

“Solid-State Fusion” Effects

A REPORT FROM THE MEETING IN SALT LAKE CITY

By D. T. Thompson

Johnson Matthey Technology Centre

The “Solid-State Fusion” or “Cold Fusion” phenomenon, including excess heat generation and the production of nuclear particles, was first reported by Professors Martin Fleischmann and B. Stanley Pons in March 1989. The phenomenon described has many fascinating facets, not least of which is the fact that investigators are unable to produce the effects “on demand”. Many of the experimental variables which seem to be significant were described and discussed at the “First Annual Conference on Cold Fusion” which was held in Salt Lake City, Utah, U.S.A., from 29th to 31st March 1990. The information presented at the conference is summarised here.

This three-day conference was timed to coincide with the first anniversary of the original announcement of the anomalous effects observed when deuterium oxide (heavy water) is electrolysed using a palladium cathode and a platinum anode in the presence of lithium deuterioxide; a diagrammatic representation of the electrochemical cell used is shown here as Figure 1. The announcement was made on 23rd March, 1989 (1) and a preliminary paper was published during the following month (2). The phenomena observed subsequently became known as “solid-state fusion” or “cold fusion”, and may crucially depend upon the exceptional ability of palladium to pack into its lattice up to an equal atomic amount of hydrogen or deuterium (3).

Since the time of the announcement there has been much discussion of the observations made and the reasons for them. Due to the radical nature of these observations—of excess heat and nuclear particles—the new phenomena have attracted both “believers” and “non-believers” in the scientific community. A central purpose of the conference was an evaluation of the ex-

perimental evidence available to date, in order to chart the path needed to achieve a full understanding of what actually happens in the process. New theories were also advanced to rationalise the experimental results. Attempts were then made to define the research that would be required in the months and years ahead to enable a full assessment to be made of the new effects, and to realise their potential from academic and commercial viewpoints.

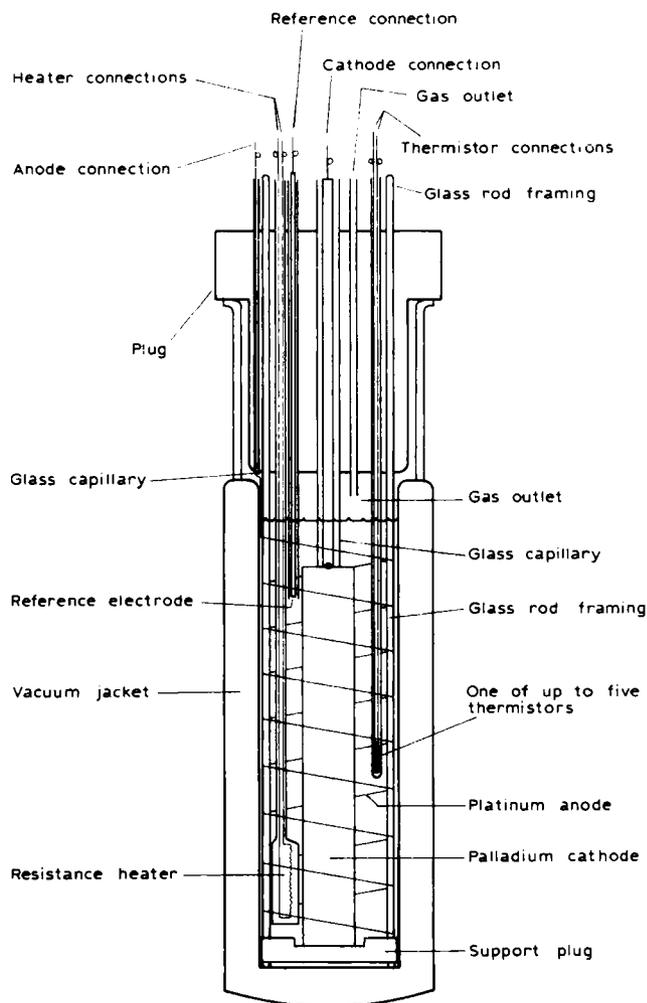
The conference presentations were generally of a high standard, drawing immediate reactions from members of the 200 strong audience, with much active, constructive and mainly friendly discussion of the various experimental results reported. Most of the current reports are coming from the U.S.A., but very significant contributions are also being made in India, Japan and some European countries, notably Russia and Italy.

