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COHERENT NUCLEAR REACTIONS IN CONDENSED MATTER

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ABSTRACT

The aim of this paper is to show that the existence of "cold" nuclear fusion in the Palladium lattice cannot be just an insignificant curiosity of nature since it derives from the peculiar interplay of electromagnetic fields and matter fields. Its understanding then requires the conceptual frame established by Quantum Electro Dynamics (QED).

The expected resistance in accepting a conceptual breakthrough in our conception of condensed matter has certainly biased the attitude of the scientific community against this phenomenon. This mistrust and the initial difficulties in the definition of the significant experimental parameters contributed to create the myth of "cold fusion" irreproducibility.

Here we sketch a conceptual path starting from the knowledge of unexplained facts known from decades to the proposal of a new field of research initiated by the experiments performed by Martin Fleischmann and Stanley Pons from 1984 to 1989

Key Words: Fusion Energy Systems, QED, cold nuclear fusion, ^{4}He detection

1 INTRODUCTION

The term "believers" to describe scientists which have obtained confirmation to the Fleischmann and Pons experiment (1), or "non-believers" for scientists which reject those results have been often used in the debate about "Cold Fusion". However, the scientific ethic would require to substitute the category of the logic to that of the faith. Even if many times in the past, the serendipity allowed important breakthrough in science, a major reason for the opposition to the trust in the reality of the phenomenon of Cold Fusion appears to be the idea that this research project was undertaken in an the absence of reliable theoretical framework. However, the decision of one of us (M.F.) to embark in 1983 on this field of research in condensed matter was the intuition that Quantum Electrodynamics, (QED.), implied that nuclear transformations of D^+ compressed into Pd lattice would differ substantially from the reactions observed in dilute plasmas. QED is the relativistic quantum field describing interaction of electrically charged particles via photons and it is therefore a good candidate to describe the interactions among particles and fields inside condensed matter. This intuition was substantially shared by Julian Swinger in 1989 (2).

A topic relevant to this research was the work carried out by Bridgman in the 1930s (3). Bridgman found that the energy stored in a lattice by intense shear and compression could be released in "Cold Explosions" in which the stored energy was converted into the kinetic energy of fragments of the lattice. This led to envisage a sort of amplification of the energy through a collective behaviour of the lattice.

A second factor was our knowledge of the work of Cöhn on electrodiffusion of hydrogen in the Pd lattice (4). This showed that hydrogen was present as protons in the lattice (deuterium had not yet been discovered at the time of Cöhn's investigations). This feature poses severe problems to the condensed matter theoreticians since it requires a very high energy for the formation of ionic hydrogen in the lattice. A possible Born-Haber cycle (5) based on dissolution of H^+ requires an energy as high as about 30 eV (i.e. $H_2 \rightarrow 2H$ requires 4.48 eV and $2H \rightarrow 2H^+ + 2e$ requires 27.2 eV).

A third factor was our knowledge of the very early literature on the subject of fusion, e.g. see the paper from Oliphant, Harteck and Rutherford (6). The importance of this paper lies in the fact that it led to investigations of the fusion process $D+D \rightarrow T + H^+$ in a Wilson cloud chamber (7). A surprising feature of these measurements was the observation of a significant number of tracks angled at 180° (whereas the track should have been angled at 160° under the experimental conditions); this could only be explained by the fusion of species which had lost most of their energy in the target!

The question posed to us are usually asked in the context of Quantum Mechanics which clearly shows that "Cold Fusion" should not be possible. The nuclear physics of deuterons in a lattice (with a space-time scale some six orders of magnitude smaller than the space-time scales of the lattice) should not differ from the nuclear physics in a vacuum (the principle of Asymptotic Freedom, AF). However AF is <u>not</u> a general property of the coherent ground state of QED in condensed matter !

