(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.

We acknowledge helpful discussions with a large number of colleagues, especially Dr P. K. Iyengar, Dr S. Gangadharan, Dr T. P. Radhakrishnan and Dr S. K. Sikka.

1. Fleischmann, M. and Pons, S., *J. Electroanal. Chem.*, 1989, **261**, 301.
2. Jones, S. E., Palmer, E. P., Czirr, J. B., Decker, D. L., Jensen, G. L., Thorne, J. M., Taylor, S. F. and Rafelski, J., *Nature (London)*, 1989, **338**, 737.
3. Garwin, R. L., *Nature (London)*, 1989, **338**, 616.
4. Nace, D. M. and Aston, J. G., *J. Am. Chem. Soc.*, 1957, **79**, 3619, 3623, 3627.
5. Nelin, G., *Phys. Stat. Solidi*, 1971, (**b**)**45**, 527.
6. Weast, R. C. (ed.), *CRC Handbook of Physics and Chemistry*, CRC Press, Florida, 1987, p. F171.

R. CHIDAMBARAM
V. C. SAHNI

Physics Group,
Bhabha Atomic Research Centre,
Bombay 400 085.

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 recorded using autoradiography. An exact contour of the coiled palladium cathode (due to tritium?) was seen on developing. Temperature rise and a rough indication of heat excess, abrupt changes in the shape of the palladium cathode specimen with concomitant heat emission, and a significant absorption by the ceric system in the dosimetry were other features reported in the experiments at CECRI. An extensive study of this problem, coupled with permeation experiments, is in progress in Karaikudi.

In spite of the above indications, scepticism reigns supreme, not only because the experiments have not been satisfactorily reproduced everywhere and explained properly[5]. Theoretical explanations are also slow to come by. That an interesting phenomenon is behind the observations is not in doubt. But debate goes on whether the calculations for the excess heat/enthalpy are realistic (how 'closed' is the system for which the calculations are made). The experimental detection of gamma rays, neutrons, tritium, etc. is also not unambiguous enough. One also wonders whether the reactions behind the phenomenon are 'chemical' or 'nuclear'. The stochasticity/fluctuations in the observations have not been helpful either!

Three components of the problem need attention. First, electrochemical aspects concerning the mechanism of deuterium reduction must be settled. With a wide range of current densities employed, possible *changes* in mechanism with c.d. must be kept in mind. Alternative paths, though they may not be serious from the current efficiency point of view, may drastically alter the surface characteristics (e.g. codeposition of metals from solution). Consequently the influx of D atoms or their coverage will also be altered. Possible barriers—especially formation of various hydrides[6]—may affect the D enrichment in the lattice. The design of electrochemical inputs (e.g. current or potential control, their profiles) is another factor of importance. The second aspect relates to 'criticality' and 'the dimensionality'. The consensus seems to be that there is a 'criticality' or 'threshold' for this phenomenon, though its nature is not clear. Besides, a 'dimensionality' effect is also suspected (cf. ref. 1)—this is less likely to be fundamental and probably influences only the 'onset of criticality'. Inspired by hydrogen permeation and attendant embrittlement effects, known in many systems, attention is given to the role of defects, including the grain boundaries[7]. Since we have a distribution of defects, and the diffusion (and aggregation) in the lattice being a stochastic phenomenon too, fluctuations (cf. the statistics and the time variation of the nearest-neighbour distances) assume importance. The part played by the lattice is the third component to be elucidated. Whether the environment of high, localized electron density in the lattice (cf. a high effective mass) leads to a re-enactment of 'muon-catalysed fusion' is to be settled. Obviously 'the observed cross-sections' for the harvesting of the products from the reactions—suspected to be fusion-like—are very low. But can these be due to the 'composite' nature of any dynamic observation (cf. several precursor stages in the preparation of the D–D system for fusion)?

In short, the coming months will shed some heat and light, to be sure. The euphoria created by the announcement of 'cold fusion' is an indicator of many things that characterize the practice of science—the long wait for a likely paradigm, an avidity for the unusual, and a sneaking desire for unbelievably simple alternatives to complex tasks. Even if the ultimate verdict goes against it, this 'cold rush' will be remembered for the hope it generated while it lasted!

I sincerely thank my colleagues V. Kapali, M. Anbukulandai Rajan, M. Ganesan, Muthuramalingam and Sheik Mohideen, who did the CECRI experiments reported here, and Dr G. P. Rao, Mr Rama Kant, Dr A. K. Mishra and Prof. K. S. G. Doss for discussions.

1. Fleischmann, M. and Pons, S., *J. Electroanal. Chem.*, 1989, **261**, 301.
2. Jones, S. E., Palmer, E. P., Czirr, J. B., Decker, D. L., Jensen, G. L., Thorne, J. M., Taylor, S. F. and Rafelski, J., *Nature (London)*, 1989, **338**, 737.
3. Santhanam, K. S. V., Rangarajan, J., O'Neil, Braganza, Haram, S. K., Limaye, N. M. and Mandal, K. C., *Indian J. Technol.* 1989, **27**, 175.
4. Mathews, C. K., Periaswami, G., Srinivas, K. C., Gnanasekaran, T., Rajan Babu, S., Ramesh, C. and Thiyagarajan, B., *Indian J. Technol.*, 1989, **27**, 229.
5. Lindley, David, *Nature (London)*, 1989, **339**, 84.
6. Pauling, L., *Nature (London)*, 1989, 339, 105.
7. Gittus, J. and Bockris, J., *Nature (London)*, 1989, **339**, 105.

S. K. RANGARAJAN

Central Electrochemical Research Institute,
Karaikudi 623 006.