Some papers addressed the excess heat effects observed, some the nuclear particles, and others the theoretical aspects. Reference to the use of Johnson Matthey palladium was made by many of the speakers.

Presentation of Experimental Results

The original announcement in March 1989 described work carried out by Pons and Fleischmann at the University of Utah using palladium rods supplied by Johnson Matthey. It was therefore appropriate that the first paper given at this meeting was by Pons. He described in detail the accuracy of his calorimetric method for determining excess heat, and distributed copies of a manuscript which has been accepted for publication in the *Journal of Fusion Technology*. The accuracy of his temperature control was ± 0.003 to $\pm 0.01^\circ\text{C}$,

Fig. 1 The electrochemical cell used by Fleischmann and Pons for their investigations included a palladium cathode and a platinum anode in an electrolyte of lithium deuterioxide in deuterium oxide, all contained within a vacuum jacketed vessel



and there was a systematic underestimation of the heat evolved by 1–4 per cent. Data have now been collected from 200 experiments; 150–200 calibrations being done each week. Excess heat of up to 100 W/cm^3 of palladium has now been recorded. At low current densities (64 mA/cm^2) a scatter of results is obtained, but at higher densities (512 mA/cm^2 and 1 A/cm^2) the reproducibility is much better and the scatter decreases. In addition to these steady heat emissions, enthalpy bursts are also occasionally observed. In a 90 day experiment these bursts can last for 2 weeks and the potential of the cell decreases during a burst. During these bursts

the thermal output of the cells exceeds the enthalpy input by factors of up to 40. Some cells are charged for weeks or months before giving excess heat. The total specific energy output during the bursts as well as the total specific energy output of fully charged electrodes subjected to prolonged polarisation ($5\text{--}50 \text{ MJ/cm}^3$) is $10^2\text{--}10^3$ times larger than the enthalpy of reaction of chemical types of processes.

An excellent paper on work carried out in sealed cells was given by O. J. Murphy of Texas A & M University, U.S.A. All the necessary control experiments had given zero excess heat. Annealed palladium rods had shorter induction

times than unannealed rods before giving out excess heat. The effect falls rapidly when lithium deuterioxide is replaced with lithium hydroxide. The experiment can also be quenched by the addition of sodium hydroxide. Enriched Li^6 deuterioxide works well. Auger electron spectroscopy on used rods did not detect any palladium on the surface. It was not easy to get gas out of the electrodes after long term electrolysis. There was a uniform lithium penetration into the palladium electrode, to 4–5 μm , to form a palladium-lithium alloy layer.

Eight experiments using 6.35 mm diameter palladium rods supplied by Johnson Matthey were described by D. Hutchinson of Oak Ridge National Laboratory, U.S.A. Five of the open cells gave a power excess of between 2–9 W for 1500 hours, out of a total operating time of 1800 hours. The other three cells remained in power balance. This initial work finished last December, but Hutchinson now has more funds and plans to work on isotope ratios in used electrodes, do control experiments with water, and to use total internal recombination systems.

Another excellent talk describing very careful flow calorimetric investigations using current densities of 400 to 600 mA/cm^2 , was given by C. D. Scott, Oak Ridge National Laboratory. The closed system used, incorporating gas recombination, was operated for 1900 hours. The palladium, of 99.9 per cent purity and obtained from Materials Research Corporation, was cast, cold worked and drawn before being annealed at 900°C for 4 hours. In an experiment run at 500 mA/cm^2 , replacement of deuterium oxide by water only destroyed the excess heat effect after 100 hours, indicating a bulk rather than a surface effect. An energy burst after 1300 hours coincided with the emission of neutrons (60 neutrons per day) and, more approximately, with gamma emissions. He found no increase in tritium production.

A report by P.K. Iyenger and M. Srinivasan of the Bhabha Atomic Research Centre (BARC), Bombay, India, described a very large number of experiments, presenting a massive quantity of information in a very short time. A major report (BARC-1500) has been published

and another is due. Neutrons were produced in bursts lasting from tens of seconds to tens of minutes, but tritium was the primary product observed with a neutron:tritium yield ratio of 10^{-8} . Most cells gave their first neutron burst when a charge of about 1 A h/cm² had been employed. This corresponds to a deuterium:palladium loading of 0.6.

