Nuclear Physics Approach

ON THE COLD FUSION MIRACLES

Swe-Kai Chen, the Materials Science Center, National Tsing Hua University, Kuang-Fu Road Sec. II, Hsinchu 30043, TAIWAN

Abstract

This paper consists of two parts. One part describes a new analytical method for the conventional electrolytic cold fusion experiment. The other part contains a discussion and explanation on the cold fusion effect. Heat bursts are observed in this experiment for both Ni(-)/Pt(+)/H_2O/K_2CO_3 and Pd(-)/Pt(+)/D_2O/LiOD cells. Careful detection of neutron and tritium has not been available, although very preliminary neutron detection of heavy water cell shows roughly two times of the background level during electrolysis. The vast experimental data worldwide show a low neutron-tritium ratio of 10^{-8} to 10^{-4}, far below the equal branching ratio, having been explained in this paper by a secondary nuclear process by the author. According to this secondary nuclear process, the generated neutrons and protons inside the solid has the chance to recombine into deuterium atoms for heavy water systems. In this sense the Huizenga's second and third miracles, the branching ratio miracle and the no nuclear products miracle, are therefore equivalent. This paper also proposes a "pycnon field" to try to treat the correlation of the high d/Pd ratio and pycno-reactions. Although the detail has not been worked out yet.

Introduction

An accurate calibration curve for heat is difficult to obtain even for a close-type electrolysis cell. However, a comparison among temperatures in cell, T_{cell}, temperatures in circulating water bath, T_{bath}, and input powers, W, in the same time period, shows an easier alternative for this matter. This method can also apply to an open cell system. Therefore it uses an open cell system in this experiment to illustrate the method.

In the paper entitled "Opposition and support for cold fusion" by Rabinowitz et al. [1], they mentioned the challenge of cold fusion with Huizenga's three miracles [2], (a) the fusion rate miracle, (b) the branching ratio miracle, and (c) the no nuclear products miracle. The review of experimental observations by Storms [3] has listed all the up-to-date reported data before 1991, showing the fact of Huizenga's challenge. Of the support most came from experimenters, while those of the opposition came from theorists. The miracles result from the fact that experimental data and observations cannot fit the conventional theory. It is no wonder that the effect is hard to consider as a fusion.

In a "Letter to the Editor," to Fusion Technology [4], Chen proposed a "fast neutron model" or "secondary nuclear fusion model" to explain the Huizenga's miracles. It is the second purpose of this paper to further discuss this model. Because the condition of the high d/Pd ratio for a high loading cathode is similar to that in stars where high pressure exists and pycno-reactions occur [5]. The high d/Pd ratio is one of the essential factors for generation of the cold fusion effect. Treating the field where the primary and secondary fusion reactions can occur, like that of the meson field, herein a "pycnon field" is proposed.

Experimental

Nuclear Physics Approach

The cell is a double-layered quartz tube with inner and outer diameters of 63.7 mm and 97.5 mm, respectively. The cell height is approximately 120.6 mm and the cell volume is about 400 ml. When the electrodes and detectors are in the cell the net volume of the solution is about 350 ml. Cooling water circulates inside the double layer of the cell and a temperature-controlled bath. The bath is with a totally 5,000 ml of water and with a pumping capacity of 15,000 ml/min. To start the experiment the bath is initially set at 55 ℃. A power supply can operate with controlled-current or voltage mode, and is with a maximal output of 300 watts. The accuracy of the power supply is plus or minus 0.1 ampere or volt. The cathode is a Ni or a Pd rod with 4.7 mm in diameter and 120 mm in length and the anode is a Pt wire with 0.1 mm in diameter. The shape of the Pt anode winding is a cylinder using a quartz sketch for support of the wire winding. The cathode is placed in the center of the Pt winding. The electrolyte of the Ni-Pt cells is light water solution of K_2CO_3, while that of the Pd-Pt cells is heavy water solution of LiOD. The cell current, I, and voltage, V, are measured once per minute with sensors. They transform into signals that can be read in a computer system to an accuracy of plus or minus 0.01 ampere or volt. Temperature readings are through Pt electric resistors and the computer minute by minute, with a measuring accuracy of plus or minus 0.01 ℃. Each resistor inserts in a quartz tube. The Ni rod melts in a VAR, homogenizes, forges, anneals and swages in laboratory. The Pd rod is from an outside supplier. A Dewar buffer helps the circulating water to keep temperature stability of the system during electrolysis. Current keeps below 10 amperes to avoid the leading head of the Pt wire to melt. Total cell resistance, R, which is the quotient of the cell voltage to the cell current, is always kept from 2 to 9 ohms.