Suppose that a fusion reaction is a physical event localized at a definite site of the lattice as it is expected according to Quantum Mechanics. The compound nucleus D+D must release its exceeding energy (in order to relax to a stationary state) in the time allowed by the Heisenberg uncertainty principle $\Delta E \Delta t \sim \hbar$. In order to reach the nearest atom at a distance of about 3 Å (i.e. about the distance between first neighbours in Pd lattice) the velocity of the energy transfer should be orders of magnitude grater than the speed of light, then the only possibility for the nucleus is to fission in fragments as expected in vacuum!

Even if we are able to find in condensed matter quantum electrodynamics, a mechanism able to justify weak interactions such as the capture of "heavy" electrons by proton as suggested recently by A. Widom (8), it is still hard to imagine a mechanism able to dissipate the energy produced locally different from a coherent electromagnetic field. Widom invokes collective proton layer oscillations on the surface of Palladium able to produce a field capable to "dress" electrons with an enhanced mass. Such a renormalization via electromagnetic fluctuation enhances the capture probability and the consequent low momentum neutron production that can induce a chain of reactions in the neighbouring condensed matter. However, according to the universally accepted principle of physics, it is impossible to dissipate energies of MeV simply by "heating" the lattice without emission of very energetic fragments that have not been observed in these phenomena. So cold fusion cannot be a localized event but implies the revision of some of our implicitly assumed facts about condensed matter.

In 1989 another of us (E.D.G.,) together with the late Giuliano Preparata and Tullio Bressani (9) investigated the system in the context of QED. This approach is based on a critical analysis of the ground state of QED (10). The ground state in condensed matter involves the atoms/molecules of a macroscopic piece of matter in an intricate dynamical interplay mediated by large amplitude (classical) e.m. field. In such a scenario the AF is not a general property of such coherent ground state because the e.m field fills the vacuum among the particles inside the matter and interacts strongly with the charges. Let us briefly summarize the main points of this dynamic.

1.1 Coherent Dynamics in Cold Fusion

a) In a Pd crystal at room temperature the d-electron shells are in a coherent regime within "coherence domain" (CD) as large as a few hundred Angstroms. Electron shells oscillate in tune with a coherent e.m. field trapped in the CD, whose frequency is in the range of soft X-rays. The coherent plasma of the d-shells is so inflexible, that at selected points in the lattice, it produces permanent lumps of negative charge able to catalyze nuclear fusion in a way akin to the muon catalyzed fusion. This catalysis amounts to an increase in the barrier penetration factor among deuterons by about 40 orders of magnitude. However, this enhancement is not enough to justify the fusion yields observed by the experimentalists.

b) Hydrogens filling the metal enter into a coherent state when x= H(D)/Pd>0.7. The corresponding CD's range between 1 and 10 μm and oscillations are tuned with a self trapped e.m. field, whose frequency is in the IR interval.

c) In the case of deuterium, when the loading ratio x>1, the above coherent state induces a further magnification of the probability of tunneling of deuterons across the Coulomb barrier making possible the large number of fusions needed to produce the observed large amounts of excess heat. The excess energy is also released in a time shorter than that required to split the "boiling" ^{4}He nucleus by the nuclear dynamics (about 10^{-21} sec.), so preventing a massive emission of neutron and tritium (11,12) so that the only nuclear ash of the process is a ^{4}He atom.

1.2 Energy Output of Cold Fusion

It is straightforward to see that such a peculiar release of energy into the lattice poses a severe question: "how the heat produced into the lattice can be extracted (and measured) avoiding the destruction of the lattice itself ? in other words "could Cold Fusion be developed into a practicable source of energy?" During the experiments performed in ENEA laboratories in Frascati, we have observed (see fig.1) the melting of the thin strip of Palladium used as a cathode in an electrolytic experiment after the loading with Deuterium and the crossing of the threshold foreseen by the theory. The scale-up of the experiments must take into account the geometry required to induce the phenomenon while such a geometry must be robust enough to dissipate the expected energy density (for civilian applications, this will lie in the range 1-10KW/cm^3).

