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Cold Fusion?

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The question mark behind the title of this paper indicates what the author considers to be the present status of this potentially revolutionary new method of energy production, also dubbed "fusion in a jar".

When two electro-chemistry researchers, Prof. Fleischmann of the University of Southampton (U.K.) and Prof. Pons of the University of Utah (USA), announced at a press conference on March 23, 1989 that they had achieved "cold" deuterium-deuterium fusion with significant energy gain in an apparatus not more complicated than equipment used in college electrolysis experiments, they startled not only the world scientific community, but the public at large. The debate over the veracity and significance of the Fleischmann/Pons (F/P) results has picked up momentum (and acrimony) ever since and often spilled over onto the front pages of international newspapers and magazines. Understandably so, if we consider the vast potential consequences not just for energy production, but also for the entire edifice of present scientific theory governing the microscopic realm.

Before describing the F/P experiments and attempting an evaluation of their results, the present status of high temperature fusion research and theory is briefly reviewed to provide the reader with some background against which to judge the potential impact of the F/P work.

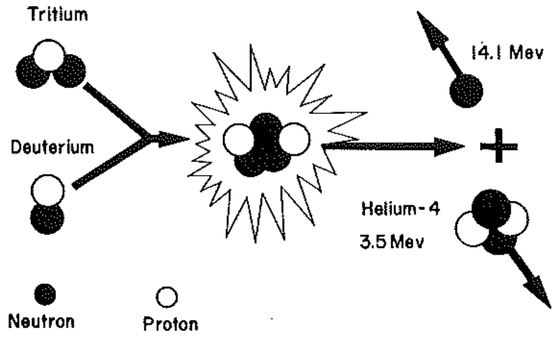
Current Status of International High Temperature Fusion Research

Nuclear fusion is the principal energy source of stars and its significance in this regard was first recognized in the mid-1920s, well before the discovery of nuclear fission. On Earth, man-made fusion has been produced in the form of H-bombs, and the international fusion energy research program, presently funded at a level of about US$ 2 billion per year, aims to produce controlled and sustainable fusion reactions for electric energy production and for a large variety of potential direct industrial applications. The two most common approaches to the solution of this problem are so-called magnetic and inertial confinement fusion (see Figs. 1-5).

Large toroidal devices (called tokamaks) have been built at costs exceeding US$ 250 million (Fig. 2) to test the scientific feasibility of magnetic confinement fusion, subjecting hydrogen isotope plasmas (ionized gases) to temperatures exceeding 100 million °C and magnetically confining them long enough (at least 1 sec) to produce a sufficient number of fusion reactions and energy output to at least offset the amount of energy necessary to produce such extreme conditions (energy breakeven).

Large lasers have also been built at comparable cost, most notably in the U.S. (Lawrence Livermore Laboratory) and Japan (Osaka Laser Engineering Laboratory), to test the inertial confinement approach (Figs. 3-5) of producing fusion by illuminating small pellets containing fusionable material with large concentrated bursts of photon energy.

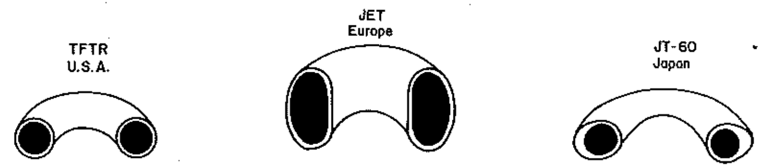
Both approaches to high temperature fusion have made satisfactory progress during the past decade (for magnetic fusion see Fig. 6), though the precise degree of progress of the U.S. inertial fusion program is difficult to judge because of military classification. Given proper funding,



HOW FUSION WORKS

The simplest fusion reaction is the fusing of two hydrogen nuclei, which produces one helium nucleus and liberates energy. In the deuterium-tritium fusion process shown here, a deuterium nucleus (one neutron and one proton) fuses with a tritium nucleus (one proton and two neutrons). Two protons and two neutrons combine to form a stable helium nucleus, while the extra free neutron flies off with four-fifths of the total energy released as kinetic energy. (The stable helium atom has the remaining one-fifth of the energy.) This kinetic energy can then be converted to heat or electricity. The energy needed to start the deuterium-tritium reaction is 10 million electron volts (megavolts), while the energy produced is 17.6 million electron volts.

