Consensus on cold fusion still elusive

Accounts of the cold-fusion experiments at the University of Utah and Brigham Young University were presented last week at a meeting at the Ettore Majorana Centre for Scientific Culture, but many questions remain unanswered.

Erice, Sicily

AFTER a full day of presentations and discussion of the recent claims of cold nuclear fusion, there was no consensus at this meeting on the results, no credible theory to explain them, but some suggestions as to where to look for an explanation or confirmation. The work of the Utah group[1] was presented at the meeting last week by M. Fleischmann, that of the Brigham Young group[2] by S.E.Jones and J.B.Szirr.

The details of the experiments are important in any comparison or assessent. Jones and his colleagues electrolyse heavy water (D_2O in a solution at pH 3 of a witches' brew of salts (including Li and Pd) with Pd foil on rough Ti or Pd chunks as cathodes, driving deuterium into the metal with a voltage of 3-25 V and cell currents of 10-500 mA. In each 20-ml cell, the anode is gold foil. A counter designed to detect and identify fast neutrons indicates a total of 170 ± 23 counts with a pulse-height spectrum consistent with that expected for the 2.45 MeV neutron of the well-known fusion reaction:

$$d + d = {}^3\mathrm{He}\ (0.82\ \mathrm{MeV}) + n\ (2.45\ \mathrm{MeV}) \quad (1)$$

J.B. Czirr described the neutron detector in detail. It detects a thermalized neutron by the light flash in ^{6}Li-doped glass. The neutron energy is determined by the overall fast light-pulse caused by protons recoiling in a liquid scintillator as the neutrons are thermalized. The counting rate is but 2 per hour in the relevant region of pulse height.

The analogous experiments[1] by Fleischmann, Pons and Hawkins use a strongly alkaline solution of 0.1 M LiOD in heavy water and drive deuterons into Pd rod cathodes (cast and machined) under the influence of cell currents up to 800 mA and voltages typically of 12 V. The plan is to detect reaction (1) by the 2.22 MeV γ-ray resulting from capture of the 2.45 MeV neutron (after thermalization) by a proton of the surrounding water bath:

$$p + n = d + \gamma\ (2.224\ \mathrm{MeV}) \quad (2)$$

The authors describe a very narrow peak at 2.2 MeV containing some 3,000 γ-ray counts for an NaI scintillation detector close to the electrolytic cells, in comparison with the 'level spectrum' in a similar detector 5 m or 10 m away. Unfortunately, the full pulse-height spectrum is not shown, so that it is not possible to verify the presence of the annihilation radiation 'escape peaks' that would lend more confidence to the origin of these counts in the neutron-proton interaction (2). Furthermore, no evidence has been given which connects the counts with current applied to the cell, and there have been no runs with ordinary water as a control.

In the scientific and patent literature over the past 60 years, there have been occasional claims of nuclear fusion catalysed by palladium, but there have previously been no credible reports of neutrons from metal deuterides, for reasons thought to be well understood.

Briefly, these are that the Coulomb barrier to close approach by nuclei of charges Z_1e and Z_2e amounts to $(Z_1e)\times(Z_2e)/r$, where r is the nuclear diameter. This amounts to about 600 keV when $Z_1 = Z_2 = 1$, reducing to a very small value the probability that, by quantum mechanical tunnelling, the deuterons in a D_2 molecule will approach within the range of nuclear forces.

Even so, the calculation of the rate at which deuterium nuclei in a molecule will undergo fusion is important as a yardstick for assessing the rates reported in the recent experiments. At last week's forum, new calculations were presented[3] by S.E.Koonin (Santa Barbara) of the number of fusion reactions per deuteron bound in a deuterium molecule by 'electrons' of normal charge but mass m^* instead of m_e. If the logarithm (base 10) of the number of fusions per deuteron per second is λ (with a subscript to indicate the fusion mode), the results come out as follows:

Log$_{10}$ of fusion rate per *d* per second				
m^*/m	1	2	5	10
λ_{dd}	63.5	40.4	19.8	9.1
λ_{pd}	55.0	36.0	19.0	10.4

Others at the meeting agreed with these results, which correct an error in some previous calculations and use a more accurate molecular potential. An important experimental point is provided by the case in which $m^* = 207$, corresponding to that in which a negative muon binds two deuterons as a molecular ion 207 times smaller in dimensions than the normal molecular ion, with λ_{dd} of some $10^9\ \mathrm{s}^{-1}$, as predicted[3] and observed[4].

These results also show the strikingly easier penetration of wide barriers by the proton. The explanation lies in the sensitivity of the chance that the Coulomb barrier will be penetrated by quantum mechanical tunnelling to the "reduced mass" μ of the two nuclei, which is $M_1M_2/(M_1 + M_2)$. Numerically, the barrier penetration factor is $e^{-2\int k(r)dr}$, where the integral runs from zero to the classical turning point r_0 and the function $k(r)$ is $[2\mu(V(r) - \varepsilon)]^{1/2}$.

The rate of neutron production claimed by Jones *et al.* is $\lambda_{dd} = 10^{-20}$, which would require that m^*/m_e was equal to 5, according to the figures in the table. A similar value of the effective mass is needed to explain the γ-ray counts reported by Fleischmann and Pons.

Although quasi-particles of high effective mass are well known in metals, the value of m^* relates to the relationship between the density of states and the energy in the band structure of the lattice. Thus a quasi-particle of effective mass 5 is not capable of binding two deuterons to a density 5^3, or 125, times that of molecular hydrogen, or of allowing the nuclei to approach one another to a distance 5 times smaller than the 0.74 Å internuclear separation in the D_2 molecule; at this distance, 0.15 Å, the repulsive potential amounts to some 95 eV.

