"In spite of my earlier conclusion, - and that of the majority of scientists, - that the phenomena reported by Fleischmann and Pons in 1989 depended either on measurement errors or were of chemical origin, there is now undoubtedly overwhelming indications that nuclear processes take place in the metal alloys." - Professor Heinz Gerischer

COLD FUSION

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A memorandum has been written on the present state of cold fusion research as of October, 1991, by Professor Heinz Gerischer.

The significance of this memorandum arises from Professor Gerischer's status. He is widely recognized to be the leading physical electrochemist in Europe and would vie for the title on a still wider basis. Apart from his long term involvement in electrochemistry he is well known as a physical chemist of the highest standing and was, until 1988, the Director of the Max Planck Institute for Physical Chemistry in Berlin.

A still further significance may be attached to Professor Gerischer's memorandum because he has been, since March 1989, a dedicated opponent of cold fusion, taking the position (more pronounced, even, in Germany, France, and England, perhaps, than in the United States) that the work of Fleischmann and Pons and the announcement of March, 1989, was due to poor measurements

Indeed, I can witness the fact that until the Como Conference of July 1991, Professor Gerischer maintained a negative opinion of the field which he confided to me at the beginning of the Conference.

My translation of the memorandum follows.

MEMORANDUM ON THE PRESENT STATE OF KNOWLEDGE ON COLD FUSION

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Concerning the origin of this memorandum: Between the 30th of June and the 4th of July, there took place in Como, Italy, the Second Annual Conference about Cold Fusion. This had been organized by Italian groups, principally from the Universities of Turin and Milan. The joint chairmen of the conference were Prof. T. Bressani (Turin) and Prof. G. Preparata (Milan).

At the end of May I was invited to attend this conference as a skeptical observer and found that I was down on the program for the last day of the conference as giving a lecture on the pros and cons of the field. There were about 60 lecturers at the meeting in groups from the USA, Italy, Japan, China, Soviet Union, and various smaller countries which all gave their results. Two comprehensive reviews had been already sent to me in manuscript form, - one of them has already appeared (1) and the other will shortly appear. On the basis of these two reviews I was able to prepare myself somewhat for the conference.

THE INDICATIONS OF OCCURRENCE OF NUCLEAR PROCESSES IN METAL-DEUTERIUM ALLOYS

In spite of my earlier conclusion, - and that of the majority of scientists, - that the phenomena reported by Fleischmann and Pons in 1989 (3) depended either on measurement errors or were of chemical origin, there is now undoubtedly overwhelming indications that nuclear processes take place in the metal alloys. The early publications were so full of errors in measurement technique and in the interpretation that the euphoria to which the discovery gave rise was rapidly replaced by disappointment when it turned out that the laboratories with the best equipment could not reproduce the results. Only very few groups found similar effects, but even these groups could not find reproducibility in their own laboratory. Furthermore the supposition that a fusion of two deuterium atoms could take place in a solid body such as PdD_x or TiD_x was contradictory to all theories of nuclear reactions. In particular the observed (or maintained) heat effects bore no relationship to the tiny amounts of nuclear products which had been found by a few authors. The main search here went towards neutrons and tritium because according to fusion of two D⁺ nuclei in hot plasmas, the following two reactions would occur with about the same probability:

$$D^{+} + D^{+} > n (2.45 \text{ MeV}) + {}^{3}\text{He} (0.82 \text{ MeV})$$

 $D^{+} + D^{+} > H^{+} (3.02 \text{ MeV}) + {}^{3}\text{H} (1.01 \text{ MeV})$

Now, the sensitivity of instruments for detecting neutrons is particularly good and therefore the majority of the measurements concentrated on experiments which would give rise to such detection. This was particularly true in experiments which were carried out at low temperatures from palladium which had been previously loaded with deuterium. In the electrochemical loading

of palladium by cathodic evolution of deuterium either from an alkaline or acid electrolyte in D_2O (predominantly with the electrolyte LiOD) from time to time a tritium enrichment would be found which was considerably higher than could arise from differences expected for separation factors during the discharge of D_2O from an electrolyte containing DTO. The occasional observation of neutrons with intensities which were decisively above the background, and with tritium amounts in the electrolyte which were certainly and indication for the occurrence of nuclear processes is very significant, but the amounts were so small that the heat observed could not by explained by their occurrence. Correspondingly, it has been found that the neutron production is sporadic and occurs in bursts. The same occurs for the tritium enrichment and also for the heat production.

The occurrence of such happenings could not in any way be foreseen on the basis of previous knowledge. Correspondingly, the authors of the papers admitted that the reported positive results were only occasionally obtained, and that many experiments ran through without any observable nuclear consequences at all, facts which lent further doubt as to the reality of the effects.

