Cold fusion: what's going on?

Sir—A significant point which is not widely known, and may therefore be overlooked in neutron measurements of cold fusion rates, is the possibility of contamination by cosmic-ray-generated neutrons; these should be taken into account in the design and interpretation of experiments.

The cosmic-ray-induced neutron background arises primarily from extra-solar protons with energies above a few GeV, which can penetrate the Earth's atmosphere and the Sun's and Earth's magnetic fields. Primaries and secondaries reaching the surface include neutrons and other energetic particles which produce neutrons in the atmosphere and the first few metres of the surface by spallation reactions. While the spectrum contains neutrons up to energies comparable to incident particle energies, a major component is due to evaporation of neutrons from struck nuclei; at birth these have energies in the range 1–3 MeV, and appear as a knee or shoulder on an otherwise continuous energy distribution. There is also a substantial component consisting of 'thermal' neutrons, which have slowed down in the environment to a poorly equilibrated thermal distribution below energies of about 0.1 eV as well as 'epithermal' neutrons whose distribution is roughly inversely proportional to the energy in the range 1 eV to 1 MeV. At energies above a few MeV, the spectrum tails off rapidly; this cascade component contains about 10% of the total. The flux of each of the low-energy components is of the order of 10^4 neutrons cm^-2 s^-1 at sea level and middle latitudes.

These figures vary according to altitude (about twice at 1,500 m elevation), and from time to time, mostly because of variations in atmospheric density and solar and geomagnetic field intensity. The e-folding thickness in the atmosphere is about 150 g cm^-2; so that, for example, barometric pressure variations of ±13 mm of mercury cause about ±10% flux variations. Sometimes, when dealing with such a general source of neutrons, material intended as shielding, and even detector material itself, can act as a source, so that some care in this respect is called for in the measurements.

As it happens, the counting rates due to cosmic-ray-induced neutrons are of the same order of magnitude as the counting rates observed in the neutron and secondary radiation detectors in many of the measurements being made. And in detectors that disperse the spectrum, the evaporation peak in the energy distribution due to cosmic-ray-induced neutrons is at nearly the same energy as that expected from deuteron-deuteron fusion, 2.45 MeV. These observations couple with the (admittedly weak, ±10%) temporal (hourly, daily) variation of the cosmic-ray-induced neutron fluxes require that this background be carefully accounted for.

Comparable neutron fluxes can be generated by accelerators, isotope sources and nuclear reactors, even at considerable distances; these contaminants of neutron measurements must also be reckoned with. Obvious means for suppressing these backgrounds are time-gating of the source, monitoring spurious sources with a second detector operated simultaneously with the detector(s) near the source under investigation, or going underground — 350 g cm^-2 (two or three metres of earth or concrete on all sides) should reduce the cosmic-ray neutrons by a factor of about 10.

John M. Carpenter
Argonne National Laboratory,
9700 South Cass Avenue,
Argonne, Illinois 60439-4814, USA

Dr Carpenter, a referee of the paper by Jones et al. on page 737, provided this comment at our invitation.

The following are extracts from the substantial numbers of letters from readers offering explanations of the two series of cold fusion experiments which have been generally reported.

Editor, Nature.

Sir—From the newspaper accounts, the very small flux of neutrons generated during the experiment of Fleischmann and Pons is being taken as proof that their conclusion is not valid, and that nuclear reactions between deuterons do not occur under the conditions they describe.

But when the kinetic energy is as small as in their experiment, the neutron and proton combine to form a deuteron that does not behave in the same way, because the nucleus of the target atom repels the proton but not the neutron. Thus, the neutron can be captured by the target nucleus while the proton, which remains outside the Coulomb barrier, will fly off.

This process, first recognized by Oppenheimer and Phillips in 1935 leads to a pure \((d, p)\) reaction and has a relatively high probability of occurrence, certainly much greater than that of the \((d, n)\) reaction. It follows that if the experiments described really brought the deuterium nuclei close enough together to interact, one should expect no neutron emission and a reaction rate much higher than that evaluated on the basis of the high-energy


deuterium.

The consequence is that fusion induced by cosmic-ray muons cannot be excluded as an explanation of the reports of radiation effects in palladium loaded electrochemically with deuterium, although the estimates of the rate of muon-induced fusion is much less than that required by the thermal observations of Fleischmann and Pons.

These developments emphasize the need for experimental data on the effects of negative muons in solids, especially metal deuterides and tritides, which are at present lacking in the open literature. Arrangements are in hand to investigate the reported palladium-deuterium effects with a muon source of greater flux than that of the natural cosmic ray radiation.