That is why it was argued at the forum last week that one should look for dynamic effects to augment the equilibrium tunnelling — phonon-assisted tunnelling (Koonin) or coherent acceleration (Ponomarev, USSR) in which travelling electron density waves may trap deuterons and accelerate them to the same velocity as the waves. The deuteron kinetic energy would then be some 3,700 times that of an electron of the same velocity and would greatly enhance the chance of penetrating through the barrier by quantum tunnelling. Alternatively, a solution could be sought in "high-T_c superconductivity or other miracle of solid-state physics".

Several experimental groups at the forum

The forum on cold fusion held on 12 April at the Ettore Majorana Center was convened by Professor Antonino Zichichi, director.

presented results showing no neutrons or γ-rays generated in replication of the experiments which have been described [1,2]. Electrolysing 1-mm by 10-cm Pd rods for 10 days gave neutron yields below 0.6 $s^{-1} cm^{-3}$ (M.M. Broer, AT&T Bell Laboratories) or less than 10^{-3} of those reported by the Brigham Young group in similar circumstances. J. E. Ziegler (IBM) reported an upper limit of 10^{-3} s^{-1} cm^{-3} for the detection of t or p from the $d+d$ reaction Experiments were reported (Celani, Frascati) with "some increase in neutron signal at the beginning of each experiment for about 5 minutes, but indistinguishable from background after 20 minutes". Experiments will be transferred to the great underground laboratory at Gran Sasso; perhaps also those who claim the ability to produce neutrons will be hospitable to those more adept at detecting than at producing them in this way.

Non l'avrei gianmai creduto... Ma faro quelche potro... ("I would never have believed this, but I'll see what I can do", says Mozart's *Don Giovanni,* quoted by L. Maiani).

This, of course, refers to the heat generation claimed[1] of some 10 W per cm^3cc for 100 hours or more, as well as destructive releases of heat that fuse and vaporize Pd and destroy the cell. The most likely explanation of such violent happenings is that they are the result of the electrochemical creation of high explosive by stuffing hydrogen into high-energy sites in Pd (analogous to the Wigner energy in neutron-irradiated graphite). But no such explanation can account for the 4 MJ/cm^3 (or 600 eV per atom) to which continuous energy release at such a rate would correspond.

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One issue to be checked is whether there is indeed any such excess heat flow to the surrounding water bath, in excess of that represented by the product of current and voltage applied to the cell (typically 0.8 Å at 12 V). Stored energy could be at most 3 eV or so in any chemical reaction, so it is of the utmost importance to enquire into the details of this measurement; unfortunately, details are lacking.

The 'excess enthalphy generation' is measured calorimetrically[1] by a "calibrated thermistor" as aΔT between the (sometimes stirred) contents of the electrolytic cell and a surrounding thermostated water bath, in comparison with the ΔT measured for a resistance heater in the cell; the thermal impedance is that posed by the dewar flask in which each experiment is conducted. For rods of 1-mm, 2-mm and 4-mm diameter, an excess heat rate is found[1] that depends strongly on the current density, amounting to 8–20 W/cm^3 at 0.5 A/cm^2, which excess heat persists during the operation of the cell for hundreds of hours, even though the surface of the Pd rod blackens.

. . . a multi-dimensional revolution. I bet against its confirmation.

I have seen insufficient evidence to believe that there is 'excess heat', since the ΔT is measured between the bath and the thermistor in the electrolytic cell itself, rather than along a fixed conductive link between cell and bath. If there are significant temperature gradients within the cell because of imperfect stirring or local recombination of hydrogen and oxygen gas, the thermistor temperature will not be the temperature of the inside wall of the flask, resulting in very substantial errors in inferred heat generation.

Even more striking than a heat-producing fusion reaction at a rate some 6x$10^{12}$$cm^{-3}$ s^{-1} is the accompanying claim to have detected the production of only 4x10^{3} neutrons per cm^3 per second. This means that fewer than 1 in 10^9 of the reactions are supposed to produce a neutron.

How can this happen? A coherent superposition of isotopic spin states for $d+d$ could cancel out the neutron-producing reaction and reinforce the $t+p$ branch (D. Wilkinson, Sussex), but would not eliminate the usual isospin-zero reaction. It would thus change the neutron branching-ratio only if the barrier penetration were greatly facilitated. This effect can be estimated, and I judge the effect is only a few per cent rather than a factor 10^9.

Suggestions of radiationless deexcitation of the ^{4}He intermediate state formed by $d+d$ thus far fail in two regards: first, the lack of a mechanism and, second, because such a mechanism would add a channel to the usual particle decay of ^{4}He rather than suppress the usual channel. Thus such a mechanism would need to be 10^9 times faster than the usual particle channels that themselves occur in nuclear transit times — a totally new phenomenon. Finally, the needed mechanism must not have shown itself in the measurement of the cross-sections — some of which were done in gas cells, but some, at times, in metal hydrides.

Somebody is going to have to eat his hat (L. Maiani).

We are also human, and need miracles, and hope they exist. (L. Ponomarev, Moscow).

A few neutrons each second (or a few thousand) from an electrolytic cell may be cold nuclear fusion or may have an 'arcs and sparks' origin. Within the next few weeks, experiments will surely show whether cold nuclear fusion is taking place; if so, it will teach us much besides humility and may indeed provide insight into significant geophysical puzzles[2]. Large heat release from fusion at room temperature[1] would be a multi-dimensional revolution. I bet against its confirmation.

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