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Nuclear Physics Aspects of Cold Fusion Experiments

Scientific Summary after ICCF-7

T. Bressani
Dipartimento di Fisica Sperimentale
dell'Universita degli Studi di Torino
1-10125 Torino (Italy)

1 Introduction

The circumstance that I made the scientific summary on Nuclear Products in Cold Fusion Experiments also after ICCF-6 [1] gives to me the opportunity of combining the comparison of the results from two subsequent conferences and of discussing globally the impressive achievements gained in these last three years. The major achievement at ICCF-6 was, to my opinion, the evidence of the correlation between Excess Heat, when measured, and the production of ^4He, observed in quantities of the same order of magnitude of what expected form the hypothesis that the reaction $d + d \rightarrow {}^4He$ + *(energy)* is the main source of energy in Cold Fusion experiments. This conclusion was reached by several experiments.

At ICCF-7, besides the confirmation of this fact, a further striking experimental result was presented, shedding light on one of the two (or three) "miracles" that were often referred to as necessary to explain the Cold Fusion Experiments. The "miracles" are:

- a lowering of the Coulomb Barrier between two deuterons, able to give a fusion rate at quasi-zero kinetic energy of $\sim 10^{-20}$ fusions/sec • *(dd)* pair;
- a pattern of branching ratios for the channels leading to different nuclear final states completely different from that known for the free *(d + d)* fusion.

In addition, and that fact is not referring specifically to the *(d + d)* fusion but to other processes (transmutations), the preference of producing final nuclei that are stable and not radioactive (also sometimes referred to as the third miracle).

2 The first "miracle" of Cold Fusion observed in a typical Nuclear Physics Experiment.

Since some years, Kasagi *et al.* have approached the scientific problem of the *(d + d)* fusion in a way completely different from that of using Cells of various kinds (electrolytic, gas loaded, ...). They tried to put in evidence anomalies in the *(d + d)* fusion when *d* is embedded in a particular lattice by means of a deuteron beam from a high current (~1 mA) electrostatic generator, and by detecting the reaction products with well accepted techniques of particle identification. In a first series of experiments they reported the observation [2] of final products not expected from the single *(d + d)* fusion, but maybe related to more complicated and unexpected processes. At ICCF-6 they reported that the cross section for *(d + d)* at ~3 KeV was a factor 1.4 higher when *d is* embedded in a Yb lattice than for a pure Pd lattice [3]. The data could be explained by assuming that an electron screening potential of 60 eV was affecting the *(d + d)* reaction in Yb.

At ICCF-7 a spectacular result was reported [4]. The *(d+d)* cross section, measured down to 2.5 KeV, is 50 times larger when *d* is embedded in PdO than when in pure Pd or Ti! The electron screening potential necessary to fit the data is now as large as 600 eV. By extrapolating the data at near zero kinetic energy with such an electron screening potential, a fusion rate fully compatible with that necessary to explain the Fleischmann-Pons excess energy as due to cold fusion is obtained.

This experiment is very important for at least two aspects. The first one, quite obvious, is that it is a dramatic proof of the influence that condensed matter effects may have on nuclear observables. The "Condensed Matter Nuclear Physics", whose first milestone is the Mössbauer Effect, may consider this experiment as the second milestone. The second aspect is that the enhancement of the cross section for *(d + d),* as measured following the method of Kasagi *et al.*, could be considered as one of the quality parameters needed in the choice of metals/compounds/alloys best suited to reach reproducible results in Cold Fusion Experiments.

Another interesting result obtained using similar techniques (a ~150 KeV deuteron beam and typical Nuclear Physics detection systems) was reported by A. Takahashi [5]. Peaks observed in the ^{3}He and ^{3}H spectra were attributed to the fusion of three deuterons in the initial state, at a rate 10^{26} times larger than that expected for the traditional theory of the *(d + d)* fusion reaction.