In a very stimulating talk, J. O'M. Bockris of Texas A & M University set out the statistics of successes and failures in his experiments with respect to excess heat and, particularly, tritium generation. Neutron measurements can be confusing since cosmic rays can interfere. In the tritium experiments he used nickel anodes, charged at 64 mA/cm^2 , then raised the current density to various values, such as 300 mA/cm^2 and 90 mA/cm^2 , for a range of times.

Palladium cathodes have been used to evolve deuterium from lithium deuterioxide solutions for up to four and a half months. Excess heat has been observed from 4 electrodes out of 28, and tritium in 11 out of 47 experiments. Some degree of correlation between excess heat and tritium production has been observed, but levels of tritium account for only 1 per cent of the heat obtained. The production rate of tritium was about 10^{10} atoms/cm²/s. The branching neutron:tritium ratio was 10^{-8} . A dendrite enhanced surface fusion model was suggested which was claimed to give quantitative consistency with experimental results.

Experiments on tritium emissions were described by E. Storms from Los Alamos National Laboratory, U.S.A. The variables explored included high deuterium:palladium ratios, impurities in the palladium lattice, impurities on the palladium surface and dendrites. He has used PdLi, PdC, PdLiC, PdB, PdS, PdBe (which possibly gave some neutrons), PdRh (which improved the deuterium:palladium take up ratio) and PdRhLi, but none of these produced tritium. LiPd took up deuterium faster than palladium. He has examined a range of palladium samples and found no particular correlations. Surface treatment of palladium with nitric acid, hydrochloric acid or hydrogen peroxide had no

effect. Heating the palladium in paraffin or paraffin + water and hydrogen sulphide appeared to promote the generation of tritium by giving rise to a coating of palladium sulphide on the surface. Roughening the surface with sandpaper was not helpful. Platinum and nickel anodes produced tritium, but not stainless steel.

Storms did not always observe tritium, but overall some 16 out of 50 experiments produced DT or DTO. The conclusions are that tritium is definitely produced in some experiments, that it does not result from contamination, and that no cell or cathode design works consistently. Carbon was present on the cathode surface.

A talk given by D. T. Thompson described some work related to an understanding of these new phenomena undertaken at the Johnson Matthey Technology Centre, U.K. This work was of a multi-disciplinary nature and was carried out by D. R. Coupland, M. L. Doyle, J. W. Jenkins, J. H. F. Notton, R. J. Potter, and their colleagues. Surface and bulk analytical work on palladium rod samples which had been returned to Johnson Matthey by Fleischmann and Pons showed that a number of elements, including platinum and lithium, had been deposited on the surface during the electrolysis. One electrolysed rod exhibited recovery of part of the wrought microstructure, which would normally require a temperature higher than about 200°C. Another rod showed recrystallisation of a portion of its length and this would normally require a temperature higher than about 300°C. These effects on the metallurgical structure could not be reproduced by filing or sawing either virgin palladium rods or palladium rods which have been electrolysed in water. Temperature programmed hydrogen absorption/desorption profile measurements on a range of palladium samples indicated wide differences in properties for the various samples, including distinctions between the behaviour of active and inactive rods. A palladium rod electrolysed in lithium hydroxide absorbed hydrogen more readily than a similar rod electrolysed in sodium hydroxide. This technique would therefore seem to be of value in

