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Evidence of a nuclear event

by Carol White

How can it be that a nuclear reaction can be induced to occur in a palladium cathode (a negative electrode) which has been packed with deuterons (heavy hydrogen nuclei which contain a neutron in addition to a proton), by electrolysis and at room temperature? Is this a new kind of fusion reaction? Is, instead—or in addition—some other nuclear reaction occurring? Perhaps some entirely new kind of chemistry can be involved? What is actually occurring locally within or at the surface of the palladium lattice? The discovery of helium-4 production by Dr. Eichii Yamaguchi may not answer these questions but it does establish that a fusion process is occurring in the palladium lattice, at least under the conditions of his gas-loading experiment.

The mere probability that cold fusion could occur at room temperature in a metal lattice is something like 1 in 10^{44} or

1 chance in
1,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000.

The emission of neutrons and the production of tritium, as a byproduct of the production of excess heat, is a recognized indicator of the occurrence of a fusion reaction in high-energy systems; however, the numbers of neutrons and amount of tritium found in cold fusion experiments are far too low—by magnitudes, for neutrons, as great as a billion times—to account for the excess heat produced. While the experiments last year by Melvin Miles at the Naval Weapons Center indicated that the production of helium-4 may be the missing link to account for the additional heat, he was unable to generate sufficient heat again to repeat his experiment. Most probably, he believes, this was because the design of his calorimetry allowed too great a rise in heat during the early loading period.

Heretofore, it has been generally accepted that chemical energies are far too low, by orders of magnitude, to affect any nuclear process, much less permit the fusing of nuclei. While the production of helium-4 is not typical of hot fusion, it is an understandable pathway for the occurrence of the reaction.

Hydrogen is the first element in the chemical table, and it is predominantly composed of one proton in its nucleus and one electron which orbits the nucleus. Deuterium is hydrogen in which there is a neutron as well as a proton in the nucleus of the atom, and still one electron. Tritium has one proton and two neutrons. (The two-ness of deuterium comes from the fact that the two nucleons—the proton and neutron—double the weight of the nucleus, and the three-ness of tritium from the fact that it has three nucleons.) The addition of neutrons to the hydrogen nucleus contributes to a potential instability which favors the possibility of fusion.

The ability of a chemical reaction to trigger a nuclear reaction opens up not only the possibility of achieving nuclear fusion under extraordinarily favorable conditions, but other new scientific frontiers as well. It is one of the ironies of the last three years, that the failure of the cold fusion experiment to produce neutrons and tritium (in the expected 1:1 ratio that occurs in hot fusion), combined with the fact that the numbers of neutrons and the amount of tritium produced are far too low to account for the generation of excess heat by a traditional fusion process, is considered a drawback to establishing the new field.

Yes, cold fusion is anomalous, but it also will be an enormous technological boon to generate a nuclear reaction which is relatively aneutronic and free of radioactivity.

The announcement by Dr. Eichii Yamaguchi, a senior scientist with Nippon Telephone and Telegraph (NTT), that he had found helium-4 in a cold fusion experiment, was greeted with great excitement among conference participants, who comprehended that it represents a major step forward in understanding the cold fusion phenomenon.

The Yamaguchi experiment

Dr. Yamaguchi was one of the first physicists to begin researching cold fusion. He received some support from NTT, although, until recently, his cold fusion researches were definitely subordinated to his other work as a solid state physicist. His work has had a certain amount of ambiguity, because—aside from one extraordinary heat burst achieved by loading deuterium into a palladium plate—using a gas-loading method, he normally gets the same amount of excess heat release from the palladium plate whether it has been loaded with hydrogen or deuterium.

Well before the news broke of Martin Fleischmann and Stanley Pons's claims to have achieved a fusion reaction at room temperature using the tools of electrochemistry, Yamaguchi was studying the anomalous properties of hydrogen. When he heard of the Fleischmann-Pons claims on March 23, 1989, he was skeptical that fusion was actually occurring, but he was well aware that there were many unknown aspects of the behavior of hydrogen. Yamaguchi chose to conduct a gas-loading experiment rather than repeat the Fleischmann-Pons design using electrolysis, because he was interested in capturing fusion products from the electrolyte which is far easier to do under vacuum conditions. Furthermore, he contends that the greater purity of the vacuum environment removes the questions raised by the possible contamination of electrolytes in explaining an anomalous event. It is also, in his view, more amenable to the application of various spectroscopy techniques.

