INTERACTION OF PALLADIUM/HYDROGEN AND PALLADIUM/DEUTERIUM TO MEASURE THE EXCESS ENERGY PER ATOM FOR EACH ISOTOPE

ELECTROLYTIC DEVICES FOR ENERGY GENERATION

KEYWORDS: *excess energy, hydrogen/palladium, ozonizer*

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Received October 12, 1995
Accepted for Publication July 16, 1996

A search for the products of fusion reactions that could be triggered by sparking in hydrogen isotopes produced a negative result with no signatures above background being found. Very significant excess energy production in both hydrogen/palladium and deuterium/palladium systems is reported. The conditions of occurrence for this excess energy production are discussed, and the formation of a tightly bound state of the hydrogen (deuterium) atom is put forward to explain the results.

INTRODUCTION

Excess energy production up to several watts has been constantly observed when a metallic-hydride-forming metal (palladium) makes contact with a discharge struck in a hydrogen isotope (^1_1H or ^2_1H) at atmospheric pressure.[1,2] Such excess energy production is also observed when electrolyzing water ($^1_1H_2O$ or $^2_1H_2O$) with metallic-hydride-forming metals (nickel, palladium).[3,4] One possible explanation of this phenomenon was the occurrence of hydrogen isotope fusion reactions in the metal. A search for the products expected from these reactions gave a negative result; no signature above background was found to explain the amount of excess energy produced.[5]

We concentrated our efforts on the way this excess energy was produced in two systems: palladium/hydrogen and palladium/deuterium. We measured the excess energy production per atom of hydrogen isotope. We found that this excess energy was higher for deuterium than for hydrogen (23 500 compared with 7100 eV/atom), both values being considerably higher than the energy obtained from the combustion of hydrogen (1 eV/atom).

To explain our results, we put forward the formation of the hydrex (deutex) state of the hydrogen atom, which occurs when a high current flows through metallic-hydride-forming metals containing large amounts of hydrogen isotopes. The properties of these atomic species can account for secondary nuclear reactions, explaining a number of the weak nuclear signatures observed in similar experiments.

METHODS

To measure the excess energy per hydrogen atom, we measured with precision the excess energy production and the hydrogen consumption in the hydrogen/palladium and deuterium/palladium systems. [Pure hydrogen (Alphagaz N55), pure deuterium (Alphagaz N27), and pure palladium (Johnson Matthey Puratronic grade) were used.]

The excess energy production was measured in a system we shall now describe. The reactors are of the ozonizer type and are cylindrical (typically 2 cm in diameter and 60 cm long) with Pyrex dielectric barriers. We have used either single-dielectric-barrier-type reactors (the electrode in contact with the gas being a 0.25-mm palladium wire) or double-dielectric-barrier-type reactors (the palladium in that case being a 0.1-mm-thick foil, at a floating potential between the two barriers). Figure 1 displays the double-barrier-type reactor, and Fig. 2 displays the single-barrier reactor.

The double-barrier reactor allows very representative blanks to be made by withdrawing the palladium foil. The discharge in that case still occurs between the two

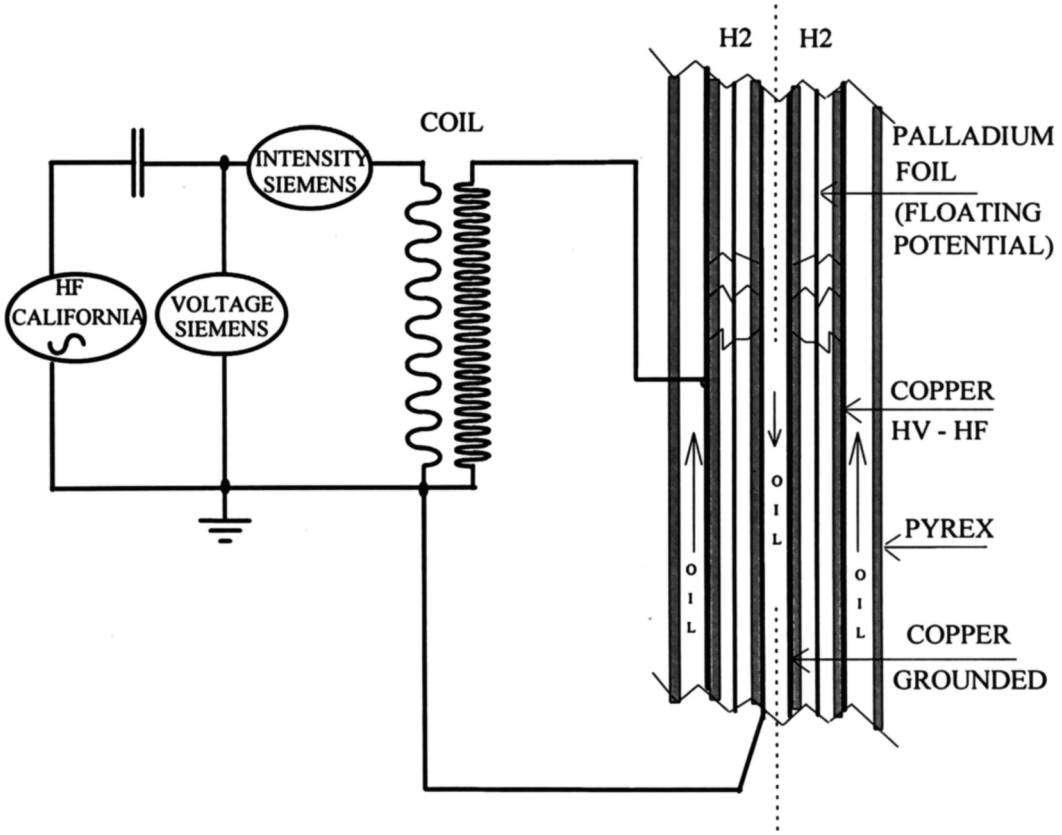

Fig. 1. Double dielectric barriers.

dielectric barriers, with no contact with any metal. A single calorimeter contains the high-voltage coil and the reactor. The high-voltage coil is powered by a high-frequency (50- to 5000-Hz), low-voltage (0- to 220-V) generator (Invertron from California Instruments) that delivers a quasi-sinusoidal signal.