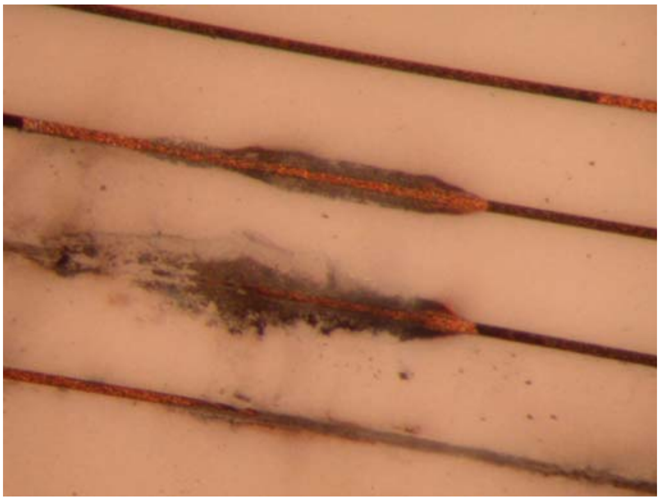

Fig.1 Thin film Palladium cathode after an experiment of cold fusion.

1.3 The Nature of the Nuclear Reaction Responsible for the Generation of Excess Enthalpy

Let us to analyze in more detail the process of release of energy in Cold Fusion. The production of ^{4}He, unaccompanied by γ-rays, demands a very fast (t <10^{-21} sec) energy transfer to the lattice electrons. The time T_0 needed for releasing the energy of 3.4 MeV necessary to put the "boiling" nucleus below the threshold of splitting is

$$T_0 \sim 1/2\ 10^{-21}\ \text{sec} < 10^{-21}\ \text{sec}$$

10^{-21} sec. is the time required by nuclear dynamics to split the nucleus (13).

In conclusion the output energy of each fusion is fast transferred to the Pd electron plasma , where it is converted to as an excitations at much lower frequencies.

There is, however, in a very short time interval, a short lived e.m. field having the frequency of γ-rays present in the Coherence Domain. At the rate of 10KW/cc, estimated both from theory and from experiments (14,15), one can calculate that in each Coherence Domain the average fusion rate is $2.5 \cdot 10^3$ sec^{-1} and the energy released by each fusion is transferred to the lattice in a time of 10^{-14} seconds, so that there is no superposition between the two events. Each fusion produces a γ-ray e.m. classic field lasting about 10^{-21} s. and spreads out on the whole volume of the Coherence Domain.

2. A COLD FUSION EXPERIMENT

The objections raised by the scientific community against the experimental evidence of excess heat production in heavy water electrolysis on Pd cathode, are mainly based on the opinion that such a phenomenon is unconceivable on the basis of the common accepted condensed matter physics, what we have already disproved in the former section, and on the criticism on the lack of reproducibility. To overcome this kind of opinions and prejudices the scientists involved in cold fusion researches have to be exceptionally rigorous and careful. Actually, the legitimate requirement of reproducibility has been quite difficult to fulfill since the theory has not focused on the parameters particularly relevant for the control of the experiment. It is worthwhile to note that most of the literature in the past decade and a half in reputed journals has reported primarily negative experiments (16). The crucial factor of the loading ratio is yet to be published in a respected journal. Now we know that the crossing of a threshold in loading ratio x=1 is mandatory to get the conditions for cold fusion to occur.

A critical point in obtaining the reproducibility is, in fact, the difficulty to overcome the loading threshold. Solving such a problem required extensive studies on the Palladium metallurgy because, as it is widely reported in literature, Palladium spontaneously (esothermic reaction) forms hydrides (or deuterides) in concentrations as high as x=0.7 but higher concentration can be obtained only by forcing Hydrogen inside powdered Palladium at very high pressure (in the order of MPa). Of course, this technique, as widely known, is completely useless for cold fusion purposes because it destroys the lattice. Cold fusion scientists have been forced to investigate this highly interdisciplinary area of science between electrochemistry and material science. These studies have produced interesting data (17,18) in literature even if the "cold fusion" words have been carefully avoided in the texts.

Even on such issue, QED provides an interesting and powerful shortcut.

