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CAN BINUCLEAR ATOMS SOLVE THE COLD FUSION PUZZLE?

COLD FUSION

TECHNICAL NOTE

KEYWORDS: *cold fusion, binuclear atoms, neutron trapping*

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The internal and external inconsistencies of cold fusion phenomena are discussed. It is shown that most of these inconsistencies can be removed by assuming the formation of binuclear atoms that have the ability to trap thermal neutrons from the natural background in a localized state.

EVIDENCE FOR COLD FUSION

The evidence for cold fusion is formed of pieces that not only contradict known physical laws but are also self-contradictory (for a well-balanced review, see Ref. 1).

Cold fusion phenomena have been claimed to occur under the following conditions:

1. during the fracture of LiD crystals impacting on solid walls (fractofusion)[2,3]
2. during electrolytic charging of palladium or titanium cathodes with deuterium (electrolytic fusion)[4,5]
3. during phase transitions associated with metastable states obtained by low-temperature absorption of deuterium into titanium turnings (fusion induced by thermodynamic instability)[6]
4. during the impact of $(D_2O)_n$ clusters on TiD, $ZrD_{1.65}$, and $(CD_2\text{-}CD_2)_n$ deuterium-containing targets (warm fusion)[7]
5. during redox reactions involving deuterium, such as $LiD + D_2O \rightarrow LiOD + D_2$ (chemofusion).[8]

Of these phenomena, only fractofusion allows an explanation in terms of known physical laws,[9] and, therefore, will not be considered in the forthcoming considerations. In the other cases, the claimed fusion rates exceed the rates predicted by current physical laws by several orders of magnitude.[10,11]

Heat has been reported to have been produced in cold fusion experiments.[4,12,13] If this heat production is ascribed to standard deuterium-deuterium (D-D) fusion,

$$D + D \rightarrow {}^3He + n + 3.28\ \text{MeV} \qquad (1)$$

and

$$D + D \rightarrow {}^3H + p + 4.04\ \text{MeV}\ , \qquad (2)$$

and reactions (1) and (2) take place with the same branching ratio as observed at high energy (0.47 and 0.53, respectively), then the number of emitted neutrons is lower by several orders of magnitude than that required to justify the reported heat production.[14]

To explain the excess heat, it is often stipulated that the branching ratio deduced from nuclear physics is no longer true at low energy and that only reaction (2) takes place. However, although tritium production has been reported,[1,15-17] a concomitant emission of charged particles has not been observed,[18] and the branching ratio *measured* in warm fusion experiments at energy of the order of 10^2 eV is claimed to be ~50% (Ref. 19).

Alternatively, reaction

$$D + D \rightarrow {}^4He + \gamma(23.84\ \text{MeV}) \qquad (3)$$

has been postulated to occur with a branching ratio completely different from that predicted from nuclear physics ($\approx 10^{-7}$). However, although ^4He has been observed,[20] no evidence of 23.84-MeV gammas has ever been found.[21]

We have proposed a model of binuclear atoms that can explain some of the evidence of cold fusion.[22,23] This model by itself is, however, unable to explain other pieces of evidence. In the following, we show that the assumption that *cold fusion phenomena are at least partially activated by an interaction of binuclear atoms with the background* is able to remove *qualitatively* all the quoted anomalies of cold fusion, and it contains elements that allow us to attack the cold fusion problem *quantitatively*.

BINUCLEAR ATOMS

We have proposed binuclear atoms to explain warm fusion[22] and chemofusion[23] phenomena.

Binuclear atoms are metastable configurations in which two nuclei are held together by the electronic energy of the orbiting electrons in an atomiclike configuration. The hydrogen-hydrogen heliumlike binuclear atom $(H^+H^+)2e^-$ is explicitly predicted to exist, although the activation energy required for its formation (~30 eV) is extremely high for ordinary chemistry, so that it can only be formed under very special conditions such as the ones occurring inside a dense collisional cascade.[24] The $(H^+H^+)2e^-$ binuclear atom is predicted to be metastable with a remarkably high activation energy (of several electron volts) for its dissociation. In the $(H^+H^+)2e^-$ binuclear atom, the electronic energy is not a constant of motion and is coupled with the nuclear kinetic energy, and the nuclei move with a kinetic energy of the order of 10 eV although they remain localized in a region of 0.4 to $0.5a_0$, where a_0 is the Bohr radius ($a_0 = 0.53 \times 10^{-8}$ cm).