The electrical power input P_{INM} is measured at the outlet of the Invertron by a high-precision numerical wattmeter (Siemens Functionmeter B 1082), giving a precision >1%. This measurement is checked periodically by using a high sampling frequency (250-MHz) oscilloscope (Phillips PM 3320A). Typical results are as follows: 162.25 W measured with the wattmeter and 162 W measured with the oscilloscope. We are thus sure that the small, high-frequency (megahertz) perturbations of the current/voltage signals caused by the partial discharges occurring in the ozonizer are correctly taken into account. Another effect of these high-frequency perturbations has to be taken into account: In the course of time, we found that at high power input (>60 W), negative excess power production (up to −4 W and stable on several days) occurred in our experiments. We were able to reproduce this phenomenon for long periods (weeks) by sparking in hydrogen with copper electrodes. We finally explain it by the release of part of the electromagnetic

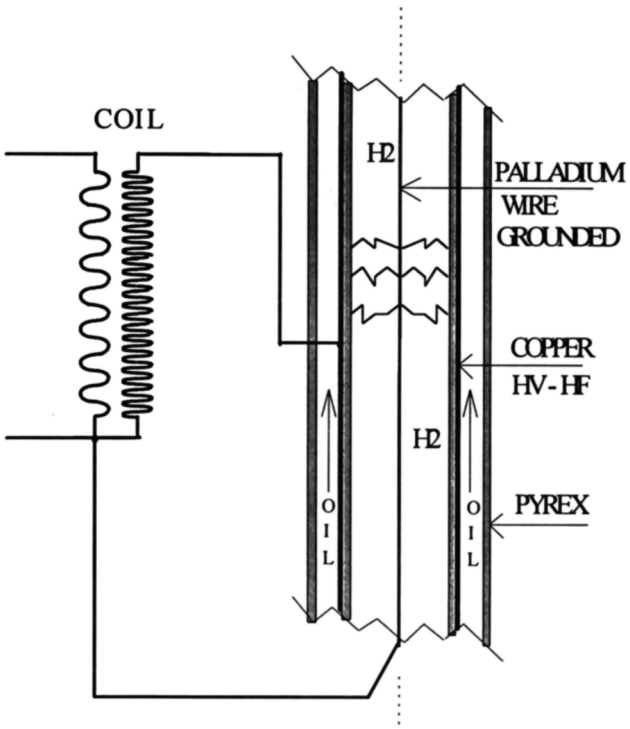

Fig. 2. Simple dielectric barrier.

energy, generated by the small, high-frequency perturbations, outside of the calorimeter (through electromagnetic coupling between the secondary and the primary of the coil in the calorimeter). This energy is actually released in the high-power amplifier of the Invertron generator, causing a systematic destruction when used over long periods at high power. The corresponding power released outside of the calorimeter has been experimentally shown to fit a parabolic correlation with P_{INM} (power input measured by the wattmeter):

$$P_{INVERTRON} = 10^{-3} \times P_{INM} \times (0.2 \times P_{INM} - 4) \ .$$

The net electrical power into the calorimeter is thus

$$P_{ELEC} = P_{INM} - P_{INVERTRON} \ .$$

The reactor and the coil are housed in a polyvinyl chloride (PVC) cylinder (10 cm in diameter, 110 cm high) that also contains the tubing for circulating silicon oil (Rodhorsil 47V20 Rhone Poulenc) through the reactor (and the coil) and the wires connecting the system to the Invertron. The PVC cylinder is wrapped in a 1-cm-thick layer of insulating material (polyethylene sponge, closed cells, 0.019 kcal/m·°C) surrounded by a copper coil (110 cm high) made of joined whorls of copper tube (1 cm in diameter) through which the silicon oil circulates. This coil is wrapped in a 5-cm-thick layer of insulating material and the resulting cylinder (24 cm in diameter) is housed in a PVC cylinder (25 cm in diameter, 140 cm high), closed at the bottom and the top by two 15-cm-thick insulating caps with holes for passing the tubing and wires. The outer PVC cylinder is surrounded by a double coil made of joined whorls of PVC tubing (1.8 cm in diameter), through which water flows at a temperature maintained at 20°C (±0.1°C) by a cryothermostat (Huber HS 40). The double coil is itself wrapped in a 2-cm-thick layer of insulating material. Figure 3 gives an overall view of the calorimetric system.

In spite of the use of high-voltage/high-frequency currents, this calorimetric system is electrically tight; i.e., no discharge occurs between the high- and the low-voltage parts (except, of course, in the gaseous gap of the reactor). It is quasi-adiabatic, with 95 to 99% of the heat being recovered in the flow of silicon oil circulating (volumetric FMI pump Model RP-D, $\frac{1}{4}$-in. ceramic head) around (copper coil) and through the high-voltage coil and the reactor. This heat flux is calculated from the measure of the silicon oil flow (111 Flo-Meter McMillan Co., checked four to six times per day with gauge flask and chronometer, resulting in a precision >0.25%) and the measures of the inlet and outlet oil temperatures (PT 100 Platinum gauge AOIP, giving a precision >0.25% on the temperature difference, the usual value of this difference being 15 to 20°C). The variations of the specific gravity and specific heat of the oil with temperature are taken into account. The oil stability during the runs is checked by periodic control of its specific gravity, by calibrations as described later, and by on-line measurement. The heat flux that is exchanged with the air of the laboratory (5 to 1%) is determined by calibration (correlation between the heat lost and the difference of temperature between the reactor and the laboratory).

The equation of the calorimeter is thus

$$P_{EXC} = P_{OIL} + P_{LOSS} - P_{ELEC} \ , \qquad (1)$$

where

P_{EXC} = excess power generated

P_{OIL} = power recovered in the oil flow

$= F \times Cp \times 4.184 \times (T_{OUT} - T_{IN})$

P_{LOSS} = power lost to the surroundings of the calorimeter (air and water from the cryothermostat)

$= K \times (T_{OUT} - T_{LAB})$

P_{ELEC} = electrical power injected in the system

F = oil flow (g/s)

Cp = specific heat of the silicon oil (cal/g·°C)

$(T_{OUT} - T_{IN})$ = difference of temperatures of this oil when leaving and entering the calorimeter (°C)

K = loss transfer coefficient (W/°C)

$(T_{OUT} - T_{LAB})$ = difference of temperatures between the oil leaving the calorimeter and the laboratory (°C).

The variable K results from a calibration procedure that will be described later.