2.1 The QED Description of the Pd-H System

Palladium hydrides exhibit very interesting features. Let us list a number of them:

a) the dissolved hydrogen get ionized after entering into the lattice and settle in their equilibrium position in ionic form.

b) the Pd-H system exhibits a complex phase diagram. At room temperature and pressure hydrogen is in a gas-like situation within the Pd lattice when x< = 0.05 (α phase). For higher values of x, a β phase emerges that coexists with the α phase; in the β phase hydrogen is confined in the octahedral sites of the Pd lattice. We get a pure β phase at x ~ 0.6 ; for higher value of x, new phases appear (19): β' and γ that coexist with the β phase , which gets increasingly depleted as far as x increases.
c) Evidence for the β→β' - γ transition is also provided by the measurement of the number of electric current carriers in the Pd-H system by means of the Hall effect (20). It has been found that each hydrogen entering into Pd lattice (in the β-phase) contributes about 0.75 electrons to the conduction band whereas for x exceeding a threshold each entering hydrogen contributes more than 4 electrons to the conduction band; since the hydrogen has only one electron on its own it must persuade more than three Pd electrons to jump into the higher energy band, so that the entering of one hydrogen implies a local reshuffling of the Pd structures.
d) The electrical resistivity ρ(x) of the Pd-H system as a function of x exhibits a peculiar behaviour (21). In the α-β phase, ρ increases almost linearly with x up to the x_0 value where the β-γ transition occurs. For higher values of x, ρ decreases quite sharply reaching the value ρ_0 of the empty metal at x ~1.1. This feature might be considered a consequence of c): the sharp increase of the number of the electric current carriers implies an increased electrical conductivity.
e) In the β'-γ phase the mobility *D* of hydrogen isotopes within Pd lattice exhibits an odd pattern; actually the heavier deuterium is more mobile than the lighter hydrogen whereas the still heavier tritium is, as reasonably expected, the slowest one, namely $D(d^+) > D(h^+) > D(t^+)$ (22). Since d^+ is a boson whereas h^+ and t^+ are fermions, the above result hints at the existence of some sort of collective behaviour of d^+ with respect to the other hydrogen isotopes. Actually the collective dynamics, as is well known, privileges bosons with respect to fermions (^{4}He , a boson, gets superfluid at 2.16 K, whereas ^{3}He gets superfluid at ~ 10^{-3} K).
f) There is electrochemical evidence (23), that at high values of x the hydrogen species perform wide oscillations in an almost unbounded state in the Pd lattice.

The last two items point to the existence of a collective oscillation of hydrogen within the lattice. However the existence of a strong cooperation among hydrogen is hardly understandable in the frame of the usual lattice dynamics (24). One could consider the possibility that a macroscopic ensemble of oscillating hydrogen could be described by a unique quantum state created by the collective dynamics. This point of view has been suggested in the last decade by G. Preparata in the frame of coherent quantum electrodynamics. Should this point of view be correct a testable consequence would emerge.

A quantum system, whose dynamics is described by a unique wave function, is able to "see" an externally applied potential as a chemical potential. This effect is the well known Böhm-Aharonov effect (25); the dynamics of a quantum system is affected by a change of the e.m. potential through a modification of the phase of the wave function. Should the ensemble of hydrogen atoms be in an unique quantum state, the chemical potential μ of $h^+(d^+)$ in Pd would be shifted by the applied electric potential $V(\vec{r})$ multiplied by the screened charge Z^*e of the $h^+(d^+)$ in Pd

$$\mu[V(\vec{r})] = \mu[0] + Z^*eV(\vec{r})$$

In eq. (1) μ [0] could be taken as the chemical potential of the point 0 of the Pd-H specimen where the electric potential is highest, so that V is the (negative) relative potential of the point $\vec{r}$ with respect to 0. The profile of the chemical potential μ is changed in such a way that the chemical potential in some regions of the system can fall below the chemical potential μ_{ext} of the ions outside. Consequently an inflow of ions would occur in those regions. This effect would be increased if it is possible to apply large electric potential differences across the system without inducing sizeable Joule heating which could inhibit the precondition for the effect, i.e. the $h^+(d^+)$ coherence. The optimal effect is expected in one-dimensional specimen whose resistance

$$R = \rho \frac{l}{S}$$

is increased as much as possible by taking a large length *l* and a very small cross-section *S*. Since the expected height of the chemical potential barrier is a fraction of one eV and Z* has been estimated as about 0.1, a voltage of about 10 Volt applied along the wire should be sufficient to induce a massive inflow of ions increasing the loading by a factor 1.3-1.4 with respect to a two or three dimensional specimen (plate or rod) under identical conditions.