There are two kinds of electrolytic operations, one for manual-controlled change and the other for change controlled by the cell itself. The measured cell-controlled voltages vary by a range of 2 volts during electrolysis, although there is a constant manual-controlled voltage. For a controlled-voltage mode, the V-I and W-I (W=VI, see Fig.1) relations are almost linear functions with a negative slope and a positive slope, respectively. The R-I curve is almost inversely linear dependence during electrolysis. This is due to the small value, i.e., 0.4-1 ohm, of the connecting resistance in the electric circuit. However, one can see the "average" of the manual-controlled values of currents and voltages roughly obey the Ohm's law (Fig.2). There are similar curves in a V-I, W-I, or R-I plot, each corresponding to a specific composition of cell parameters. These parameters contain the following factors: the degree of the cell temperature, the extent and concentration of the solution, the loading degree of the H or D atoms in cathode rods, conditions of the cathode rods, and the action of addition of H_2O or D_2O into the cell (For keeping a constant

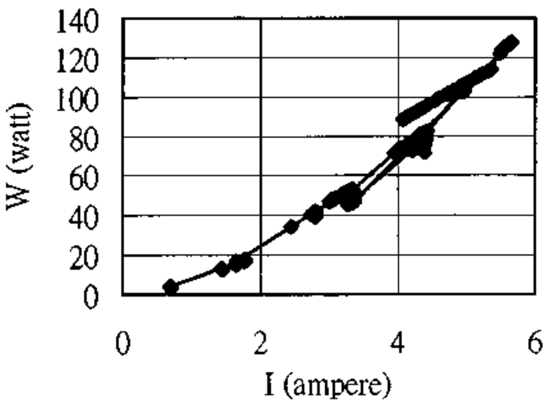

Fig. 1. The plot of W-I for a Pd/Pt/D_2O/LiOD cell

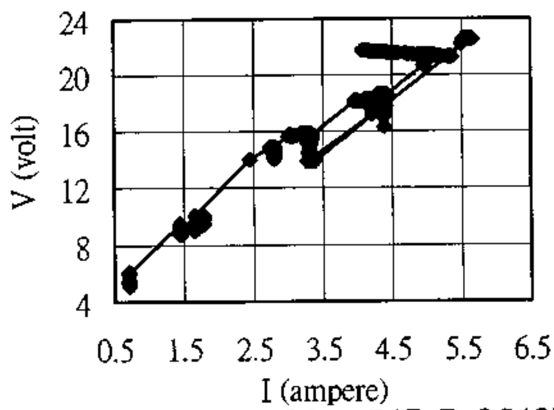

Fig. 2. The plot of V-I for a Pd/Pt/D_2O/LiOD cell

solution extent in the electrolysis cell). One can have two kinds of filling of water, i.e., by manual or by an automatic device with a level sensor. The manual-charge of light or heavy water changes the cell electrolytic condition violently, as compared with the automatic charge of water. A black film deposits to the surface of the electrodes and precipitates in solution. Chemical analysis of the black film and precipitation with the ionized coupled plasma method (ICP) show a composition of mainly Pt (78.7 %, see below). A magnetic stirrer uses in the cell in order to keep a homogeneous distribution of cell temperature. To make sure that the bath temperature is supplied from the cooling of the cell, the circulating power of the bath is checked every minute in experiment. All curves in this experiment have lines, each connecting two time-consecutive points.