The heat flux that is generated by the friction of the silicon oil through the reactor and tubing is calculated from the measurement of the pressure drop of the oil through the unit. The corresponding power (which adds to the energy input to the unit) is $W_L = mgh$ (when m is the mass flow of oil in kilograms per second, $g = 9.81$ m/s^2, and h is the pressure drop in m); W_L varies from 0.3 to 0.6 W (for $m = 2 \times 10^{-3}$ or 3.5×10^{-3} kg/s, respectively).

The calibration curve was established during calibration runs where the system was heated in different ways: resistors, discharges in argon with the two types of reactor (with metal in contact with the discharge), and discharges in hydrogen in the double-barrier reactor with no metal between the dielectric barriers. In the runs with resistors, the power was delivered either by a direct-current generator or by the California generator (with cos φ varying from 0.35 to 1). The power lost to the air is

$$P_{LOSS} = P_{OIL} - P_{ELEC}$$

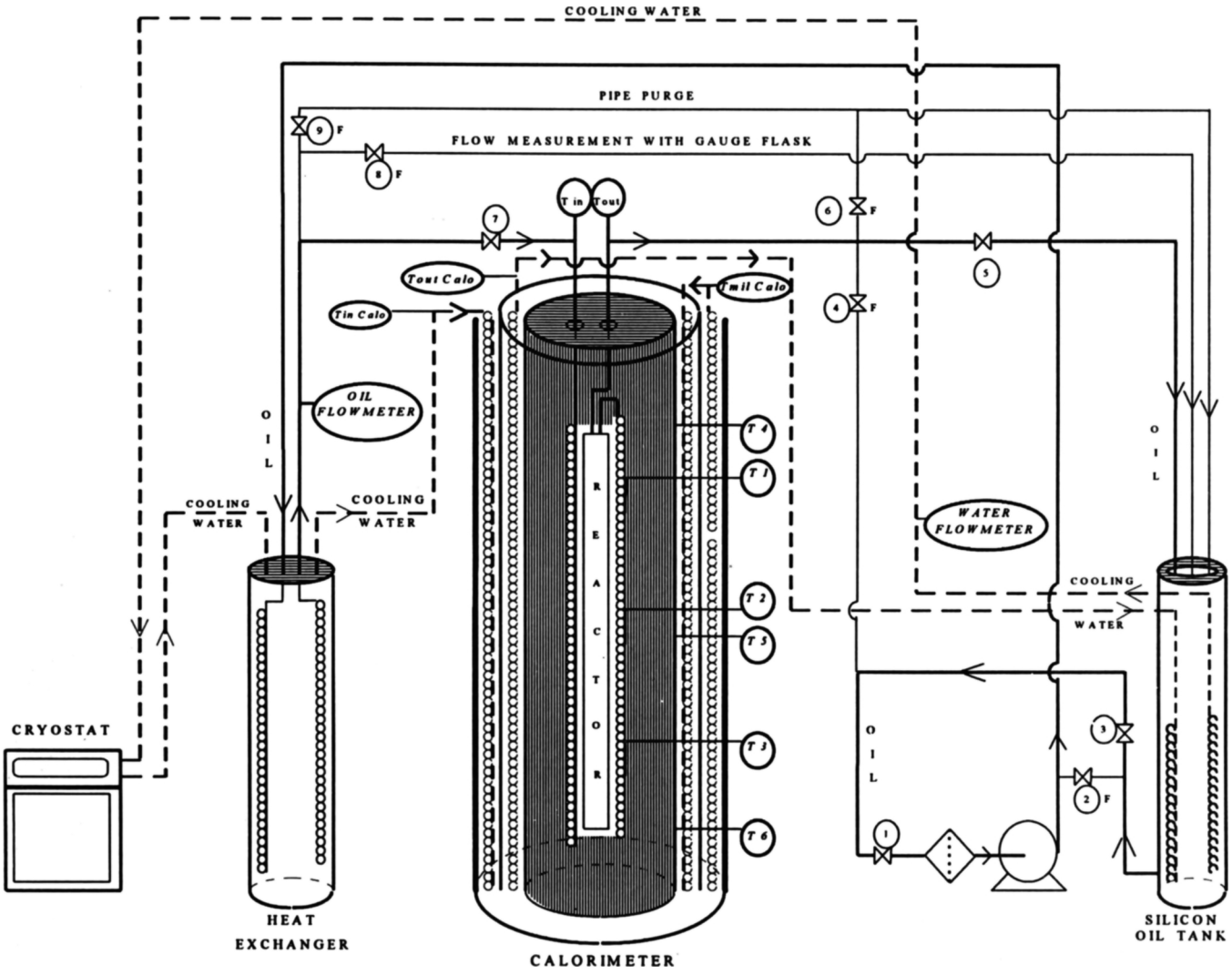

Fig. 3. Overall view of the calorimeter setup.

and is correlated with the difference of temperature between the reactor and the air of the lab:

$$P_{LOSS} = K \times (T_{OUT} - T_{LAB}) \ .$$

This correlation has been established with an oil flow of 2. 9 $\times$ 10^{-3} kg/s, corresponding to W_L = 0.47 W. No correction has been applied for other oil flows between 2 and 3.5 $\times$ 10^{-3} kg/s.

Figure 4 shows that all calibration points fall on the same correlation no matter how the system is heated. Moreover, the calibration runs with a discharge show that the system is electrically tight; i.e., no discharge occurs that could interact with the various components of the calorimetric system (insulation, PVC, etc.). Electrical charge transport only occurs in the gas gap of the reactor.