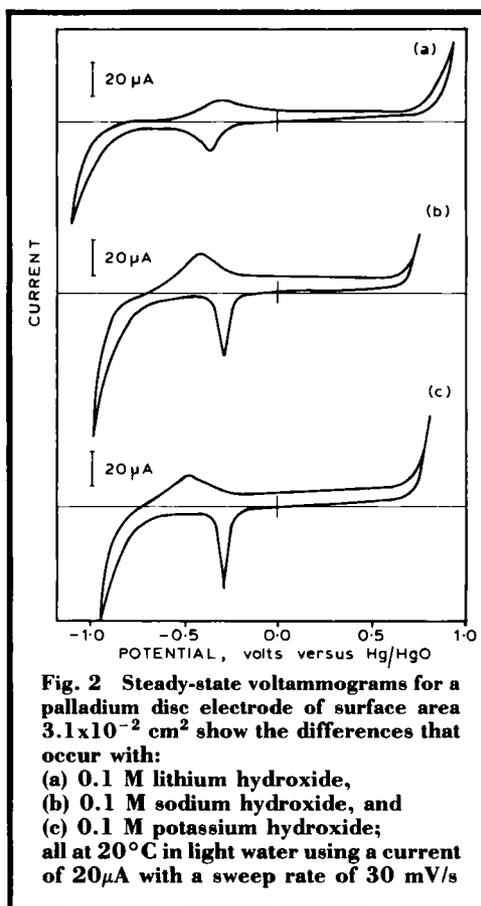


Fig. 2 Steady-state voltammograms for a palladium disc electrode of surface area $3.1 \times 10^{-2} \text{ cm}^2$ show the differences that occur with:
 (a) 0.1 M lithium hydroxide,
 (b) 0.1 M sodium hydroxide, and
 (c) 0.1 M potassium hydroxide;
 all at 20°C in light water using a current of 20 μA with a sweep rate of 30 mV/s

characterising the palladium electrodes. Electrochemical measurements conducted in light water showed that there were significant differences between the behaviour of palladium in lithium hydroxide on the one hand, and in sodium hydroxide or in potassium hydroxide solutions on the other hand, as can be seen in Figure 2. Finally, a preliminary investigation using time of flight SIMS indicated a reduction in the $\text{Li}^6:\text{Li}^7$ ratio found on the surface of an active rod, from the 11 per cent quoted by Pons to 4 per cent. The results indicate that lithium may play a role in the effects described.

Theoretical Aspects

A paper by G. Andermann of the University of Hawaii, U.S.A., described a theoretical model (Nu-Q) for rationalising the electro-

chemically induced nuclear events observed in deuterium loaded palladium cathodes. He proposed a theoretical model based on the formation of a new neutral particle, namely two bound neutrons, designated as neutrium (Nu). He postulated that Nu, under favourable conditions, may be absorbed by a deuteron to yield quatrium (Q), where Q decays to produce various high energy nuclear Nu, thus providing plausible explanations for the achievement or non-achievement of various high energy events. The model also accounts for the possibility of Nu being absorbed by palladium or other heavy nuclei.

Discussion of Results

In a panel discussion on thermal phenomena the overall conclusion proposed was that there can be a steady state emission of excess enthalpy. This depends on the materials used, and there seems to be a threshold density of deuterium required in the palladium to produce the phenomena. Superimposed on the excess enthalpy effect can be bursts of enthalpy. A variety of calorimetric techniques have been used to observe these effects. They could derive from the bulk or the surface of the material and there could be a correlation with neutron and gamma emissions. On the other hand the heat emission could be a bulk effect, and the particle emissions a surface effect. A complex picture is emerging with a large number of variables to be controlled; it may be important to get the system as clean as possible. The loading with deuterium is critical. The overvoltage and surface conditions must be defined, particularly with respect to preventing deposition on the surface of the cathode.

The heat effects do not seem to be explicable in chemical terms. Production of 10–20 MJ/mol is the most exothermic chemical reaction which could be conceived to occur in the system (such a reaction would account for no more than 3 per cent of the observed excess heat). The lack of repeatability of the phenomena is still a major area of concern; it is not yet possible to go into the laboratory and turn on the effect.

Another panel discussion on nuclear

phenomena concluded that the Texas A & M, BARC, Los Alamos and Oak Ridge results seemed significant, but as D. H. Worledge of the U.S. Electric Power Research Institute pointed out, investigators must be able to reproduce these results. The phenomenon itself seems to be transient, and the required property of the lattice may be destroyed by the phenomenon, and thus it may then be necessary to look at another new system to get the effect again. To date the excess power and nuclear phenomena have been largely studied separately and experiments need to be designed to observe both simultaneously. Since tritium is easy to measure, this at least should be sought in all experiments wherever possible. There should be significant advantages in using closed systems. Therefore reliable He^3/He^4 analysis is required.