As far as the interpretation of the nuclear reactions goes it has been suggested (4,5) that a reaction occurs which plays no part at all in the hot plasmas, namely:

$$D + D > - {}^{4}He (0.076 \text{ MeV}) + \text{gamma } (23.77 \text{ MeV})$$
 (Eq 3).

The gamma radiation which should occur according to this reaction is, however, not observed. However, very recently there have been reports about the observation of helium in electrolytically evolved deuterium from a $\text{LiOD/D}_2\text{O}$ solution in cells with palladium electrodes. In these experiments heat production was also calorimetrically observed. The amount of ^4He was indeed in the right order of magnitude according to equation 3 although the agreement was not quantitative. On the other hand, corresponding water blank experiments using $\text{LiOH/H}_2\text{O}$ showed neither any heat excesses nor any helium in the evolved hydrogen gas.

AN EVALUATION OF THE RESULTS OBSERVED SO FAR

Although there are many discrepancies in the reports which are at hand, and although there are many open questions, there now lie before us several indications that fusion reactions do occur between deuterides in metals. This gives rise to a new situation. It is entirely an open question whether such processes could be used as the source of energy but this, of course, can only be decided if the processes which have been revealed in the work discussed here are researched and given a theoretical basis. In any case I consider it absolutely necessary that these phenomena are systematically researched and the conditions for their reproducibility cleared up. That a nuclear reaction can be stimulated by interaction with a solid lattice and made to take another path from that which it would take in the plasma, is an entirely unexpected discovery with possibly wide-ranging consequences. It demands confirmation and further experimental evaluation. In the following a number of experimental and theoretical questions are raised which are at the present time entirely open.

The overwhelming problem is the lack of reproducibility in the results. The anomalous phenomena in palladium and titanium can only be seen after very long times of loading, usually after several weeks. In the loading there is a phase change in which the alpha phase is changed to the beta phase and this involves a change in lattice constants which gives rise to a volume increase of about 15%. The microcrystalline structure of the solid seems to play an important role here. However, the structure of the solid is not yet characterized. The lattice structure seems to be an important part of the conditions necessary for the setting up of the anomalous effects.

In the electrochemical experiments the characteristics of the surface in the charging of the metal with deuterium plays a great role. The effects in the electrochemical experiments are greater than those in loading from the gas phase. The reason for this is probably the increased activity of deuterium atoms which occur in the first step of loading according to the reaction:

$$D_2O + e > - D_{ad} + OH^-$$
 (eq. 4).

The slower the following reactions (5 and 6) are, - these lead to molecular deuterium, - the greater is the activity of the absorbed D atoms on the surface:

$$D_{ad} + D_{ad} > -D_2$$
 (eq. 5)

$$D_{ad} + D_2O + e > -D_2 + OD^-$$
 (eq. 6)

The activity of adsorbed atoms determines the loading of the metal lattice with D atoms which go from the surface to the interior of the lattice. In this way one can build up a super-saturation of the lattice with D-atoms and this super saturation increases with the surface activity of the adsorbed D. If one tried to read super saturation in the metal by increasing the pressure in the gas phase, enormous pressures would be necessary.

In the literature it is reported that extremely long times of electrolysis are necessary before phenomena are observed and these can give rise to the deposition of impurities on the surface of the electrode. This gives rise in turn to a change of the overpotential in the current-potential curve (7) and also in the analysis of the surface composition which will certainly take place on long term electrolysis (8). Such absorbance can give rise to an inhibition of the recombination rate of the surface atoms to the molecular product in reactions 5 and 6. In this way the activity of adsorbed hydrogen can be increase. On the other hand, if the inhibition affects reaction 4 then the reverse effect occurs. In fact, it is possible to think of an acceleration of reactions 5 and 6 by the impurities. Thus, it has been shown for palladium cathodes that these contain platinum which obviously arises by the partial dissolution of the anode. It is known that if oxygen is evolved at high rates upon an anode there is certainly the danger of anodic dissolution. Correspondingly it is known that platinum deposition on palladium increases the recombination and therefore decreases the activity of adsorbed D.

Apart from the observation of neutrons, proof of the presence of the nuclear products 3 He, and 4 He are difficult to observe because many of the experiments are carried out in open systems, the evolved gases seldom being collected. The consumed $D_{2}O$ has to be replaced. In this way one builds up impurities in the electrolyte in the cell and the products in the gas phase are lost.

Only a very few experiments are carried out in closed systems in which the D_2 is converted to D_2O on a catalyst and re-introduced into the electrolyte (9,10) or, alternatively, the D_2 which is evolved is oxidized back to D_2O (or D^+) (11).

The latter process corresponds to the anodic process in a hydrogen-oxygen fuel cell. In such experiments the reaction products build up in the electrolyte or in the gas volumes which are collected. This has so far only been used for tritium analysis.