His design calls for the coating of one side of a palladium plate with a very thin oxide and putting a thick gold film on the other. The oxide inhibits the release of hydrogen or deuterium from the cathode, and the gold acts as an absolute barrier to its diffusion. The gas-loading technique that he used is fairly standard; in this instance the oxide was manganese oxide. At the time when he began his experiments he had available to him a 15-year-old accelerator, which was just about to be decommissioned. Over several months, he was able to use its vacuum chamber for his experiments. The vacuum chamber is the heart of an ion implanter and accelerator. The one he used was about half the size of a hotel dining room. The advantage of utilizing this vacuum chamber was that he was easily able to calibrate neutron emissions. In normal use of the accelerator, deuterated palladium would be bombarded with deuterons and would routinely emit high-energy neutrons.

After placing the palladium (already coated on one side with manganese oxide) into the vacuum chamber, Yamaguchi then heated the chamber to between 300° and 400°C. He annealed the palladium in order to force hydrogen out of the palladium lattice. Then he introduced deuterium into the chamber in a gaseous form and he began to reduce the temperature gradually. As he did so, the deuterium gas penetrated the surface of the palladium (still uncoated by the gold, but having a thin oxide layer of only several angstroms).

After the palladium was loaded to about 60% with deuterons (typically the highest loading possible except by electrolysis), then the other side was plated with gold, and the chamber was evacuated. The period of loading before the gold was plated onto the palladium was about two days. Once the gold was introduced onto the palladium plate, the deuterium could leave only by penetrating the oxide layer, which was very thin, only 200Å. Even though the oxide layer is not impermeable to the deuterons or protons, it slows them up before they are transported out from the plate, creating a pileup near the surface. Yamaguchi calls this an accumulation layer.

The surface of the palladium plate that he used was 9 square inches. When the plate is brought from a chilled state to room temperature, it begins to bend at either end, thus further concentrating the deuterium in the region of its center. The sample bends away from the oxide layer which becomes the outside of the newly curved plate. Yamaguchi likens the process of the emission of deuterons or protons to what happens when a sponge is squeezed.

On July 4, 1989, Dr. Yamaguchi witnessed an extraordinary event. His neutron counter registered the emission of 10^6 neutrons. The gas release was so explosive, he said, that not only was the interlock activated, but the pump was also broken. Yamaguchi estimates that the entire amount of gas that had been in the palladium plate was released within one second. He was wearing nylon gloves at the time, but, when he released the chamber and reached in to touch the palladium, he burned his hand. A further indication that a fusion event had taken place was the condition of the plate itself. The color disappeared from the gold surface, indicating that alloying must have taken place there. For this to have occurred, the temperature must have reached at least 800°C. Furthermore, the sample was uniformly bent. The oxide surface was expanded, while the gold surface had shrunk. The gold surface is 10 times as thick as the oxide—2,000Å.

A nuclear event

The simultaneity of the four events was also very important in convincing Yamaguchi that he had seen a nuclear event, rather than a chemical one. Fully confident now of the reality of the phenomenon of cold fusion, he proceeded to repeat the experiment 20 times, but he has never seen such a result again. By this time, he had to release the accelerator that he was using and build his own test device, which was completed in April 1990.

He then began a new experimental series, which gave him highly repeatable results. In fact, he got 100% reproducibility of excess heat, explosive gas release, and bending of the plate. However, the amount of heat was three orders of magnitude less than in the July 4 experiment. Most disquieting, the experiment worked equally well when he loaded the palladium with hydrogen as with deuterium. This, of course, again raised the question of whether he could be seeing a genuine nuclear reaction.

The design of the experiment was changed, because he was now injecting electric current onto the surface of the plate, on the oxide side, which he did at the stage after the loading and the gold plating. This works because the deuterium atoms in palladium have an effective charge. In these experiments, there were no observed neutron bursts. He estimates that he got excess heat of about 1 watt per 0.9 cubic centimeters, as compared to the first results where he estimates achieving a power density of around 500 watts. Of course, with this kind of experiment, calorimetry is difficult and can only be a rough approximation. The power release occurred two hours after the injection of current. He reported these results in October 1990 at the first cold fusion conference held at Brigham Young University in Provo, Utah. "It occurs two hours after injecting current," Yamaguchi said. "I reported this at the conference in Provo in October 1990; then I had to conclude that this probably occurred because of some unknown chemical reaction, with fusion occurring at the limit of the effect," such as that which occurred in the July 4, 1989 experiment.

