron has to be included in Pd. The present experiment give warning for fusion experiments in such a way that the detection of neutron and other radiations has to be made sufficiently after the replacement of hydrogens to deuterium in Pd occurred.