Results and Discussion

The $Ni/Pt/H_2O/K_2CO_3$ electrolysis cell

The chronicle record of T_{bath} shows two heat bursts during electrolysis (Fig. 3). One can see from the record of measured power (Fig. 4) that for heat burst at $35{,}200^{th}$ minute there is a five-watt increase, induced by manual filling of H_2O in the cell. For heat burst of $35{,}400^{th}$ minute there is a big increase in power, 70 watts, also induced by filling of H_2O in the cell. In electrolysis process total amount of K_2CO_3 keeps nearly constant. No K_2CO_3 is added in the cell. Not every time of H_2O filling can rise the measured power. It depends on the cathode condition. If one is checking the hysteresis loop of T_{bath} to T_{cell} for an experiment during $45{,}362^{nd}$ to $48{,}602^{nd}$ minute (Fig. 5), one can verify this point. The point density in the curves stands for the time length of stay for states of sets of T_{bath}-T_{cell}. The longer stay, the heavy density of points. The lower part of the hysteresis loop is generally the heating condition, while the upper portion is the cooling condition (e.g., the H_2O charge). In the T_{bath}-T_{cell} plot the cooling curve of the cell (addition of H_2O into the cell) extends to the left of the hysteresis loop, and the cooling curve of the bath (addition of cooling water into the bath) extends downwards. There are also minor and major loops in the T_{bath}-T_{cell} plot. The T_{bath}-W plot show different states of T_{bath} at two specific values of measured power (Fig. 6). The key to the heat burst in this experiment is to understand the following questions. Why does the H_2O addition to the cell change the cell resistance so much and irregularly? Does this mean the resistance of the cathode also change in a similar way the resistance does?

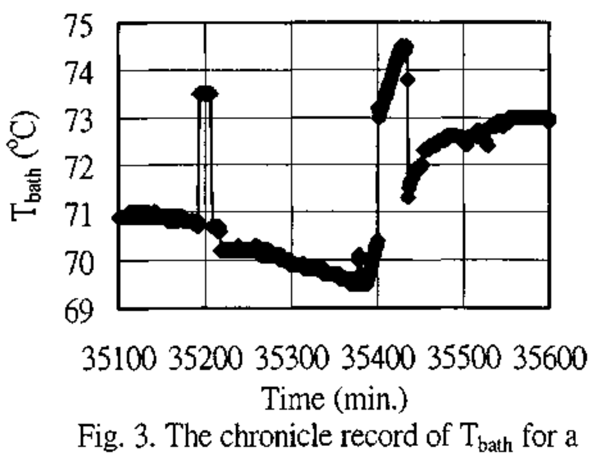

Fig. 3. The chronicle record of T_{bath} for a $Ni/Pt/H_2O/K_2CO_3$ cell

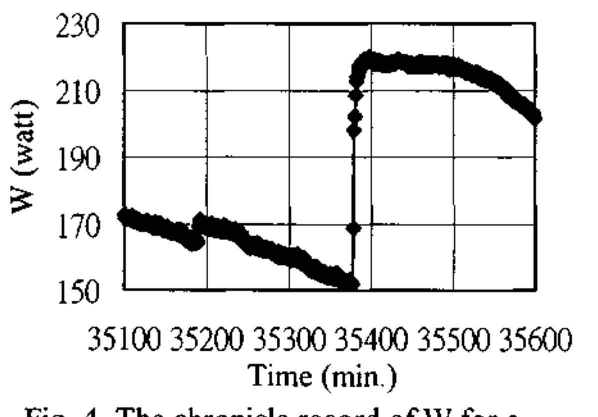

Fig. 4. The chronicle record of W for a $Ni/Pt/H_2O/K_2CO_3$ cell

The $Pd/Pt/D_2O/LiOD$ electrolysis cell

A big heat burst occurs at 3550^{th} minute during an experiment (Fig. 7). For this heat peak T_{bath} and T_{cell} increase at the expense of decreasing power (Fig. 8). The plot of T_{bath}-W shows increase of 85 to 100 °C for decrease of 109 to 88 watts (Fig. 9), while the plot of T_{cell} -W shows increase of 94 to 100 °C for the same decrease of watts (Fig. 10). The resistance of the cell at this peak is a maximum because of the water boiling during the occurrence of the heat burst.