Fig. 1. How fusion works.



TFTR U.S.A.	
Minor radius	0.85 meters
Major radius	2.48 meters
Toroidal magnetic field	5.0 tesla
Plasma current	3.0 million amperes
Pulse duration	2 seconds
External heating power	27 megawatts
Designed for D-T operation	

JET Europe	
Minor radius:	
horizontal	1.25 meters
vertical	2.10 meters
Major radius	2.96 meters
Toroidal magnetic field	3.45 tesla
Plasma current	7.0 million amperes
Pulse duration	30 seconds
External heating power	44 megawatts
Designed for D-T operation	

JT-60 Japan	
Minor radius	0.95 meters
Major radius	3.0 meters
Toroidal magnetic field	4.5 tesla
Plasma current	2.7 million amp.
Pulse duration	5-10 seconds
External heating power	54 megawatts
Hydrogen operation only	

Fig. 2. The three largest tokamaks compared.

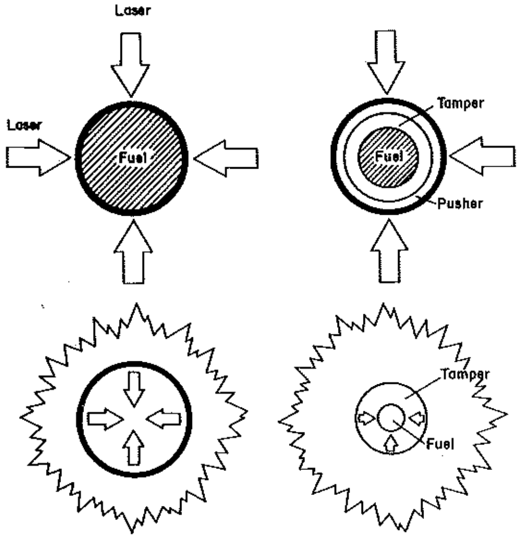


Fig. 3. The principle of laser fusion: laser light in a time span of nanosecond range illuminates and compresses the fusion fuel (D-T) to achieve fusion.

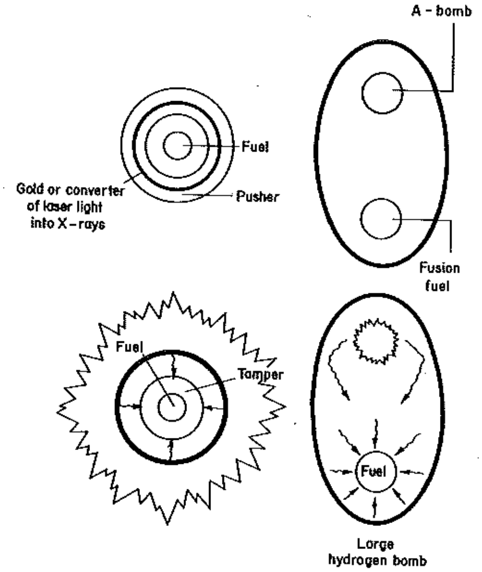


Fig. 4. Advanced laser fusion targets: these targets work according to the same principle as the H-bomb; laser energy is converted into x-rays, which compress the fuel nearly isentropically to achieve fusion.