Several $(H^+H^+)2e^-$ binuclear atoms can be considered in relation to the constituting hydrogen isotopes. The hydrogen isotopes are henceforth denoted by the symbols H, D, and T and the corresponding nuclei with the symbols p, d, and t; the $(H^+H^+)2e^-$ binuclear atom is referred to as $(pp)2e$, the $(D^+D^+)2e^-$ as $(dd)2e$, etc.

Deuterium-deuterium binuclear atoms $[(dd)2e]$ can be formed in all kinds of cold fusion experiments. The way they may be formed in warm fusion and chemofusion is described in Refs. 22 and 23. Binuclear atoms may be formed in electrolytic fusion according to the mechanism advocated by Pauling[25] to explain heat excess, provided that the excess energy is imparted to deuterium atoms essentially uncoupled from the host matrix.[26] The mechanism advocated by Pauling is essentially the same as that responsible for the thermodynamic instability in deuterium absorbed in titanium, so that even in this case, binuclear atoms can be formed. (That binuclear atoms may be formed in fractofusion is understood by observing that during the formation of the fracture, macroscopic energy is imparted to a few degrees of freedom.)

Deuterium-deuterium binuclear atoms can explain some cold fusion phenomena on the basis that in a binuclear atom, the nuclei are confined within a region of 0.4 to $0.5a_0$, which allows (according to the calculations of Ref. 10) fusion rates of the order of (10^{-31} to 10^{-26} s^{-1})/(d-d pair), the upper limit of which is not too far from Jones et al.'s initial report[5] [$\approx 10^{-23}$ s^{-1}/(d-d pair) in a ground-based laboratory] and is in line with the most recent determinations in deep underground conditions.

Deuterium-deuterium binuclear atoms alone, however, cannot explain the remaining pieces of evidence, especially the calorimetric data without neutron emission and those on tritium and ^{4}He enrichment.

INTERACTION OF BINUCLEAR ATOMS WITH THERMAL NEUTRONS

While charged particles are expected to interact with the binuclear atom as a whole, neutral particles are expected to interact separately with the components of the binuclear atom in all cases but one—*when the reduced de Broglie wavelength of the neutral particle is close to the size within which the nuclei are localized.* This condition is equivalent to the de Broglie condition for the existence of stationary closed orbits with radius equal to nuclear separation.

A comparison of the putative $(dd)2e$ size ($a_0/2 = 0.26 \times 10^{-8}$ cm) with the reduced wavelength of thermal neutrons (0.29×10^{-8} cm at 2.2×10^5 cm/s) suggests that thermal neutrons can be trapped in stable orbits inside the binuclear atom. It is also expected that the more thermal neutrons are trapped inside binuclear atoms, the more efficient cold fusion phenomena are. Therefore, if the temperature of the maximum cold fusion efficiency is known, one has direct information on D-D separation in the binuclear atom. Assuming the validity of the Menlove et al. results,[27] which show that the maximum number of neutron bursts in cold fusion experiments resulting from a thermodynamic instability occurs at a temperature $T \sim 240$ K, and assuming a neutron energy between the reference value ($k_B T$, where k_B is the Boltzmann constant) and the average one ($3/2 \cdot k_B T$), one gets a nuclear separation in the binuclear atom in the range of 0.26 to 0.32×10^{-8} cm compared with a theoretical estimate of $\sim 0.26 \times 10^{-8}$ cm.

In all cold fusion experiments except warm fusion, the apparatuses are unavoidably embedded in a field of thermal neutrons. In fact, in most experiments, the search for emitted neutrons requires that they are first thermalized and then allowed to react with ^{10}B or ^{3}He proportional counters to detect ionization due to reaction products. In these experiments, the detection process modifies the neutron field impinging on the target. Even when the emitted neutrons are detected before thermalization (as in Ref. 5), the neutron flux impinging on the target has a high thermal component because of the presence of large amounts of D_2O (in electrolytic fusion), D_2 (in fusion induced by a thermodynamic instability), or structural materials.

It is, therefore, not unrealistic to assume that in ground-based experiments, the formation of a $(dd)2e$ binuclear atom is accompanied by the capture of a thermal neutron in a stable orbit, this process having a capture cross section of $\pi(a_0/2)^2 \approx 10^{-17}$ cm^2, several orders of magnitude higher than the typical cross section of neutron capture (10^{-24} to 10^{-21} cm^2)—the binuclear atom is a way to open a window of atomic size on the nuclear world.