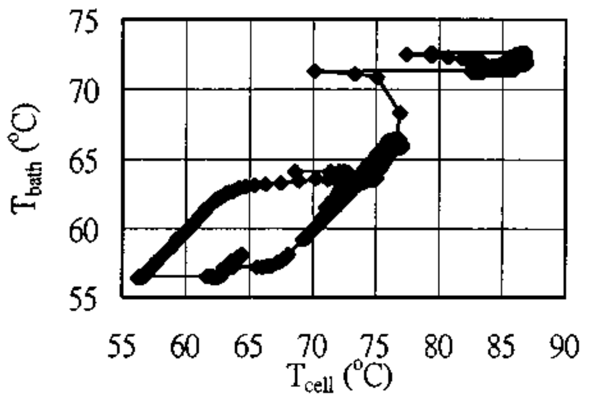

Fig. 5. The plot of T_{bath}-T_{cell} for a Ni/Pt/ H_2O/K_2CO_3 cell

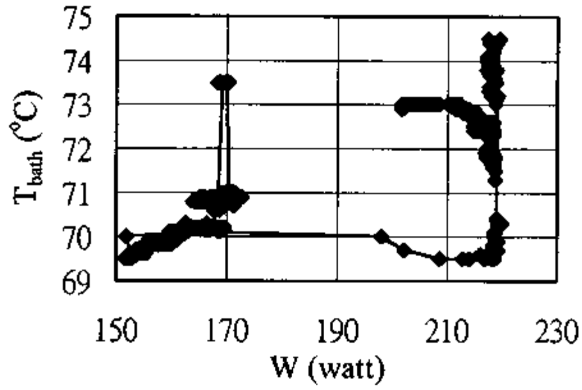

Fig. 6. The plot of T_{bath}-W for a Ni/Pt/H_2O/K_2CO_3 cell

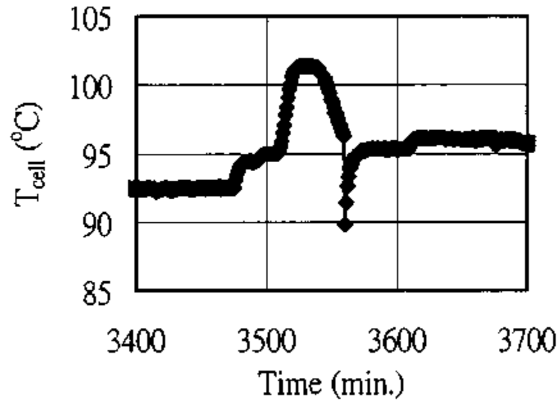

Fig. 7. The chronicle record of T_{cell} for a Pd/Pt/D_2O/LiOD cell

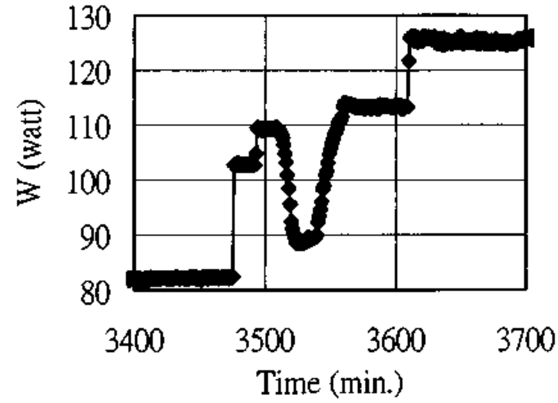

Fig. 8. The chronicle record of W for a Pd/Pt/D_2O/LiOD cell

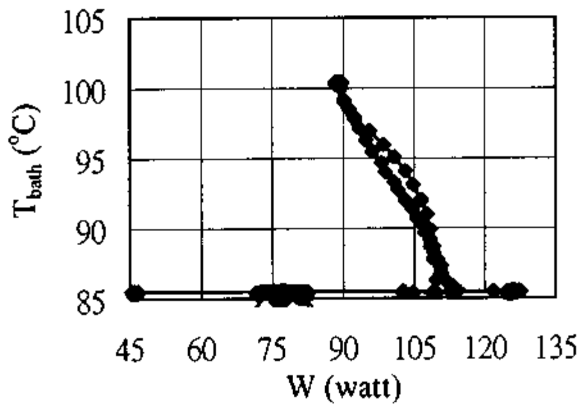

Fig. 9. The plot of T_{bath}-W for a Pd/Pt/D_2O/LiOD cell

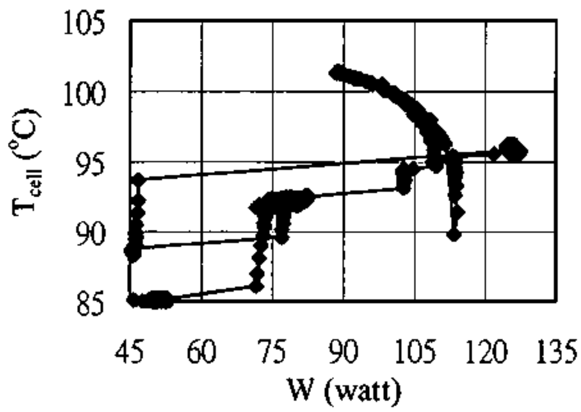

Fig. 10. The plot of T_{cell}-W for a Pd/Pt/D_2O/LiOD cell

The analysis of black precipitation in Ni/Pt/H_2O/K_2CO_3 cells

During the electrolysis there is accumulation of black precipitation in the electrolytic cell. The precipitation sticks on the surface of both electrodes as a thin film until the thickness of the film is large enough. Then the thick film breaks from the surface, and precipitates in solution. Although the establishment of the film rises the resistance of the cell, it shows that the resistance only ranges

of a small value, i.e., from 2 to 9 ohms, most of the time during electrolysis. It is observed that V-I curves are always straight lines with negative slope and with different set values of controlled-voltage of the power supply as parameters in curves. The slope of the Ni-H_2O cells is about 0.375 ohm, while that of the Pd-D_2O cells is about 0.35 ohm in this experiment. The W-I curves are also straight lines with different set values of controlled-voltage of the power supply as parameters in curves, but with positive slopes. Although the separation of the thick film from the electrode surface prevails frequently during electrolysis, there are occasionally large changes in current for a specific controlled voltage. However, the filling of water in cell changes the current to a large extent. It is believed that the loading condition of the cathode is key to the current change.