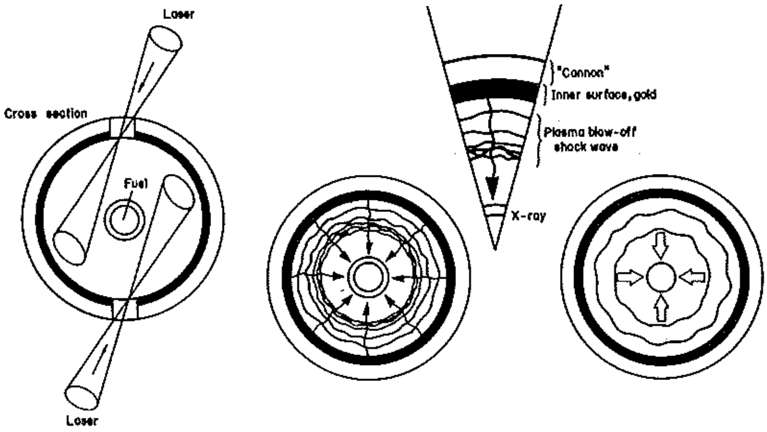
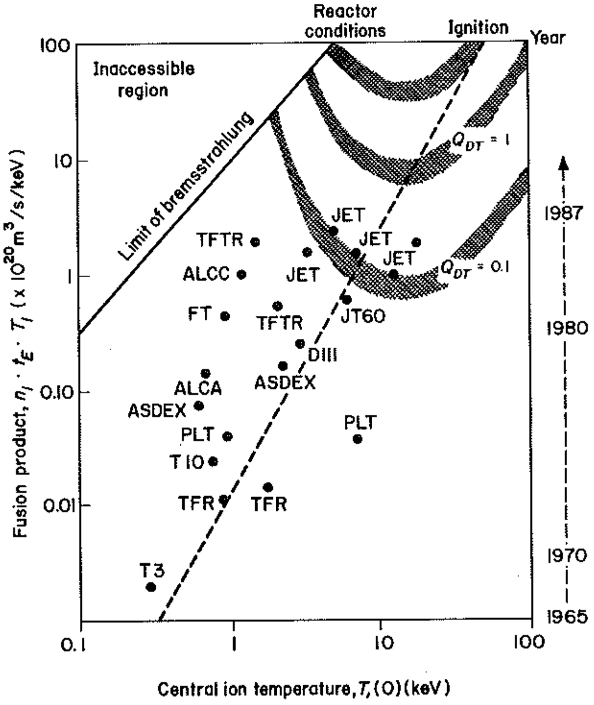


Fig. 5. The Osaka cannonball - a nonablative laser fusion target.

engineering test facilities for magnetic fusion could come on line during the second half of the 1990s and fusion-based central electric power stations will almost certainly be realized during the first decade of the next century.

The easiest fusion reaction to ignite is that of deuterium-tritium:

$$D + T \quad = \quad \text{He-4} + n \ (17.6\text{MeV}) \qquad (1)$$



JET Joint Undertaking

Fig. 6. Progress of fusion experiments in tokamak devices.

In this case, the two heavy hydrogen isotopes fuse to form the next heavier element, helium-4. It is principally their reaction, which is being experimented within the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory (USA) and the Joint European Torus (JET) in Culham, England.

The next easiest reaction to ignite is that of deuterium-deuterium, which involves two possible paths, each occurring at about the same rate:

$$\mathrm{D} + \mathrm{D} = \text{He-3} + \mathrm{n}\ (3.2\ \text{MeV}) \qquad (2a)$$

or

$$\mathrm{D} + \mathrm{D} = \mathrm{T} + \mathrm{p}\ (4.0\ \text{MeV}), \qquad (2b)$$

where the products are either helium-3 and a 2.45 MeV neutron (n) or a tritium nucleus and a proton (p). These reactions are relevant to the F/P experiments.

Other possible reactions, that may also eventually have to be considered in the case of cold fusion, are :

$$\mathrm{D} + \text{He-3} = \text{He-4} + \mathrm{p}\ (18.3\ \text{MeV}) \qquad (3)$$

and

$$\text{Li-6} + \mathrm{D} = \text{Li-7} + \mathrm{p}\ (5.0\ \text{MeV}) \qquad (4)$$

where lithium-6 and lithium-7 are isotopes of the chemical element following helium.

With these preliminaries out of the way, let us now turn to the cold fusion experiments. But first note again that, until the announcement of the F/P results, the above fusion reactions were only considered realizable at extremely high temperatures (particle velocities) and with the aid of machines costing hundreds of millions of dollars to construct. This explains the shock effect and disbelief produced by the "fusion in a jar" claims.

The Fleischmann/Pons Experiment

The relatively simple F/P experimental set-up (not taking into account the more sophisticated diagnostic instruments) is shown in Fig. 7.