2.2 The Experiment Design

At the end of the 1990s, about 10 years of experience in cold fusion experiments performed all over the world by many unrelated groups of scientists had been collected. It was clear to us at that time that the phenomenon, even though weak and unsystematic, was real and well understandable in a certain theoretical frame. It must be said, however, that most of the experiments proposed encountered a widespread scepticism in the scientific community because of an erratic reproducibility of the results reported, a situation which has only two possible explanation: either the phenomenon does not exist or there is an insufficient control over the relevant experimental parameters. As we have already said, such a poor control was mainly due to the complexity in obtaining and maintaining the right concentration of Deuterium in Palladium.

One common feature of those experiments was the unpredictability of the start and stop time of the excess heat generation. Sometimes, several weeks of initiation time were required to start the phenomenon without any apparent change in the system, while at other times the excess heat started immediately after the beginning of electrolysis. Such a lack of causality between the action of the experimentalist and the response of the system leave room for the possibility of spurious interpretations which can affect the observations and pollute the results.

Bearing in mind the theoretical framework depicted by Giuliano Preparata and Emilio Del Giudice (see references) and with a strong feeling in the rules of the scientific debate we (A.D.N., A.F., E.D.G. and Giuliano Preparata) started an experimental program aimed at having the contemporary evidence of : a) the existence of a threshold in the loading ratio; b) the heat excess production; c) the ^4He production. The hint of QED should have been able to let us to control the loading through the above described "Böhm-Aharonov" effect applied to a Palladium cathode in electrolysis in heavy water, and the "triple coincidence" technique should rule out the spurious events. The main difficulties to overcome were the geometry of the cathode and the Helium detection. As shown in the previous subsection, the best candidate to minimize the Joule effect was a "quasi" one-dimensional structure such as a thin film deposition with a planar dimension much greater than the other. Unfortunately, Palladium deuteride becomes very brittle with loading, and thin films tend to detach from the substrate. The solution to the problem was found after several attempts of deposition in different physical condition which led to the geometry shown in Fig. 2.

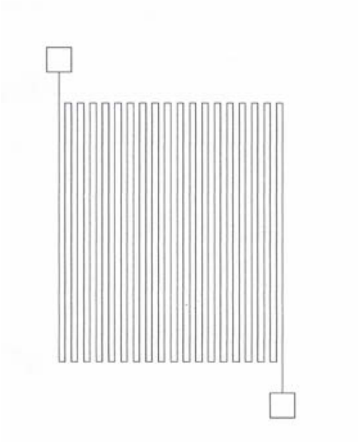

Fig.2 . The Palladium cathode geometry used for cold fusion experiment: 2μ thick x 54 μ wide x 100 cm long; Pd mass m=1.29 mg (=1.2 ·10^{-5} moles)

An innovative technique was developed, able to produce thin films that are able to resist several cycles of loading and de-loading.

However, the very tiny amount of material (1.2·10^{-5} moles) used limits the effective measurement of Helium. In fact, for a given excess power ΔP(W), the expected yield is given by:

$$\frac{\delta n_{He}}{\delta t} = \frac{\Delta P(W)}{24MeV \cdot N_A} = 4.32 \cdot 10^{-13} \cdot \Delta P(W) mole \cdot s^{-1} \qquad (3)$$

For a typical excess power in the range of a few tens of mW

$$\frac{\delta n_{He}}{\delta t} \approx 10^{-15} \div 10^{-14} mole \cdot s^{-1} \qquad (4)$$