In his new series of experiments, Yamaguchi had introduced an electric current, which created a potential difference between the two sides of the palladium plate, and this electron wind may have had a remarkable effect on the phenomena that he observed. These phenomena were observed only when the gold surface was positively charged. With a reversal of the current direction, there was no expansion on the oxide surface nor excess heat evolution. How to explain these results remains open, but clearly, in the new series of experiments, Yamaguchi had departed still further in his design from the "conventional" electrolysis experiment. Because of the nature of the explosive gas release, which follows upon heat bursts, it would appear that the electric current acts to heat the palladium, creating a temperature gradient perpendicular to the surface, rather than to create electromigration.

In this latter series of experiments, he used a more sensitive neutron detector than he had in the beginning, and he added a sensitive charged-particle detector instead of continuing the neutron detection only. (This is a silicon diode produced by EG&G or Camberra, both American companies, which have a preamplifier, amplifier, and multichannel analyzer in order to detect the energy spectrum.) On one occasion, with a deuterium-loaded plate, he detected charged particles, having a maximum energy of 3 million electron volts (MeV), a result which occurred only in 1 out of 64 experiments. However, this one time, there were three such bursts and these were strongly correlated to excess heat production. Yamaguchi believes that these may have indicated tritium production which was of too small an amount to measure directly.

New results

Yamaguchi's new results came after he purchased a highly sensitive quadripole mass spectrometer which allowed him to measure helium-4 *in situ*. The emission of helium-4 gas was strongly correlated in time with heat emission, and the increase of the loading ratio, and only occurred when a deuterated gas was used. Nonetheless the amount of helium detected was in excess of the measured heat increase, suggesting the presence of radiation. With the new spectrometer, he was also able to detect the production of tritium. The alpha particles (i.e., helium-4 nuclei) that were emitted had an energy of from 4.6 to 6 MeV, and protons were also detected at energies of 3 MeV (proton emissions indicate the presence of tritium), but the amount of these was small compared to the emission of helium-4.

This indicates that in condensed matter—the palladium lattice—fusion occurs by an unusual route, producing low quantities of tritium and helium-3, but also producing helium-4. Such a reaction would have a negligibly small probability in a typical high-energy fusion reaction. The probable absence of high-energy gamma radiation is also anomalous from the point of view of hot fusion, but is explained by Fleischmann and Pons along the lines of the superradiance model of cold fusion of University of Milan physicist Giuliano Preparata, in terms of the existence of coherent phenomena which allow the interaction of the fusing deuterons with the palladium lattice. (Dr. Preparata explained his superradiance theory in the Spring 1992 issue of *21st Century Science & Technology,* "New Insights on Water and Sonoluminescence.")

Other models such as those of Nobel Prize laureate Julian Schwinger and MIT's Peter Hagelstein also suggest the importance of coherence phenomenon. Akito Takahashi has a multi-body fusion model which, however, is not supported by the energetics of the Yamaguchi results—although, of course, the experimental conditions in this gas-loading experiment may, in fact, mean that a different nuclear process is occurring than in the typical Fleischmann-Pons experiment.

It remains the case that last winter's electrolysis experiment by Osaka University's Dr. Akito Takahashi, in which he used a palladium-plate configuration, rather than the needle-like cathode favored by Fleischmann and Pons, is still the most dramatic validation of the results found by the two cold fusion pioneers.

Takahashi results replicated

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The Takahashi experimental design was successfully confirmed at Los Alamos National Laboratory by Dr. Edmund Storms, who also got 20% excess heat in an extremely careful closed-cell experiment. Storms also determined certain crucial characteristics in the palladium which influenced the success or failure of experiments, by comparing results using materials from two batches of palladium supplied by Tanaka Metals. One batch of palladium worked, while the other was decisively flawed.

The Third International Conference on Cold Fusion is already forcing a shakeup in those entrenched circles who chose to deny the reality of the phenomenon.