The calibration runs were performed over a period of 4 months, including three complete dismantling of the

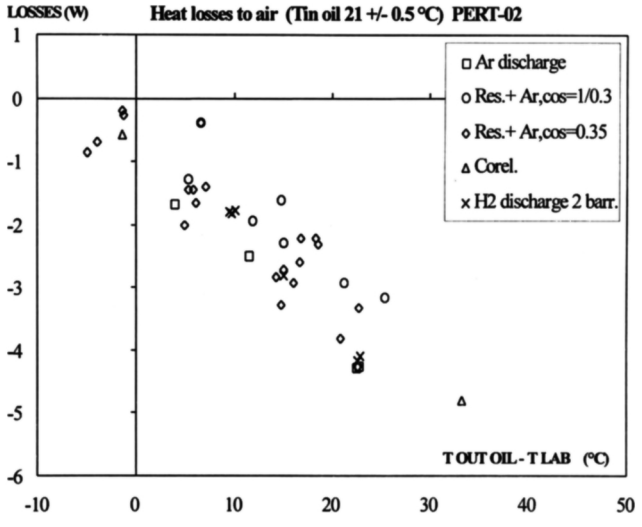

Fig. 4. Heat losses to air as a function of oil temperature.

reactor and calorimetric system. The various ways of heating are shown in Fig. 4: heating with discharges in argon in contact with palladium (Ar discharge); with resistors under argon atmosphere with various $\cos\varphi$ (Res + Ar $\cos\varphi$ = 1/0.3; Res + Ar $\cos\varphi$ = 0.35), and with discharges in hydrogen, without contact with any metal, in a double-dielectric barrier reactor (H2 discharge 2 barr.); corel are two points of the best linear fit of experimental data. Over this period, the standard deviation of the excess power measurement (zero for calibration runs) varies with P_{ELEC} from 0.7 to 1.1 W (for P_{ELEC} = 100 and 150 W, respectively). This demonstrates the stability of the system and its accuracy.

Hydrogen consumption is measured by a simple pressure balance of the reactor and its feeding reservoir (300 cm^3 initial pressure at 500 kPa). The reservoir, the pressure regulating valve, and the tubing of the hydrogen system are shown in Fig.5; they are made from stainless steel. A 40-cm-long (1.6-mm-i.d., 3.2-mm-o.d.) FET Teflon tube connects the stainless-steel tubing to the Pyrex reactor. The reactor is tight up to 150 kPa of hydrogen and the reservoir and tubing up to 700 kPa. No leakage is detectable over periods of several days.

All data required for the excess power and hydrogen consumption measurements are collected every 15 min by a data logging system (Centrale d'acquisition AOIP SA 70).

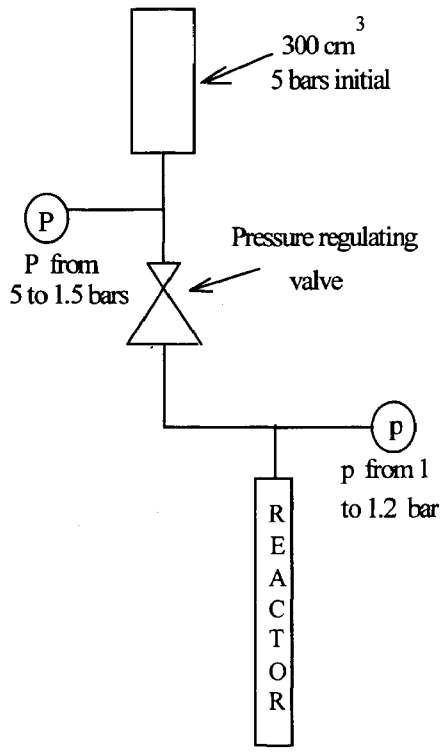

Fig. 5. Hydrogen consumption measurement.

RESULTS

The excess power produced is measured during active runs that last from 3 weeks to 3 months (to eliminate transient situations that can occur at the beginning of a run and to check the stability of the excess power produced with time). Active runs are those in which a discharge is struck through a hydrogen isotope in contact with a hydride-forming metal. Before each active run, the temperature gauges are calibrated. Each active run begins with a calibration (2 to 3 days) in which the reactor is under argon, H_2, D_2, or air and the system is heated by resistors and powered by the California generator. At the end of the run, after the discharge has been cut off, a calibration is also performed. Intermediate calibrations are performed for long runs. These calibrations ensure that the properties of the silicon oil are stable. The results of these active run calibrations are checked to fit the calibration curve, which was established as described earlier. The excess power during the whole experiment is computed every 15 min according to Eq. (1).

The results of the active runs are very dependent on the type of palladium used:

1. Runs with foils (double, dielectric barrier) gave results ranging from 0 to 4 W of excess power (for 100-W power input). This erratic performance was shown to be related to the mechanical resistance of the palladium—the palladium that gave negative results was found after the experiment with scales on the surface. The loading ratio for these negative experiments was of the order of 0.75. On the contrary, the surface of the palladium that gave positive results was found to be unaltered after the experiment. In that case, a strange behavior of the computed loading ratio [see Eq. (2) for its calculation] was observed (figures up to 2.5 were measured). This will be discussed later.

2. Runs with wires (single dielectric barrier) always gave positive results; the wires were never found altered after an experiment. The strange behavior of the computed loading ratio was also observed. Excess power generation up to 9.5 W for the hydrogen/palladium system and up to 13.5 W for the deuterium/palladium system was observed (for 150 W power injected). If we only take into account the power recovered in the oil flow (4.2 W for hydrogen and 8.2 W for deuterium, the power lost in the air and in the Invertron being 5.3 W in both cases) and given the measured standard deviation (1.1 W), these results are very significant.

A comparison of two active runs, one with negative results and one with positive, is shown in Figs. 6a and 6b. The negative run was with a palladium foil (which was found altered after the experiment) and a double dielectric barrier (hydrogen was used). During 1.5×10^6 s, the excess power was 0 ± 2.2 W (99% confidence level). The positive run was with a palladium wire and a single dielectric barrier (hydrogen also was used). The excess