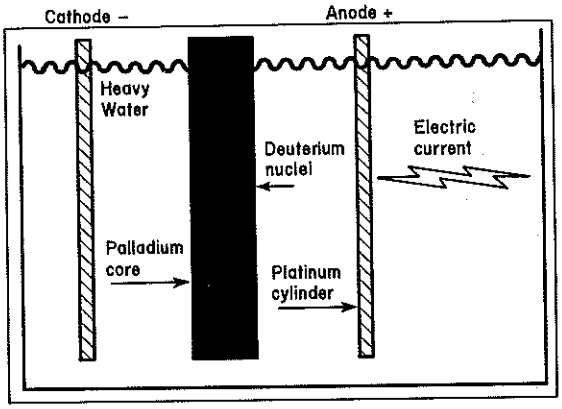


Fig. 7. Simple F/P experimental set up.

In their paper "Electrochemically Induced Nuclear Fusion of Deuterium"[1], F/P describe their observations and measurements as a current is passed through the D_2O/electrolyte solution, saying most importantly that:

1) "Enthalpy generation can exceed 10 W/cm^3 of the palladium electrode; this is maintained for experimental times in excess of 120 hours during which typically heat in excess of 4 MJ/cm^3 of electrode volume was liberated. It is inconceivable that this could be due to anything but nuclear processes. " [?] [Emphasis added]
2) "... the γ - ray spectra which have been recorded in regions above the water bath adjacent to the electrolytic cells... confirm that 2.45 MeV neutrons are generated in the electrodes by the reaction

$$^2D + {}^2D \quad = \quad {}^3He\ (0.82\ MeV) + n\ (2.45\ MeV) \qquad [cf.(2a)\ above].$$

... We note that the intensities of the spectra [and thus the neutron flux] are weak.." [Emphasis added].

So, is it really fusion? And if so, how to explain it? F/P have challenged scientists around the world to replicate their experiments and "fusion jars" have probably been set up in nearly 100 laboratories worldwide. So far the results reported are contradictory and thus inconclusive, though at least the obvious control experiments of replacing D_2O with H_2O in the eletrolytic cell have shown no significant heat generation. Thus it is certainly the deposition of deuterium in the palladium electrode that is responsible for the F/P effect.

But again, is it really D-D fusion that is responsible for the electrode heating? The wisecrack of a fusion scientist that if it were fusion then F/P should be dead, points to a major theoretical dilemma:

The large amount of heat generated is not accompanied by an anywhere near large enough neutron flux to make a convincing prima facie case for fusion. The author does not believe that the cold fusion controversy will be resolved decisively until scientists begin to formulate coherent scientific hypotheses and design crucial experiments capable of shedding light on and explaining the high heat/low neutron count paradox. The rather few and very preliminary attempts that have been made to come to grips with cold fusion in theoretical terms are reviewed below.

Some Theoretical Considerations

Current fusion theory stipulates that significant rates of fusion of heavy hydrogen nuclei require temperatures approximating 100 million °C, with ignition of self-sustaining fusion reactions becoming possible only when the product of the ion density (particles per unit volume) and confinement time exceeds $5x10^{22}$ s/m^3. Such extreme conditions are, of course, not relevant to cold fusion. At room-temperature nuclei are clothed with electrons and the rate of fusion in molecular hydrogen is governed by the probability of zero separation of two nuclei (quantum - mechanical tunneling through the Coulomb barrier). For the deuterium molecule, equilibrium separation between deuterons is equal to 0.74 Å with a "natural" fusion rate calculated at about 10^{-70} per D_2 molecule per second.