The collection of black precipitation during two-month electrolysis can reach an amount up to 1-gram order. This amount is helpful for doing chemical analysis. The original K_2CO_3 contains Na lower than 0.05 wt. %, silicate lower than 0.003 wt. %, Ca lower than 0.002 wt. %, Al and Mg lower than 0.001 wt. %, Fe, Cu, and Pb lower than 0.0005 wt. %, and As lower than 0.0001 wt. %. The electrodes, Ni and Pt, are 99.99 wt. % in purity. Chemical analyses of the black precipitation by a precision ICP-AES show a composition of 78.73 Pt-6.33 K-1.81 Ca-1.15 Mg-0.755 Fe-0.6 Ni-0.358 Si-0.184 Cr-0.137 B-0.13 Na-0.123 Pb-0.030 Zr-0.025 Nd-0.024 Mn-0.019 Zn-0.018 Cu-0.016 Ti-0.011 Sr-0.008 Li-9.52 others (including O) in weight percentage. Only contents of Pt, K, Ni, and Si indicate that they come obviously from the materials of the system. The high contents of Ca, Mg, Fe, Cr, B, Na, Pb, Zr, Nd, Mn, Zn, Cu, Ti, Sr, and Li are not present in the system at the start of the electrolysis. From the total amount estimation of the individual element, except Pt, K, Ni and Si, the concentration seems to be higher in 1 to 2 orders. It is hard to say that some of them come from the product of the nuclear reaction. But it is worth to take a thorough analysis of the precipitate.

The explanation of the cold fusion effect using a secondary reaction and a pycnon field

According to the conventional fusion theory in d-d reactions, there are two nearly equal branches,

(1) d + d = t(1.008 MeV) + p(3.052 MeV)

(2) d + d = ^{3}He(0.817 MeV) + n(2.452 MeV).

If in the solid state these two primary reactions can occur, neutrons with 2.452 MeV are "fast", and a "free" neutron is with a half-life of 12.8 minutes [6], then neutrons coming from Reaction (2) can recombine with protons coming from Reaction (1) to form a deuterium,

(3) n(2.452 MeV) + p(3.025MeV) = d(6.41 keV) + γ(7.696 MeV)

One can easily see that the equal branching ratio (or n/t ratio ~ 1) showing in Reactions (1) and (2) is equivalent to n/t ratio ~ 10^{-8} to 10^{-4} [3], if a secondary reaction, Reaction (3), fully involves in reactions. In this case the total enthalpy generation in one event will be

(4) Q = (4.033 x 0.5 + 3.269 x 0.5 + 2.226) MeV = 5.877 MeV.