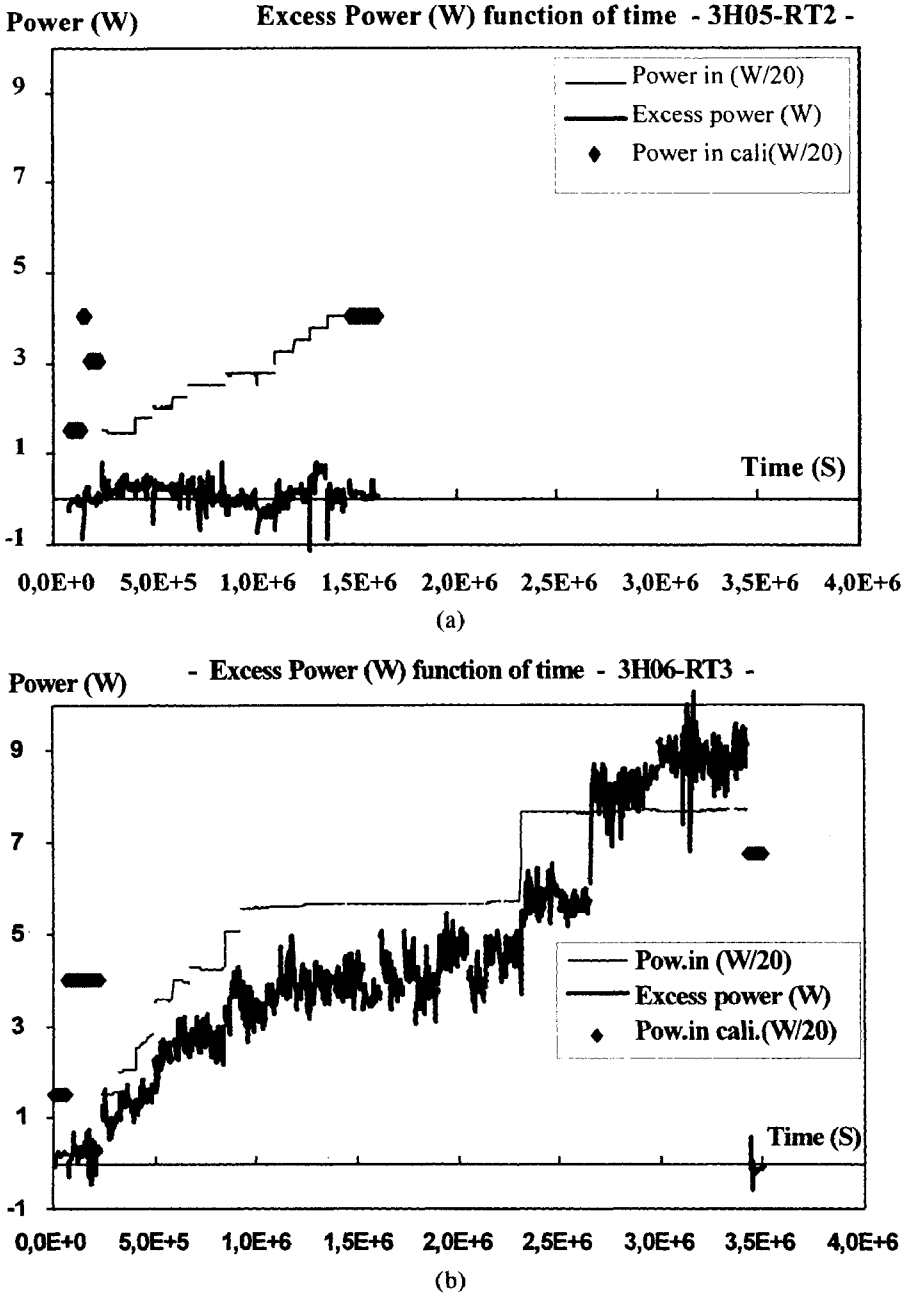

Fig. 6. Excess power as a function of time: (a) experiment 3H05 and (b) experiment 3H06.

energy increased on a period of 3.5×10^6 s to reach 9.5 ± 2.2 W (99% confidence level). The increase observed at 2.8×10^6 s is due to a change in operating conditions (as discussed later).

The results of a run with the palladium/deuterium system ere very interesting. It can be seen from Fig. 7 that the excess power production reached the level of 13.5 ± 2.2 W (99% confidence level) with a mean value of 9.2 W. After 2×10^6 s, the excess energy decreased from 2 to 0 W. This can be attributed to the loss of control of the operating conditions because of a breakdown of the data logging system (the ▲ symbols on Fig. 7 indicate this period). After repairing the data logger, a calibration was run (at 4.8×10^6 s) that gave 0 W excess energy production. The increase of the excess energy production from 0 to 14.5 W was obtained, as with hydrogen, by decreasing the reactor temperature. From 7×10^6 to 9×10^6 s (end of the experiment, due to a leakage in the silicon oil tubing), the excess power fluctuated from 7 W to values up to 12 W, with a mean value of 9.2 W. These

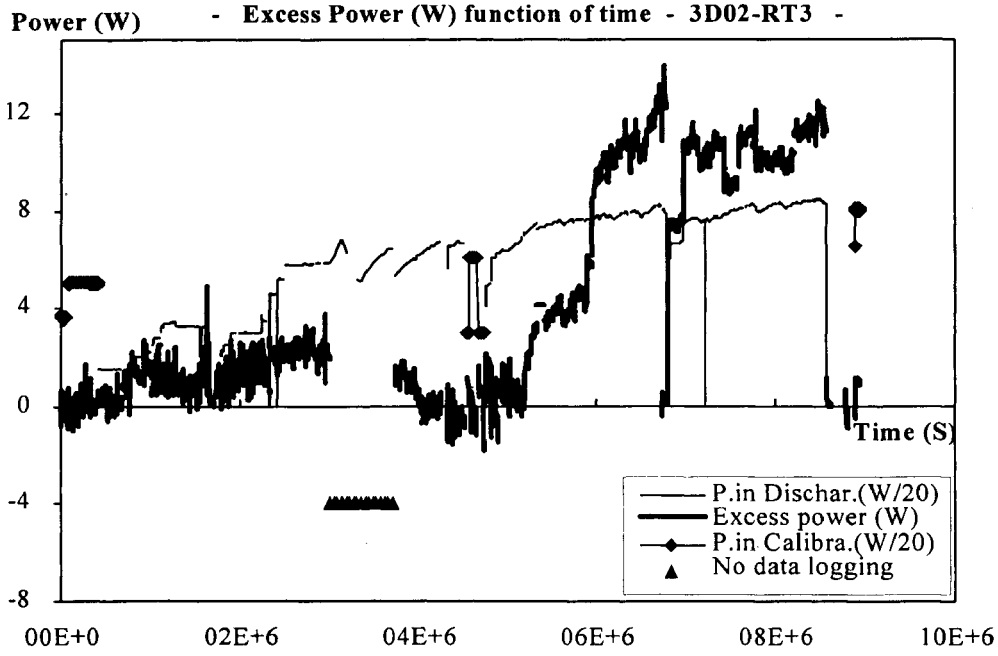

Fig. 7. Excess power as a function of time, experiment 3D02.

values are very reliable because three calibrations were made during the run (cutting off the discharge and using resistors to heat the system), one at the beginning, one after $\sim 5 \times 10^6$ s, and one after $\sim 9 \times 10^6$ s (2 days before the end of the experiment). (See Fig. 7 where these calibrations are indicated by ♦.) These three calibrations yielded 0 W excess power generation (with the usual 1.1 standard deviation). Moreover, an in-line measurement of the specific heat of the silicon oil was installed in the experimental setup (at the outlet of the main calorimeter) at 8×10^6 s. No variation of this specific heat was observed during the rest of the experiment, and its measured value was the same as the value taken for computing the excess power generation by Eq. (1).

