COMMENT

The announcement through the news media and later in scientific journals of the experiments on 'cold fusion' has generated a great deal of debate both on the authenticity of the claims made and on the possible mechanisms of the process. We publish below the views of three Indian scientists—two nuclear physicists and an electrochemist.

—Editor

MATERIALS ISSUES IN THE SO-CALLED 'COLD FUSION' EXPERIMENTS

In a recent electrochemical experiment with palladium cathode and platinum anode immersed in 99.5% D_2O + 0.5% H_2O plus 0.1 M LiOD, Fleischmann and Pons[1] claimed to have seen an 'excess heat', which they ascribed to 'cold fusion' of deuterium nuclei electrochemically infused into the palladium lattice. These authors and Jones *et al.*[2] have attempted detection of neutrons/^{3}H as signatures of fusion based on the well-known reactions

$$D + D \rightarrow {}^3He\ (0.82\ MeV) + n\ (2.45\ MeV),$$
$$D + D \rightarrow {}^3H\ (1.01\ MeV) + p\ (3.02\ MeV),$$

and have found some favourable evidence. So far efforts to confirm their findings in various laboratories, including the Bhabha Atomic Research Centre, have been somewhat inconclusive, although some neutrons appear to have been seen occasionally. The reported neutron production[1] is about six to nine orders of magnitude less than what the 'excess heat' would imply. These observations have generated a great amount of debate[3] concerning the nuclear physics of the D–D reaction; novel ideas have been proposed, including the reaction $D + D \rightarrow {}^4He$, with the added requirement that the energy (23.8 MeV) be delivered directly to the lattice. Even when they have been observed, often it has been claimed that neutrons appeared only intermittently. In view of these features we deem it prudent to draw attention to some of the relevant solid-state aspects of the Pd–D system that might be involved in some way.

Absorption of hydrogen/deuterium by Pd has been studied for a long time and is known[4] to be strongly exothermic. Neutron diffraction[5] experiments show that H/D goes into the octahedral sites in the Pd lattice. Accompanying this uptake is a structural change, with the solid changing from the α phase at low H/D concentrations to $\alpha + \beta$ phase at higher values to an eventual β phase. Both the phases are f.c.c., with cell constants $\approx$3.89 Å and $\approx$4.03 Å respectively. Calorimetric studies[4], using activated Pd and molecular D_2 gas, show that, at 30°C, the heat released during the formation of PdD_x rises from $\approx$7.50 kcal per mole of D_2 for $x \approx 0.023$ to $\approx$8.43 kcal per mole of D_2 for $x \approx 0.422$, and the authors assert that 'these heats show a definite increase for each increment of gas added throughout the mixed-phase region'. Thus, as more D atoms are loaded into Pd, one may expect that the β-phase regions (with a higher lattice constant and, presumably, better cohesion) would grow in the matrix of α phase, leading to regions of localized strains. We may conjecture that, eventually, abrupt atomic readjustments may occur, giving rise to conditions—such as local heating and energetic deuterium motions—that are relatively more favourable for some of the D–D fusion mechanisms proposed in the literature. This description also suggests that results of the electrochemical experiments could be very much sample-dependent.

Let us next turn to the enthalpy release. Actually there are several adsorption, absorption and desorption processes involved in the experiment using an electrochemical cell. But here we will concentrate only on the heat of formation of PdD_x, which has not received enough attention. We first note that in electrolysis using Pd as a cathode because of its special ability to dissolve H/D, one generally does not observe any evolution of H_2/D_2 in the beginning, as these are absorbed by Pd. We may also bear in mind that the values of the enthalpy release in the formation of PdD_x quoted above from ref. 4 relate to the situation with *molecular* D_2. If we were to measure these for nascent (i.e. atomic-form) deuterium, then the enthalpy released would be larger by the dissociation energy[6] of D_2, viz. 106 kcal per mole of D_2. Assuming that the

(cathodic) current in the Fleischmann–Pons experiment is only due to flow of D^+, we can then infer the amount of deuterium impinging on the Pd cathode and then roughly estimate the rate of enthalpy release due to deuteride formation. We estimate that it is of the same magnitude as the claimed 'excess heat' of Fleischmann and Pons and emphasize the need to include it in the total energy balance calculations.

To sum up, we feel that the neutronic signals reported to have been seen in some of the recent electrochemical experiments deserve to be viewed in the light of the materials science of palladium deuteride. Although, if it is finally confirmed, this so-called 'cold fusion' would be physically very interesting, the possibility that it will lead to a significant new energy source appears doubtful at present.

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ELECTROCHEMICALLY INDUCED COLD FUSION?—A COMMENTARY

THE thrust of the now famous experiments of Fleischmann and Pons (FP)[1] and Jones *et al.*[2] is to show how simple electrolysis of D_2O can cause a phenomenon suspected to be nuclear fusion. The primary energy input in such experiments is electrical and what is involved as the primary driving force is the potential difference (of the order of a volt) across the cathode–electrolyte (in heavy water) interface. The initiation is the reduction of D^+ ions in the solution to atomic D, adsorbed on the electrode. Adsorbed D atoms diffuse with ease into the Pd, Ti or whatever is the substrate chosen for this purpose, as shown by extensive permeation experiments. Any hydrogen-storage material or hydride-forming metal is viewed as a likely candidate for being used as such deuterium infusion electrodes.

The claim of 'cold fusion' is based on observations purported to result in an excess of enthalpy, besides significant counts of neutrons and a record of gamma radiation. Under certain conditions, there is also the dramatic effect of the case of the vanishing (rather vaporizing) electrodes, as reported by FP! Though details about fusion reactions postulated to explain the above observations are unknown, several possibilities, with products being ^3He or ^4He or ^3H and n or γ, have been recognized. The mechanism of energy transfer and redistribution in the lattice is not understood, however.

The Indian response to the first announcements of the findings by FP and Jones *et al.* has been to try to confirm or disprove the earlier observations. Santhanam *et al.* (Tata Institute of Fundamental Research, Bombay) reported[3] 'an excess power produced during the experiment' and also success in efforts to detect gamma rays or neutrons. The electrolysis was conducted with 66 mA/cm^2 at a Ti cathode and a BF_3 counter in front of the electrolyte cell. Mathews *et al.* (Indira Gandhi Centre for Atomic Research, Kalpakkam) also reported temperature rise, and 'heat evolution' twice that supplied[4]. They reported statistically significant neutron counting with the palladium electrode which carried a current of about 400 mA/cm^2.

The Radioelectrochemistry Section of the Central Electrochemical Research Institute (CECRI), Karaikudi, reported some of its preliminary results to its Research Council on April 29 1989. Quadruplicate experiments with current densities in the range 40 to 1250 mA/cm^2 were carried out over a duration of 24 to 140 hours, on palladium electrodes. Control experiments using pure conductivity water were carried out under identical conditions. In a rather simplistic way, measurements for gamma radiation employed GM counters and chemical dosimetry. Residual activity (long after electrolysis) on the metal cathode samples was also