3 Nuclear Products in Cold Fusion Experiments

It is well known from more than hundred experiments that neutron emission from Cold Fusion Cells is very low, if present at all. In case of positive results, the signal for neutron emission hardly exceeds a statistical significance of a few standard deviations. In this framework, two quite interesting results were presented at ICCF-7.

The first one was presented by Matsui [6], in summarizing the results of the "New Hydrogen Energy" project in Japan. He reported that the neutron energy spectra measured by 40 experiments are peaked at 2.5 MeV, as expected from the $d + d \rightarrow n +^3 He$ reaction.

The second one, by Oya et *al.* [7] is the first observation, to my knowledge, of a clear correlation between the excess power from a (Pd-LiOD) electrolytic cell and the neutron emission. The correlation coefficient is nearly constant for the three different experiments that were discussed in detail at ICCF-7.

^3H is another nuclear ash that was often observed in Cold Fusion experiments, at a rate higher than that of neutrons, but in any case not sufficient, by at least 5 orders of magnitude, to explain the reported Excess Heat. Claytor *et al.* [8] reported the final results of a careful study of ^3H production by Plasma excitation of Deuterium loaded Pd and Pd-alloys. The ^3H content was measured in real time, *in situ,* by a clever experimental procedure. Energy spectra and half-time measurements agreed with the assumption that the observed radioactive nucleus was ^3H. The statistical significance of the data exceeds 10 σ. The experiment of Claytor *et al.* is, to my opinion, very convincing; the only drawback, common to nearly all Cold Fusion experiments, is that the phenomenon was observed only in a limited amount of runs. The question of the reproducibility still has to be solved.

Let me now turn on ^4He measurements. Following my comments at ICCF-6, by the experimental facts ^4He seems to be the only nuclear ash produced in Cold Fusion experiments that may account quantitatively for the reported Excess Power. Three experiments presented at ICCF-7 confirmed this hypothesis, one not, but with some *caveat.*

At ICCF-6 the Osaka Group presented the first results on ^4He -Excess Heat correlation with their closed electrolytic cells. The correlation was not clear, due probably to calibration problems of the Spectrometer [9]. At ICCF-7 more positive results were reported. In some cases, a significant increase of ^4He was observed, exceeding by a factor even 15 the number of ^4He atoms present in the cell before the electrolysis.

Matsui [6] showed a quite remarkable result obtained at NHE Laboratory at Sapporo. They examined the ^4He content from a Pd wire that produced Excess Heat in the experiment of Celani *et al.* [10] at Frascati. A nice signal due to ^4He, well resolved from the neighbouring peak due to D_2 was observed, corresponding to a quite high fusion rate.

Finally Quiav *et al.* [11] reported a measured ^4He excess from a D_2/Pd gas loading experiment, lasting one year. The ratio He/Ne, particularly important for monitoring possible contamination from the atmosphere was measured before and after the experiment and found to be a factor 1.8 larger at the end of the experiment than at the beginning.

So far about the experiments reporting positive results on ^4He detection. Let me now briefly recall the experiment with a negative result. It was reported by Yamaguchi and Sigiura [12], and is an upgraded version of the previous experiment by Yamaguchi and Nishioka [13]. It is based on a heterostructure of Pd deuterated in gas phase. The Pd sample is prepared with a quite sophisticated system of magnetic transfer rods that enables one to perform all the necessary manipulations *"in vacuo".* The full apparatus is built in stainless steel, in order to avoid possible contaminations from atmosphere. Quite surprisingly, this new set-up, of global quality much superior than the previous one, is equipped with a Q-mass spectrometer (Bolzers QMA410) with a mass resolution worse by more than a factor two than that reached in the previous experiment.

The peak excess power observed with such a type of samples was up to 8 W for and input power of 0.1 W. with a 100% reproducibility. No clear evidence was found for the presence of ^4He and the authors conclude that the ^4He peak observed in the previous experiment may be an artifact, however with the *caveat* that the poor mass resolution in the present experiment could also be a reason for not observing ^4He.