The hydrogen consumption, together with the weight of palladium used in an experiment, allows the calculation of the loading ratio:

$$\text{H (or D)/Pd} = \{\text{mmol H (or D)}\}/\text{mmol Pd} \quad . \qquad (2)$$

The evolution of this loading ratio with time is given in Fig. 8a (no excess energy production, experiment 3H05) and Fig. 8b(excess energy production, experiment 3H06).

For experiments that gave negative results, the behavior of this loading ratio is normal; values are limited to 0.7/0.75, and once this value is reached, it remains constant for the rest of the experiment, meaning that once the palladium is loaded with hydrogen, no extra consumption of hydrogen occurs. On the contrary, for experiments giving an excess energy, this ratio always increases. Apparent values of this loading ratio up to 5 have been measured in experiments with wires. This cannot be explained by the loading of hydrogen in the palladium up to these values (electrolysis and hyperbar experiments give values limited to 1:1.1). This means that sizable quantities of hydrogen disappear in this experiment (up to 80×10^{-6} cm^3/s compared with the background value of the system, 5×10^{-6} cm^3/s).

One obvious explanation is leakage, which we exclude because, when the discharge is cut off, the consumption of hydrogen ceases. Another explanation would be the combination of hydrogen with material inside the reactor. This seems impossible; the only material in contact with the discharge is Pyrex (and, of course, palladium). Ionic implantation of hydrogen in the Pyrex, or permeation of hydrogen through it, is excluded by experiment 3H05 (Fig. 8a) where the Pyrex is submitted to the discharge in hydrogen and where no unexplained loss of hydrogen occurs. Small amounts of copper and steel are also present in the reactor but are not in contact with the discharge. The quantities of hydrogen they could absorb were calculated and found to be several orders of magnitude lower than the missing hydrogen. Their presence cannot explain the phenomenon. Finally, by weighing the palladium before and after the experiment, we saw that in all cases, the final loading ratio thus measured did not exceed 0.8. No hydrogen is thus stored in cavities of the palladium after experiment.

The excess energy production per atom hydrogen can then be calculated from the preceding measurements. As an example, Fig. 9 is a plot of the cumulated excess energy versus the cumulated hydrogen consumption as measured in experiment 3H06 (Figs. 6b and 8b). It can be seen that after the initial period when the power input is increased, a straight line can be drawn. This means that

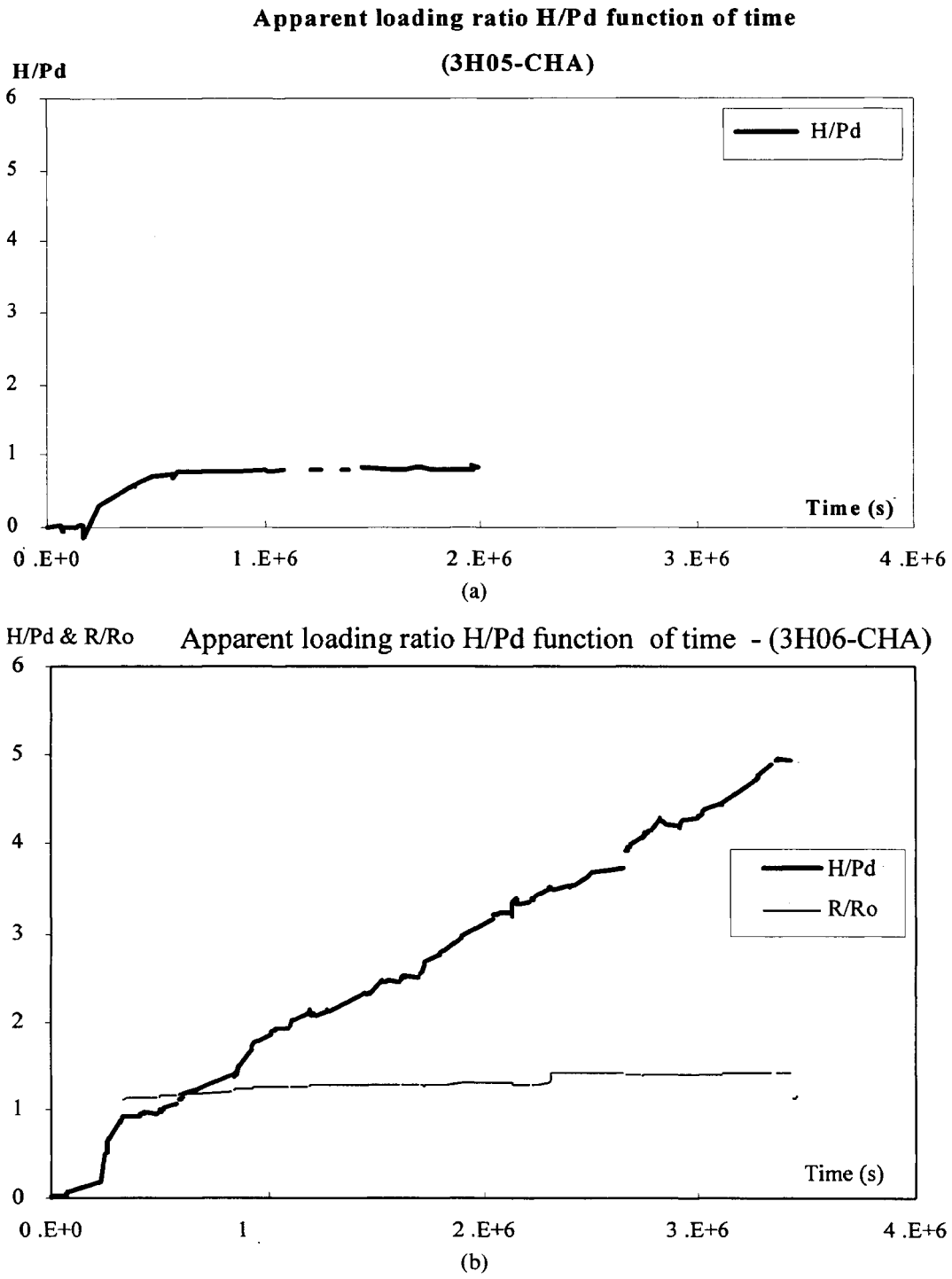

Fig. 8. Apparent loading of hydrogen/palladium as a function of time: (a) experiment 3H05 and (b) experiment 3H06.

under stable conditions, the excess energy per hydrogen atom is constant. The slope of the straight line gives this energy. We find 7100 eV/atom of hydrogen, with a standard deviation of 800 eV.