The calorimetric measurements have been greatly improved. In the open cells there are still difficulties concerning the loss of heat along with the evolved gases. Closed cells do not have this difficulty but they are much larger in volume and are less sensitive to the measurement of heat. In general there exists in all electrochemical cells the problem that the energy input of the cell is large (large current densities) and must be carefully measured in order to set up a clear and sure energy balance. The uptake of energy varies with the cell resistance and the overpotentials of the electrode. The excess energy in most of the experiments which have been described so far is considerably less than the energy which is being used for the electrolysis. A typical excess heat measurement amounts to 10-20% of the energy put into the electrolysis over several hours. A few measurements have given 100% and more. A few measurements do give 100% of heat and even more but are perhaps somewhat doubtful. On the other hand, there were plenty of indications at the conference that some authors were withholding their results because of patent considerations.

The experimental problems in the measurement of gas loading is much less well known to me and I do not wish to comment upon it. It is noteworthy that neutron production which exceeds the background intensity can only be obtained by warming up these samples which have been charged at very low temperatures.

THEORETICAL PROBLEMS

The most decisive problem is the question: How can a solid body influence the course of nuclear processes? ³ Thus, the point is, - how can the screening of the repulsive forces between the

¹ Note added by JOMB: At a recent meeting at the California Edison Company, Robert Bush of Pamona University in California revealed measurements on very thin films which, when calculated to a per cc measurement of heat, give about 1 kW per cc.

² Note added by JOMB: In particular Mike McKubre and his group at SRI have been reporting 250-450% heat for some months. The rumor is that this is an understatement. EPRI has decided to continue to build a practical plant for the production of energy from cold fusion which should be completed by 1997.

³ Note added by JOMB: On the other hand, the well accepted Mossbauer effect surely is already and example of the effect of a lattice upon a nuclear process.

two atomic nuclei be achieved so that successful tunnelling can occur? The second question is, how can the pathways be altered so that they go in the direction of reaction 3 and thus allow a ratio of 10^6 - 10^9 for the predominance of tritium over neutrons (compare the expected 1:1 ration of nuclear chemistry in hot plasmas). (2)

A further riddle is the absence of hard gamma radiation which should occur corresponding to reaction 3. How can the gigantic energy of this reaction be diffused over the solid body without emitting radiation (although weak x-rays have been seen on a photographic plate)? (6,12)

There are various attempts at theoretical interpretation (1), and some of these are really quite far out. It has even been suggested that an unknown elementary particle is a catalyst in these processes (13). Without sufficient material to overview the theoretical contributions I will not make any further comments on these theories.

WHAT SHALL BE DONE?

The works which have been so far reported are works which concern individual questions. Attempts are being made to reproduce experiments and to modify the technique. A systematic characterization of the electrochemical and experimental conditions has not yet been carried out. As the largest effects are being observed under the electrochemical conditions it is necessary to concentrate on the electrochemical experiments.

Fleischmann and Pons reported in the meeting in Como concerning their experiments with palladium alloys (probably with silver) and maintain that they have been able <u>reproducibly</u> to observe large excess heats. No details of the experimental arrangements were given because of their wish to maintain patent conditions. ⁴

There is also evidence that the composition of the electrolyte plays a considerable part in the occurrence of the anomalous effects. It is absolutely essential to research the connection between overpotential, hydrogen content, and surface characteristics of palladium or palladium alloys in a systematic way. This could probably be carried out with light hydrogen, beginning with the hypothesis that a very high loading of D in metals is necessary for fusion, because in respect to loading, H and D hardly differ from each other. One could then come back later to the experiments with D_2O and with the knowledge of what has given rise to the high loading with hydrogen. In this respect it is necessary to have a method which allows a rapid measurement of the amount of hydrogen in the palladium. Here resistance methods are probably the best. Parallel to the information obtained in the measurements it would be necessary to build calorimeters which have requisite controls and work in an enclosed manner so that heat production and nuclear products can also be observed with a minimum amount of ambiguity. The decisive proof of excess heat arising from nuclear reactions will, of course, be the occurrence of the corresponding amount of 4 He. If this

⁴ Note added by JOMB: The experiments of Fleischmann and Pons are being carried out in Nice with support of a Japanese group connected to Toyota.

can be confirmed, further steps for the optimization of the energy yield can be carried out.

These goals require the cooperation of scientists from various fields. One needs electrochemists, metal scientists, particularly those with knowledge of metal hydrides, engineers for the building of cells and the computerization of data, persons with experience in calorimetry, mass spectroscopy, and one needs nuclear physicists for the radiation measurements. A team of this kind should be in a position to clear up the basic situation fairly quickly. Of course, the first thing is to confirm the facts. The fact that, in the Republic of Germany this work has been inhibited is no longer justified. It could, later on, be regarded as a very unfortunate gap in German research when compared with the present activity in other countries and particularly in Japan.

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