The question thus arises how this exceeding slow rate could be massively increased (by, say, at least 50 and up to 80 orders of magnitude), without great increase in temperature (particle velocity), in order for cold fusion to be accounted for. Or, to be more specific, what is it about confinement of deuterons in a metal lattice that would make them fuse in a low temperature regime? Two hypotheses, exemplifying some current thinking, are as follows:

1) S.E. Jones et al.$^{2)}$, Brigham Young University, USA:
What happens in the case of cold fusion may be comparable to muon catalyzed fusion. By replacing the electron in a hydrogen molecular ion with a more massive muon, the internuclear separation is reduced by a factor of 200 (the muon to electron mass ratio), and the nuclear fusion rate correspondingly increases by roughly eighty orders of magnitude. This extraordinary variation in the magnitude of the fusion rate leads one to suspect that even small perturbations of the hydrogen molecule's wave function could result in a dramatic change in the spontaneous fusion rate. Imposing boundary conditions on the H-molecule's nuclear wave function simulating the confinement of nuclei within a lattice cell, a fusion rate of the order of 10^{-24} /s is calculated. This fusion rate conforms to the actually measured neutron flux from cold fusion experiments carried out at Brigham Young University.

Commentary:

The Jones hypothesis is interesting, but has two pitfalls. First, a rate of 10^{-24} is too slow to explain the F/P results. Second, if wave function boundary conditions could be found to account for the F/P effects, a very high neutron count would likely also be implied – contradicting the F/P findings.

2) H. Aspden [3], University of Southampton, England:
   The hypothesis is twofold:

a) A new theory of gravitation that has yielded an accurate theoretical evaluation of the constant of gravitation and has been shown to have relevance to the phenomenon of warm superconductivity, applies to cold fusion as well. The theory distinguishes between normal gravitons balancing matter of mass-energy 6.149 GeV and supergravitons balancing matter of mass-energy 95.17 GeV. The proposition is that when deuterons leave the heavy water environment and enter the dense matter environment (palladium, titanium) their normal gravitons have about one microsecond in which to merge into the supergravition state. During the one microsecond period after absorption into the dense matter the deuterons are vulnerable to the vacuum field energy fluctuations associated with the graviton transition and sufficient energy is conferred upon them to catalyze deuterium-deuterium fusion.
b) No significant neutron flux is observed, because there are no neutrons in stable matter, but only metastable antiproton/positron combinations.

Commentary:

Even a rather cursory evaluation of the Aspden dual hypothesis would go well beyond the scope of this paper. The hypothesis is presented here to demonstrate that a full explanation of cold fusion will almost certainly involve some entirely new theoretical accounts of the atomic nucleus and of the interaction of electro-magnetic phenomena with the geometry of space/time. This makes cold fusion not only experimentally challenging but – perhaps along with warm superconductivity – will catalyze badly needed new impulses in theoretical physics. Every scientist should welcome the implied theoretical challenges and opportunities for potentially revolutionary innovations.

CONCLUSIONS

The present status of the cold fusion controversy can be fairly summed up as follows:

1. Extraordinary amounts of heat production in F/P-type experiments have been observed not only by F/P themselves, but by numerous researchers attempting to replicate the University of Utah experiments. No electro-chemical explanations are available to account for the observed phenomena.
2. Nuclear reactions provide for the most plausible alternative account. However, the lack of sufficient neutron production puts the nuclear fusion hypothesis in doubt.

The scientific community's reaction to this dilemma, so far, has been most disappointing. Tinkering with the F/P experimental set-up or petty and cynical comments from fusion researchers worried about competition for funding of their own established projects will not make the controversy go away. Too much is at stake, both for science and for the future of humanity at large. Heavy water is cheap and abundant, constituting one part of 6500 of ordinary sea water. Just imagine the economic opportunities and consequences implied by virtually unlimited, cheap and clean energy production!

So, the challenge to scientists is clear: Formulate hypotheses and design experiments capable of clarifying the dispute. Instead of taking sides himself, the author will paraphrase the recent comment on cold fusion by one of the world's most senior fusion scientists, Edward Teller, who, admirably, has never allowed alleged unassailable theories to blind him to contrary evidence:

> "Before the Fleischmann/Pons presentation (March 23) of their results I regarded cold fusion as horrible nonsense; now I am happy to think that I may have been horribly wrong."

REFERENCES

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2) Jones, S.E. et al., *Cold Nuclear Fusion in Condensed Matter* and *Theoretical Limits on Cold Fusion in Condensed Matter*. (Unpublished manuscripts, Mar. 23 and Mar. 27,1989).
3) Aspden, H., *Cold Fusion as a Supergravition Transition*. (Unpublished manuscript).