The main results obtained with hydrogen and deuterium are given next. For the case of hydrogen, the results obtained in experiment 3H06 (Figs. 6b and 8b) are summarized in Table I. At the beginning of period III, the decrease of the reactor temperature was achieved by increasing the oil flow from 2×10^{-3} to 3.2×10^{-3} kg/s. This decrease of temperature was immediately followed by a very fast increase in the hydrogen consumption (few

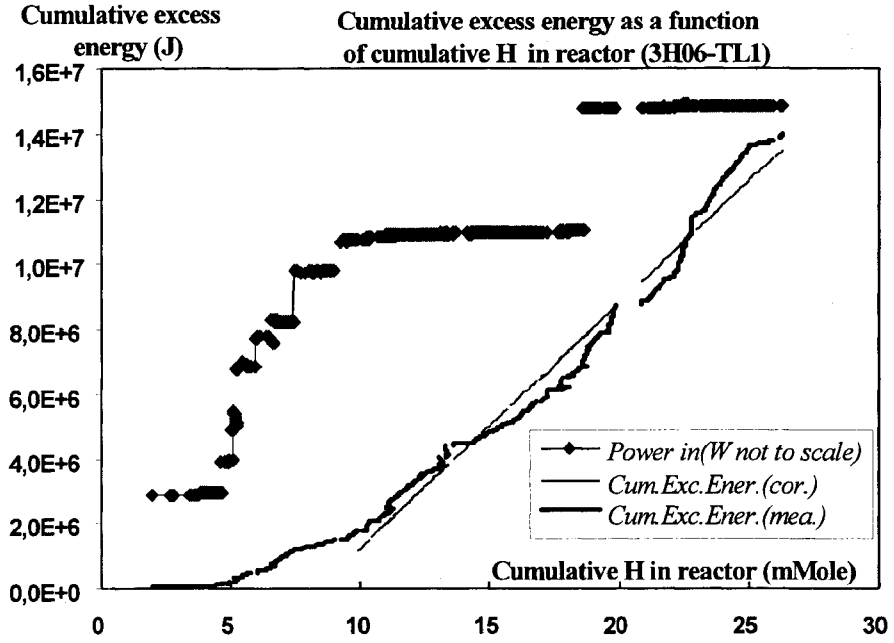

Fig. 9. Cumulative excess energy as a function of cumulative hydrogen in the reactor.

minutes), followed by a slightly slower increase in excess power generation (few hours), which reached 9.5 W at the end of the experiment. The 3.2-W increase of excess power generation between periods II and III cannot be explained by the small difference in friction losses (0.25 W). We tentatively relate this increase to an increase in the surface concentration of hydrogen in the palladium, favored by the decrease of temperature.

The overall excess energy production was 16018300 J. This cannot be explained by known chemical reactions. The combustion of all the hydrogen involved in the experiment (26.36 mmol) would have yielded 6400 J and the known hydriding process of the palladium even less (1900 J, corresponding to a mean power of 0.2 mW on the period).

After cutting off the discharge, the hydrogen consumption ceased. Weighing the palladium after experiment showed that it contained 4 mmol of hydrogen (corresponding to a loading ratio of ~0.75, the quantity of palladium in the reactor being 5.35 mmol). During the experiment, a total of 22.36 mmol of hydrogen (16.48 during steady-state situations) has been lost from the reactor in an unexplainable way.

We conclude from these measurements that

1. an excess energy of >16000000 J has been produced (2500 times higher than the most exothermic known chemical reaction that could take place in the system, the combustion of all the hydrogen involved)

TABLE I

Excess Energy Production per Hydrogen Atom for Experiment 3H06

Period	Duration (s)	Hydrogen Consumed (mmol H)	Excess Energy on Period (J)	Mean Excess Power (W)	Excess Energy (eV/atom H)	Power Input (W)	Reactor Temperature (°C)
CAL	230000	0	0			Calibration	
INC	695000	9.88	1737500	2.5	1800	Increasing	
I	1390000	9.63	5838000	4.2	6300	115	56
II	342000	1.41	1846800	5.4	13600	150	69
III	767000	5.44	6596000	8.6	12600	150	50
Total	3424000	26.36	16018300	4.7	9000[a]		

[a]Excluding period INC.

2. the excess energy per atom hydrogen is a constant under stable conditions (the most probable value is 7100 eV with a standard deviation of 800 eV; the fluctuations of this quantity observed in Table I can be attributed to the way we measure the hydrogen consumption, i.e., more adapted to the overall consumption than to the instantaneous one)
3. hydrogen is lost in an unexplained way during the production of excess energy.

For the case of deuterium, the results obtained during experiment 3D02 (Fig. 7) are summarized in Table II. At the beginning of period II, the decrease of the reactor temperature was achieved by increasing the oil flow. This decrease of temperature was followed by an increase in deuterium consumption together with an increase in excess power, from 0 to an average of 9.19 W (with peak at 13.5 W) over a period of ~860000 s. The overall excess energy production amounted to 30350000 J. This cannot be explained by any known chemical reaction. The combustion of all the deuterium involved in the experiment would have yielded 4150 J and the known hydriding process of the palladium even less (1220 J corresponding to a mean power of 0.15 mW on the period). The overall deuterium consumption was 17.16 mmol, corresponding to an apparent deuterium/palladium loading ratio (at the end of the experiment) of 2.91, which is unexplainable. At the end of the experiment, the deuterium in the wire was recovered by electrically heating this wire to ~300°C (in the reactor before dismantling). The deuterium recovered (4.5 mmol) gave a deuterium/palladium loading ratio of 0.8. The deuterium lost in an unexplainable way was thus (17.6 − 4.5) = 12.66 mmol.