The densities of the sun and white dwarf are 1.76 x 10^2 and 4 x 10^8 kg/cm^3, respectively. Although most of solid materials have relatively small densities, at the order of 10, the density of nucleus in an atom is 2.3 x 10^{17} kg/cm^3. One can see from the phase diagram of d-Pd that high d/Pd ratio means a high fugacity (pressure) of deuterium. The high d/Pd ratio is one of the essential factors for generation of the cold fusion effect. If the secondary reaction, Reaction (3), is possible, there should be a field correlated to the high fugacity and the pycno-reactions in stars [5]. Treating the solid state field where the primary and secondary fusion reactions can occur like the meson field in the nucleus of an atom, a pycnon field is proposed here. If one assumes that the reaction under a condition of a very high nucleus density and a high deuterium fugacity in Pd lattice is governed by an exchange of a virtual pycnon, like the meson change in nucleus, one may deduce reaction details. The mass of the pycnon, m_{pycnon}, may be calculated by

(5) $m_{pycnon} = \Delta E/c \sim h/(\Delta t \cdot c^2)$,

where

Δt is the life time of p and n produced in Reactions (1) and (2).

If one assumes that $\Delta t \sim \Delta x/c$ and $\Delta x \sim 10^{-10}$ m in solid state, then $\Delta t \sim (10^{-10}\ \text{m})/(3 \cdot 10^8\ \text{m/sec}) = 0.3 \cdot 10^{-18}$ sec. Therefore,

(6) $m_{pycnon} \sim (6.626 \cdot 10^{-34}\ \text{J·sec}) / [0.3 \cdot 10^{-18}\ \text{sec} \cdot (3 \cdot 10^8\ \text{m/sec})^2]$
$\sim 2.21 \cdot 10^{-32}\ \text{kg} / (9.11 \cdot 10^{-31}\ \text{kg/electron mass})$
$\sim 0.0243\ m_e$.

It is assumed that the secondary reaction can occur under the pycnon field during the time of Δt after the primary reactions.

Conclusions

1. The hysteresis loop of T_{bath} to T_{cell}, and T_{bath}-W and T_{cell}-W curves show discrete enthalpy states in hydrogen-loaded nickel or deuterium-loaded palladium cells. When there are extra temperature-affected factors from surroundings and the system, the hysteresis curves are distorted or changed. From analysis of the curves, one can properly indicate that if there is excess heat generation at a specific moment in the cell.
2. Heat bursts are observed for both Ni-H_2O and Pd-D_2O cells in this experiment.
3. A secondary fusion reaction for the recombination of neutrons and protons is proposed to explain the equivalent of Huizenga's second and third miracles on Pd-D_2O cold fusion effect. A pycnon field is also discussed in this paper.

Acknowledgments

The author wants to thank the Materials Science Center of the National Tsing Hua University and the National Science Council of the Republic of China for financial support under contract Nos. NSC 81-0405-E007-548, 83-0405-E007-012 and 84-2216-E007-035. Thanks are also due to Messrs Chi-Yung Liang and Chih-Lung Chang, and Profs. Chi-Meen Wan, Chi-Chiao Wan and Liq-Ji Yuan for their help in experiment.

References

1. M. Rabinowitz, Y.E. Kim, V.A. Chechin and V.A. Tsarev, "Opposition and Support for Cold Fusion," Transactions of Fusion Technology, 26, 3(1994).
2. J.R. Huizenga, "Cold Fusion: The Scientific Fiasco of the Century," University of Rochester Press, (Rochester, NY, 1992), p.110.
3. E. Storms, "Review of Experimental Observations about the Cold Fusion Effect," Fusion Technology, 20, 433(1991).
4. S.K. Chen, "A Letter to the Editor," Fusion Technology (Sep. 1995), submitted and unpublished.
5. A.G.W. Cameron, J. of Astrophys., 129, 676(1959).
6. J.M. Rabson, Phys. Rev., 77, 747(1950).