Professor Bockris said that this meeting, and particularly the work of Scott, had convinced him that there were two mechanisms operating, one to produce heat and the other to produce tritium. His dendrite mechanism for tritium, requiring 10^9 volts/cm, was now theoretically credible following the paper presented by Y. E. Kim of Purdue University, on the screening of D-D interactions on surfaces and at tips of the protrusions from the surface. With the new funding available to him, Bockris is going to make dendrites of known geometry and undertake long term measurements looking for gamma emissions, tritium and heat, simultaneously.

Conclusions

In his summing up Fleischmann made reference to a 1934 letter to *Nature* by Rutherford and his colleagues in which D-D fusion was postulated (4). He then summarised all the areas where apparent evidence for solid state fusion had been obtained during the past year, namely: excess enthalpy, bursts in enthalpy; tritium, bursts in tritium; neutrons, bursts in neutrons; X-rays, gamma rays and bursts in these. He recommended that emphasis should now be concentrated on confirming reaction products, such as He^4 . New theories were emerging, but one year was too short a time in

which to have fully evaluated them.

After his brief talk there was a standing ovation from the 200 delegates, almost all of whom had remained in attendance until 5.00 pm on the Saturday afternoon! Only a few sceptics remained seated. Undoubtedly much more work

will be executed and discussed before all of the essential variables necessary to repeat the effects on demand are clarified. The full consequences, both scientific and technical, can be properly assessed only when all the significant variables have been identified.

References

- 1 C. Cookson, *Financial Times*, 23rd March 1989, 1 and 26
- 2 M. Fleischmann, S. Pons and M. Hawkins, *J. Electroanal. Chem. Interfacial Electrochem.*, 1989, 261, 301; *op. cit.*, 1989, 263, 187
- 3 F. A. Lewis, "The Palladium-Hydrogen System", Academic Press, New York, 1967
- 4 M. L. Oliphant, P Hardeck and Lord Rutherford, *Nature*, 1934, 133, 413; (see also P. I. Dee, *Proc. R. Soc.*, 1935, 148, 623)

Platinum 1990

Assistance provided by numerous people knowledgeable about the platinum industry worldwide has once again contributed to the usefulness of the annual review of the platinum group metals market, recently published by Johnson Matthey.

During 1989 supplies of primary platinum reached 3.375 million ounces troy, while total demand in the western world was 3.465 million ounces, the second highest annual requirement. For the third successive year, Japan was the largest regional market taking the equivalent of 48 per cent of the total western world's demand for platinum, and some 70 per cent of this was absorbed by the jewellery manufacturing industry.

On a worldwide basis, the largest use for platinum was, once again, for autocatalysts. Although vehicle production fell in North America, a tendency to higher loadings of platinum metals on catalysts, as well as a rise in stock levels, resulted in increased demand. Purchases were also up in Europe as manufacturers fitted catalysts in advance of EEC clean-air legislation. In January 1990 eight out of every ten petrol-fuelled cars sold in West Germany were equipped with three-way catalysts. By the year 1993 it is anticipated that platinum off-take by car manufacturers in Western Europe will be as high as 750,000 ounces. Fresh demand is expected to arise later in the decade in Eastern Europe, where air quality is a major problem.

In response to a growing public awareness of the damage being caused to the environment by the activities of man, a special seven page feature in "Platinum 1990" considers various ways in which the platinum metals are already being utilised to destroy polluting substances. Such applications are likely to grow. In addition, new technologies making use of the remarkable combinations of properties possessed by the platinum metals will result, hopefully, in processes that do not produce pollutants. Automotive spark plugs tipped with platinum metals are expected to reduce the chances of engine misfire, thus improving fuel economy and reducing emissions of unburnt fuel. In the longer term, the use of fuel cells to power electrically-driven vehicles could eliminate, or substantially reduce, the polluting emissions produced by conventional internal combustion engines.

Those who regard platinum as an industrial metal may be surprised to learn that it is also being used increasingly for the manufacture of luxury high quality watches.

Readers of *Platinum Metals Review* who do not have ready access to "Platinum 1990", and who need an authoritative source of commercial information about the platinum metals, should address their requests for a free copy of this comprehensive survey to the author Mr. Jeremy S. Coombes, Johnson Matthey P.L.C., New Garden House, 78 Hatton Garden, London EC1N 8JP.