Moreover the typical composition of the gas mixture in an electrolytic experiment is: a) atmospheric air which contains about 5.2 ppm of ^{4}He; b) D_2O vapour, in equilibrium with the liquid electrolyte; c) D_2 and O2 dissociated at the electrodes. The atmospheric air can be removed by purging the experimental environment with ultra pure (99.99999%) Nitrogen gas and the D_2 and O_2 moles can be accurately evaluated through Faraday's law. Thus we can expect the concentration of produced ^{4}He in the gas mixture be in the range of a few ppb with respect to N_2, and a few ppm with respect to D_2. The conventional mass spectroscopy technique seems inadequate to detect such a small quantity of ^{4}He in an environment substantially full of N_2 and D_2 . Even if a high resolution quadrupolar mass analyzer was required to resolve the difference between the masses of ^{4}He and D_2 molecule, the huge background of D_2 is likely to hide the smaller ^{4}He signal in the tail of the D_2 signal. Thus a suitable filtering process was realized, able to remove all the chemically active gases present in the atmosphere to be analyzed. Note that a detailed paper on the mass spectroscopy technique specially developed for this purpose was submitted to J. of Vac. Sci and Techn. As a first step, we started an experimental campaign which ran for two years. As a result, we were able to demonstrate a reliable and consistent set of data showing the presence of ^{4}He in samples 3 out of 5 experiments in heavy water like the one shown in Fig.3.

High values of ^{4}He atoms measured in the control experiments (with LiOH solution) were removed in a further refinement, fluxing the experimental environment with N_2 in order to reduce air contamination. The result on the following 11 experiments (5 out of 11 were control experiments) showed an average content of ^{4}He atoms in heavy water experiments 10 times higher than in light water experiments.

In those experiments we were able to detect the Helium presence in gas samples collected during the experiments at inhomogeneous time intervals. Furthermore, we wanted to evaluate, in real time, the atmosphere over the electrolytic cell in order to compare the results with the data of loading and heat excess. We were then forced to solve a number of technical problems such as the sampling of gases evolving from the cell at regular interval of time and without perturbing the electrolysis and the exact measurement of very small and complicated volumes in order to give an exact evaluation of the number of atoms detected (Italian Patent BO2004A000516, and BO2004A000517). Technical papers on these items have been recently submitted to specialized journals (Rev. Sci. Instr.).

The triple coincidence experiment described here is the result of a steadily amelioration of the experimental technique and of the refinement of the experimental set-up. These results should be considered as a confirmation of the results already obtained in the past.

2.3 The Results

The experiments showed that whenever a suitable electrical potential was applied across the cathode, a sudden increase in the loading was observed and, almost simultaneously, excess heat and ^4He were observed (compatible with the sampling time of the mass spectrometer and the thermal response of the calorimeter).

The description of the experimental technique is out of the scope of this paper but details on both the technique and the results can be found in ref 26.

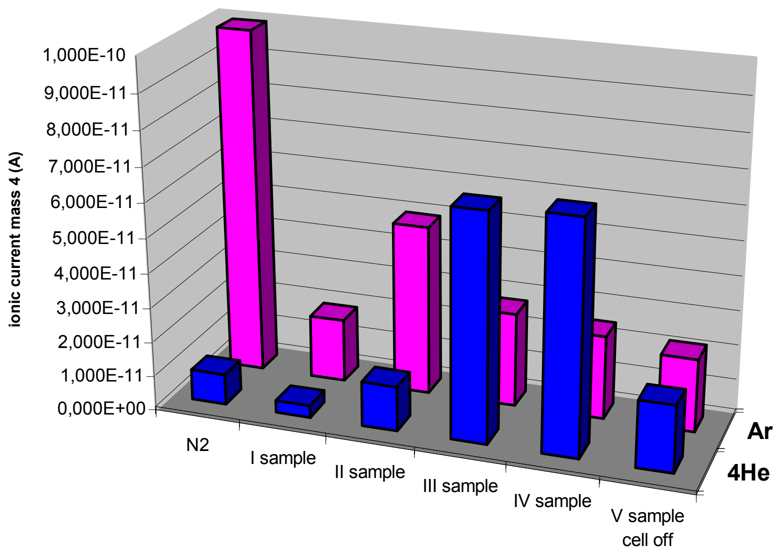

Fig.3 Values of the ionic current as read by mass quadrupole analyzer (QMA) in a typical experiment of electrolysis of LiOD on Pd cathode. The samples are not equally spaced in time. The comparison with the Ar signal tell us about the possible air contamination of the sample. These preliminary experiments were conducted using dry N_2 from boil off from a liquid nitrogen tank as purging gas.