For this reason I put this last experimental result of Yamaguchi and Sigiura under the class "unclear results" in Fig. 1, which is an updated version of the time evolution of experiments aiming to measure ^4He from Cold Fusion cells.

A final remark is that the experiments confirm that ^4He is the more convincing candidate of nuclear ash released in the energy producing reactions involved in Cold Fusion cells, when they provide Excess Heat. ^4He is expected not only from *(d + d)* fusions, but also from other nuclear reactions that may release energy, like *(d, a)* on ^{10}B contained in the Pd rods [14].

4 Transmutations?

I have always been absolutely skeptic about the possible existence of transmutations in Cold Fusion experiments. My attitude was determined both by the scarce quality of the experiments, suffering from low statistics and/or lack of complete control of the parameters and/or several other drawbacks, and by the extreme difficulty in finding a plausible explanation for such phenomena. The experiment of Iwamura *et al.* [15] however is quite different from the previous ones. Their cell, in which deuterium atoms are flowing through a Pd plate separating an electrolytic solution of D_2O/LiOD from a vacuum chamber, showed quite strange phenomena, like the production of Ti in quantities larger than the maximum contamination present in the samples and an isotope shift of the Fe atoms after the run.

The experiment is very well done and analysed. If other experiments of this class will be performed, I feel that I will be obliged to review my attitude towards transmutations.

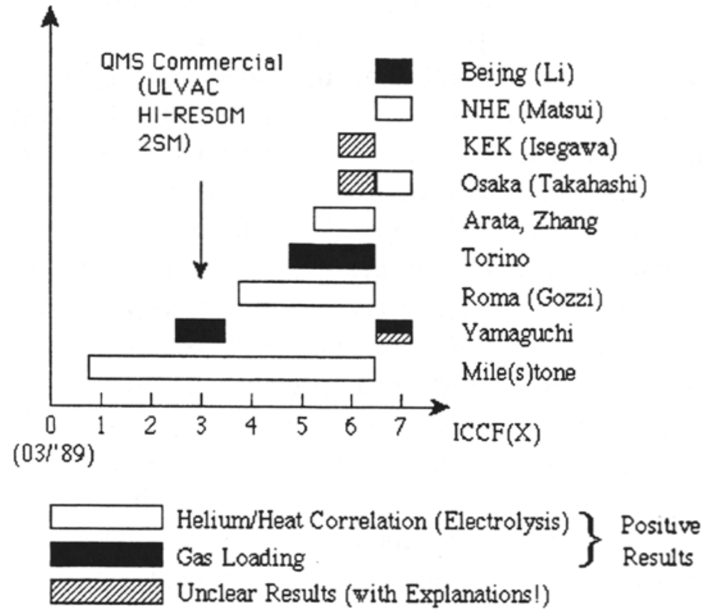

Figure 1: Evolution of dedicated experiments on ^4He production: the abscissa scale indicates the edition of the subsequent ICCF's held up to now.

5 Conclusions

I feel that ICCF-7 has represented a quite important turning point in the evolution of Cold Fusion. Concerning the two "miracles" mentioned in the Introduction, my impression is that the first one (the lowering of the Coulomb Barrier and the consequent increase of the fusion rate) is no more a miracle but a physical effect, as demonstrated by Kasagi *et al.* [4]. The second one (the inversion of the branching ratios for the final state products of *(d+d)* fusion in a lattice compared to the free case) is still a miracle, in the sense that it happens sometimes, due to the lack of reproducibility. But when it happens, it seems to show the same features: very few neutrons, a little bit more ^3H, abundant ^4He, the latter in the same order of magnitude of the Excess Heat in the hypothesis that it is due to nuclear fusion reactions.

These facts have and will influence the scientific attitude of the Cold Fusion community. The lack of reproducibility has a negative impact on the engineering efforts towards the realization of a power demonstration device. On the contrary scientific efforts performed mostly by University groups and oriented towards a physical comprehension of the effect seem to be more constructive and could lead, maybe at ICCF-8, to a comprehension even of the second "miracle" of Cold Fusion.

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