A.J. McCVEVOY
Ecole Polytechnique Fédérale de Lausanne,
CH-1015 Lausanne, Switzerland
C.T.D. O'SULLIVAN
University College, Cork, Ireland


Sir—In my theoretical investigations of the electronic structure of the H2 molecule (Phys. Lett. 123, 170; 1987), I have found that the two nuclei and the electron can form a collapsing quasi-molecule—a compact system whose dimensions decrease with time to zero. (The extreme case is when the electron is at the centre-point between the two nuclei.) In general, in collapsing molecules like these, the repulsive Coulomb interaction of the nuclei and the gaskinetic pressure of the electron are less than the attractive Coulomb forces between the two nuclei and the electron. The closest approach of the two nuclei depends on the initial state of the electron, its binding energy and the mean value of the kinetic energy in particular.

The probability of the tunnelling effect is therefore identical with the probability of formation of a collapsing quasi-molecule. Thus it is clear that the electrons present in the matter are responsible for the Coulomb-barrier tunnelling, and that the process which has been observed depends on quasi-molecular systems.

M. GryzINSKI
Soltan Institute for Nuclear Studies, Swierk-Otewn 05-400, Poland

Sir—Reports of the experiments by Fleischmann and Pons contain a paradox that, if fusion reactions do occur in them, either too much energy is liberated or too few neutrons are detected. I wish to suggest a possible explanation.

I start from the hypothesis that the palladium contains regions where the density of deuterons is sufficiently great for d-d fusion to occur by one of the reactions leading either to H and a proton or to 3He and a neutron. The product particles will be produced within a region where the density of other particles is very great. The mean free paths of the particles will then be very small, and it appears reasonable to assume that even though these high-density regions will be geometrically small, they will be optically large that even the most penetrating particles, such as neutrons, will remain trapped inside them. In this situation, the particles produced by fusion reactions will undergo multiple scattering collisions until a new reaction occurs.

Several such reactions are possible, including fusion reactions of deuterons with 3H and 3He (yielding 4He and a neutron or proton respectively) and the radiative capture of protons or neutrons by deuterons. These reactions are exothermic, releasing large amounts of energy.

It is crucial that these processes can also form multiplicative chains, especially if the γ-rays released are of radiative capture reactions yield further energetic neutrons and protons by the photodisintegration of deuterons. The reaction chains will come to an end only when reactive particles escape from high-density regions to those where the density is insufficient to sustain them.

The main products of these reaction chains will be α-particles, but the reactive particles such as neutrons and H will only infrequently be released to the environment.

FRANCESCO PREMUDA
Nuclear Engineering Laboratory,
University of Bologna,
I-40136 Bologna, Italy

Pulsar formation

Sir—Lindley states that the report2 of a half-millisecond pulsar in the remnant of supernova 1987A “has surprised everyone and could, if confirmed, stand on its head”. He has apparently overlooked several papers (refs 4 and 5, for example) suggesting that pulsars may form directly as rapidly rotating neutron stars “in original spin” with weak magnetic fields, without the need for “resurrection” after birth as a slow rotator followed by subsequent decay of the magnetic field and spin-up by accretion of matter from a companion star.

Even before the discovery of millisecond pulsars, we discussed the question of why collapsed stars rotate so slowly, and pointed out that if there was significant mass ejection during the formation of a neutron star, and if it had a strong magnetic field, it was likely to be born spinning slowly. We argued, furthermore, that if the progenitor giant core of the neutron star has a strong magnetic field, it is likely to have been rotating relatively slowly, as the magnetic field would have enhanced transfer of angular momentum from it to the envelope during later evolutionary phases. We furthermore stated that if weak-field neutron stars could form at all, they would be born spinning fast. If the optical emission from the half-millisecond pulsar arises from incoherent synchrotron radiation at the light cylinder, and sealing by the optical luminosity and magnetic field of the Crab pulsar, it follows that the half-millisecond pulsar indeed has a weak magnetic field of B~10^10 gauss.

With the discovery of six millisecond pulsars (with periods ≤12 ms), of which four are in binary star systems, several authors concluded that ‘resurrection’ was required to account for their observed properties. A key requirement for the ‘resurrection’ model is that the magnetic field of neutron stars must decay on a timescale of a few million years. But arguments against significant neutron-star magnetic-field decay have been proposed (for example, ref. 8). Furthermore, calculations by Sang and Channugum8 showed that there are very serious difficulties with all the models so far proposed for field decay. In addition, there is no satisfactory detailed model that explains how single millisecond pulsars can be formed from binary star systems. Even in the case of PSR 1957 + 20, where there is evidence of matter evaporating from the companion, the spin-down rate indicates insufficient energy loss from the pulsar to evaporate the entire companion star. When combined with all the difficulties of the ‘resurrection’ model, the discovery of the half-millisecond pulsar seems to provide substantial further support for the view that at least some millisecond pulsars can be born “in original spin”.

K. BRECHER
Department of Astronomy,
Boston University,
Boston, Massachusetts 02215, USA
G. CHANNUGUM
Department of Physics and Astronomy,
Louisiana State University,
Baton Rouge, Louisiana 70803, USA


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