We conclude from these measurements that

1. an excess energy of >30350000 J has been produced (7300 times higher than the most exothermic known chemical reaction that could take place in the system, i.e., the combustion of all the deuterium involved)
2. the excess energy per atom hydrogen is a constant under stable conditions (the most probable value is 23500 eV with a standard deviation of 1100 eV)
3. hydrogen is lost in an unexplained way during the production of excess energy.

DISCUSSION

The following experimental evidence has been gathered:

1. In previously reported experiments,[5] the upper values found for the ashes expected from the known fusion reactions of $^{2}_{1}H$ were found to be much too low (>10 orders of magnitude) to explain 5 to 10 W of excess energy (for 1 W these values should be 10^{12}/s for protons, tritons, neutrons, and $^{3}_{2}He$; 10^{7}/s for $^{4}_{2}He$ and gamma rays of 24 MeV; or 3×10^{11}/s for $^{4}_{2}He$ if this is the only ash). In the case of $^{1}_{1}He$, no gamma rays of 511 keV were observed that could have resulted from the annihilation of positrons formed by the known $^{1}_{1}H$ fusion reaction.

2. Excess power generation has been measured with a high confidence level (99%). Taking into account the total excess energy generated (16000000 J for hydrogen and 30000000 J for deuterium), the following explanations have been eliminated (their effect would be several orders of magnitude lower than what is observed): hydrogen combustion, palladium hydriding, silicon oil combustion, hydrogen reaction with materials in the reactor, and exothermic modification of the Pyrex under the influence of the electrical charges deposited by the discharge.

TABLE II

Excess Energy Production per Hydrogen Atom for Experiment 3D02

Period	Duration (s)	Hydrogen Consumed (mmol H)	Excess Energy on Period (J)	Mean Excess Power (W)	Excess Energy (eV/atom H)	Power Input (W)	Reactor Temperature (°C)
CAL	403200	0	0			Calibration	
Loading	3632400	5.51	3741300	1.03	7000	Increasing	
I	964800	0.0	0	0	0	125	52
II	864000	0.62	1391000	1.6	23300	155	56
III	2744100	11.03	25218300	9.19	23800	155	45
Total	8608500	17.16	30350600	4.7	23700[a]		

[a]Excluding period loading.

3. This excess power is generated in a very specific way, the excess energy per atom of hydrogen being a constant for a given set of reactor conditions. The value of this energy is on the order of 7100 eV for hydrogen and 23 500 eV for deuterium. Moreover, this excess power generation occurs simultaneously with an unexplained loss of hydrogen from the reactor.

The Hydrex (Deutex) Hypothesis

The hypothesis of the formation of a tightly bound state of hydrogen (deuterium) in cold fusion experiments has been put forward.[6,7] In such bound states, the electron is much closer to the proton than in normal hydrogen. This could explain both a high energy of formation and a greater than normal capacity to diffuse through any material. Hence, energies of formation of several thousand electron-volts and loss of hydrogen through the walls of the reactor could be explained. The energy of formation of the tightly bound hydrogen state could be released in the form of low-energy X rays that could be absorbed in the reactor and could cause the excess energy production.

We hypothesize that the formation of this tightly bound hydrogen state could occur if the following conditions are met for one proton and one electron inside the palladium lattice:

1. Their spins are parallel.
2. They get sufficiently close (100 to 500 fm).

These conditions might be met at the occasion of the jump of hydrogen (proton) from one octahedral site of the palladium to another, when a high electrical current flows through the palladium lattice highly loaded with hydrogen (hydrogen/palladium ratio close to 1). If the existence of this tightly bound state of hydrogen is proven to be possible (as proposed in Refs. 6 and 7), then the formation of this bound state should release much more energy than the well-known formation of the usual hydrogen atom (tens of kilo-electron-volts compared with 13.6 eV), and this excess energy would not be contradictory with the fact that the ground state of normal hydrogen is a minimum energy state. Simply, the hypothetical new tightly bound hydrogen atom (hydrex) would be a different species from the usual hydrogen atom, with a different ground state.

We note that the well-known quantum mechanical description of the normal hydrogen atom results from application of the Schroedinger or Dirac equations to a simplified system comprising one pointlike positive electrostatic potential (the proton) and an electron at rest at its starting position. We deal here with a very different system, where fast electrons interact with cold protons very closely surrounded by periodic negative potentials (the electrons of the palladium lattice) through which these protons drift by electrodiffusion. It should not be excluded that the application of the Schroedinger or Dirac equations to this complex dynamic system could give results different from the treatment of the simplified system, leading to the normal hydrogen atom. Finally, we note that the type of proton/electron interaction that occurs in palladium loaded with a hydrogen isotope is very likely to be unusual in nature. This could explain why the formation of the hydrex state of hydrogen should not be frequent in the universe. Moreover, shortly after its formation, this tightly bound state should be readily destroyed and converted to normal hydrogen by cosmic rays of energy higher than its energy of formation (7 to 23 keV, depending on the isotope).

Expected Properties of the Hydrex (Deutex) State of Hydrogen

Apart from its high energy of formation and its capacity to diffuse $\underline{H}_\bullet$ (hydrex) should be a small atom (hundreds of femtometres) with a permanent electric dipole. When getting sufficiently close to a nucleus present in the metal lattice, it could be confined against it. The probability of electron capture by the nucleus can thus be increased as with $^{40}_{19}K$, for example (as also proposed in Ref. 7),

$$^{40}_{19}K + \underline{H}_\bullet = {}^{40}_{18}Ar + {}^{1}_{1}H^{+} + e^{-} + \nu \ .$$

Similar reactions should be expected for $^{138}_{57}La$ and $^{50}_{23}V$, which give exothermic electron capture reactions.

These reactions could account for a number of weak nuclear signatures observed in the experiments.

CONCLUSION

From these results, we conclude that a very promising reaction occurs in metallic-hydride-forming metals when loaded with hydrogen isotopes and submitted to high transient electric currents. We think that explaining the phenomenon by a rearrangement of the bounding between the proton and the electron, due to the confinement of the metal lattice, is more plausible (although not known) than invoking highly improbable fusion reactions. We intend to put more effort into understanding this reaction.

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