We completed the measurement comparing three experimental situation: a) electrolysis in heavy water with a critically loaded (x>1) cathode; b) electrolysis in heavy water with an under-critically loaded cathode (x<1); c) electrolysis in light water (H_2O) with a critically loaded (x>1) cathode. The results are summarized in Table I.

Table I . Comparative results of 4He production from an electrolytic cell

	Electrolyte	Loading	Average ^{4}He yield (atoms/sec)	Total amount of ^{4}He atoms measured in gas phase	^{4}He atoms produced/initial
Experiment (1)	LiOD	x > 1	$6.1 \pm 0.8 \times 10^{10}$	$8.1 \pm 0.2 \times 10^{14}$	25.5 ± 0.8
Experiment (2)	LiOD	x < 1	$-2 \pm 3 \times 10^{8}$	$-2 \pm 3 \times 10^{11}$	-0.2 ± 0.1
Experiment (3)	LiOH	x > 1	$4 \pm 3 \times 10^{9}$	$1.37 \pm 0.04 \times 10^{14}$	$1.82 \pm .03$

The comparative analysis of the three experiments described above leads to the following conclusions:

In experiment (1), we detected an anomalous production of ^{4}He, which cannot be accounted for on a conventional basis, such as contamination. Furthermore, the start of the helium production coincides with the achievement of the super-critical loading and the appearance of thermal anomalies. Experiment (2) demonstrates that, in a sub-critical system, no excess helium production occurs. The helium detected in experiment (3) is clearly compatible with desorption from the light water electrolyte.

The ability of our experimental set-up to carry out a real-time analysis of the content of inert gases during the electrolysis, allows us:

a) to check for the coincidence of three independent parameters, i.e. cathode loading, excess heat and Helium production;
b) to establish whether or not the helium production may be due to a contamination source, by comparing the yields of Helium and Argon.

3. ARE NUCLEAR TRANSMUTATIONS, OBSERVED AT LOW ENERGIES, CONSEQUENCES OF QED COHERENCE ?

Many reports (27) point to the existence of nuclear transmutations occurring in solid metal lattices when they are loaded with hydrogen isotopes beyond a threshold. Elements absent before the loading were found thereafter and the natural relative abundances of the isotopes of the host metal were modified. The high energies required cannot be produced in any conceptual frame where phonon excitations only are present. A major conceptual difficulty arises from the large Coulomb barrier between the nuclei, whose overcoming would require large amounts of energy. Actually, only the fusion of nuclei having Z=1 can be made possible by the enhancement mechanisms due to coherence, whereas, for Z >1, since the dependence upon Z of the Gamov penetration factor is exponential, the probability of the barrier crossing is negligible. The only possible agents for nuclear transmutations should be in our case the uncharged ones: neutrons or e.m. fields. Leaving aside for now the possibility to have thermal neutrons in the lattice as suggested by Widom (see ref. 8,) let us point our attention on the field of 24 MeV lasting in the lattice 10^{-24} seconds as explained in section 1.3.

Almost sixty years ago the phenomenon of Giant Dipole Resonance, GDR, was discovered (28, 29, 30), which is a wide maximum of the interaction between nuclei and γ-photons located at 14-15 MeV. GDR is connected with the excitation of quantum collective modes in nuclei. The peak energy, as shown by Goldhaber & Teller, coincides with the binding energy of two closed shells in a nucleus. In a sense, under the γ-field, the nucleus enters a vibrational state capable of breaking the binding, releasing single nucleons or full shells. It is conceivable that the extended γ-ray field consequent to an event of fusion has a very high probability to interact with at least one nucleus enclosed in the Coherence Domain and induce a GDR. And, actually, the frequency of such a field is, for at least 10^{-21} sec, in the range between 16 and 24 MeV.

We then propose the following experiment:

There is preliminary indication (31) that Ni nuclei may be present in cathodes, subsequently to cold fusion. We propose to look for nuclear transmutations of Pd according to a probable scheme of a split of the nucleus into closed shells, i.e. the anomalous production of argon isotopes, as partner nuclei of Ni in a possible Pd fission process.

The closed shells that could appear in a Pd nucleus (Z= 46) have the following magic numbers: 28 protons (Ni) and 20 neutrons (^{38}Ar) which correspond to the reactions:

$$^{104}Pd + \gamma \text{ field} \rightarrow {}^{66}Ni + {}^{38}Ar \quad (5)$$

$$^{102}Pd + \gamma \text{ field} \rightarrow {}^{64}Ni + {}^{38}Ar \quad (6)$$

A detailed calculation of the interaction parameters of the coupling of the extended γ-ray field (which is not a single photon!) with nuclei is needed.

However the existence of such extended γ-ray fields is a necessary consequence of the coherent theory of cold fusion. Such fields appear, in the frame of accepted principles of quantum physics, as the likeliest engine to give rise to nuclear transmutations in the metal lattice at room temperature.

4. CONCLUSIONS

The existence of an anomalous heat excess produced during the electrolysis of heavy water with Pd cathode have been proved by several experimentalists all over the world with different (sometimes very different) experimental procedures, and have been approached by many theoreticians starting from different (sometimes very different) descriptions of condensed matter. However, for the last 15 years, some guidelines have been shared among physicists involved in cold fusion researches: a) the existence of a threshold in the Deuterium loading in Palladium is generally assumed as necessary even is some scientist considers it as not sufficient b) the absence of the yield of neutrons and tritium, correlated to the heat measured, as foreseen by the theory of nuclear fusion in vacuum; c) the presence of ^{4}He as nuclear ash of the process; d) the existence of other nuclear reactions, as transmutations of heavy elements, in condensed matter at room temperature; e) the necessity of collective behavior in condensed matter in order to cope with this new phenomenology.

The next question is: “can such a phenomenon be envisaged, in the near, future, as a new source of energy?” The main efforts of the “cold fusion community” have been devoted to clarify the physical or chemical-physical environment in which the phenomenon takes place and to convince the scientific community about its reality. However, it could be wise to start considering this question.

In order to create a device able to produce significant amounts of energy for civilian uses, we still have to know: a) which is the highest temperature reached by the Palladium during the ignition: the extremely high density power (1-10 KW/cm^3) evaluated by the experiments poses severe limits to the design of the device; b) since the heat emitted at very high temperature is mainly emitted as infrared radiation, we need to elaborate a technique of “out equilibrium” calorimetry in order to evaluate and correctly catch all the heat produced; c) the duration of a possible device for energy production is subjected not only to the possible “burning” of the cathode but also to its eventual contamination due to several cycles of loading-deloading in occasions of switch-on-off of the device.

It is clear that, from an engineering point of view, we are just at the beginning of the challenge, but the peculiarity of this possible source of energy is “probably” worthwhile. Cold Fusion is, in fact, a very high density source of energy, very different from fossil fuels and also from the other known nuclear energy (fission, thermonuclear fusion) devices which require large-scale power plants. This means that its best use will be a non centralized, energy production, right at the site where it will be consumed, thus reducing the cost of energy losses in distribution and thermal wastes, i.e. the fact that a significant part of energy produced in a conventional plant subsequently reverts to waste heat into the environment. Moreover the easy management of fuels (water), materials (it is reasonable to think that Palladium metal could be replaced by special Pd based material or, better, by another more abundant and cheap element such as Nickel or Ni compounds) and wastes (^{4}He) makes cold fusion a promising energy source for the future, for people willing to take the chance.

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