Neutron trapping by binuclear atoms is essentially a hypothesis resting on the coincidence of the reduced wavelength of the thermal neutron with the nuclear separation in the binuclear atom. Although neutrons interact mostly with a nucleus within a nuclear force range of a few fermis, nuclear separation plays an important role in neutron scattering because of the wavelike nature of neutrons. For instance, it is well known that neutron interaction with an ordered lattice of scattering centers localizes the neutrons along directions given by the Bragg condition. Less known, however, truly general, is the phenomenon of Anderson localization; this phenomenon is a typical quantum effect for which a particle in a sufficiently disordered distribution of scattering centers remains localized in the neighborhood of its initial position even after a very long time.[28] Remembering that deuterons in a binuclear atom have kinetic energy of ~10 eV while thermal neutrons have kinetic energy of ~25 meV, our basic assumption is that fast-moving deuterons are felt by thermal neutrons as a strongly disordered distribution of scattering centers that are responsible for a kind of Anderson localization of the neutron inside the binuclear atom.

If this hypothesis is correct, heat production and tritium or ^{4}He enrichment are presumably due to the stably trapped thermal neutron in the binuclear atom.

To demonstrate how this evidence is explained by this hypothesis, consider the interaction of the trapped neutron with the deuterons constituting the $(dd\cdots n)2e$ binuclear atom. The neutron continues to collide until one of the following events occurs:

1. The neutron escapes from the binuclear atom,

$$(dd\cdots n)2e \rightarrow (dd)2e + n \ , \tag{4}$$

possibly because of binuclear atom dissociation,

$$(dd\cdots n)2e \rightarrow D + D + n \ . \tag{5}$$

2. The neutron is captured by a deuteron with gamma emission,

$$(dd\cdots n)2e \rightarrow (dt)2e + \gamma(6.27\ \mathrm{MeV}) \ , \qquad (6)$$

where γ(6.27 MeV) denotes one or more gammas for a total energy of 6.27 MeV. In the hypothesis that only one gamma is emitted, the triton acquires a kinetic energy of ~7 keV, and it is expected to fuse very easily with the deuteron in its binuclear atom (or, with a much lower probability, with another deuteron). The kinetic energy of the recoiling nucleus is an element of high energy in otherwise cold fusion phenomena.

Events of the first type result in depletion of the neutron flux (due to neutron capture by binuclear atoms) and then in a delayed neutron emission due to reactions (4) and (5).

Events of the second type produce prompt gammas and eventually evolve either to release tritium when the $(dt)2e$ binuclear atom dissociates,

$$(dt)2e \rightarrow \mathrm{D} + \mathrm{T}$$

(this process produces tritium without neutrons and can be seen as a magnified D-T conversion), or to produce ^{4}He via conventional *d-t* fusion,

$$(dt)2e \rightarrow {}^4\mathrm{He} + n + 17.55\ \mathrm{MeV}$$

(this process produces ^{4}He without 23.84-MeV gammas and can be seen as neutron-catalyzed fusion). The emitted fast neutron (14.04 MeV) has a chance to be thermalized in the target (and thus to be responsible for a distributed background of spallation protons or neutrons) or to be backscattered from the walls and therefore to continue the chain.

The pathway of the possible reactions for reacting deuterium-deuterium atoms is shown in Fig. 1.

Of course, most of the strongest claims of cold fusion (e.g., ponderal tritium enrichment or measurable heat production) cannot be explained by this basic assumption alone. Indeed, if both tritium enrichment and heat production are limited by the thermal neutron background, they should be of the order of $10^{-3}\ \mathrm{cm}^{-2}\cdot\mathrm{s}^{-1}$ (the typical thermal neutron flux in a moderating nonabsorbing medium) and $10^4\ \mathrm{eV/cm}^2\cdot\mathrm{s}$, respectively, lower by several orders of magnitude than the most optimistic claims of cold fusion. However, the proposed model contains elements (e.g., neutron-catalyzed fusion) that suggest that amplification mechanisms of the elementary steps described here can become active in suitable conditions.

Together with the $(dd)2e$ binuclear atom, $(dp)2e$ and $(pp)2e$ atoms are also possible, which are expected to be able to trap thermal neutrons like the $(dd)2e$ binuclear atom. The expected pathways for $(dp\cdots n)2e$ and $(pp\cdots n)2e$ decays are shown in Figs. 2 and 3, respectively. From these pathways, it follows that

1. Although $(pp\cdots n)2e$ atoms may fuse, this reaction occurs without heat production (in agreement with Ref. 13).

2. All cold fusion phenomena are characterized by temporary neutron depletion accompanied by delayed neutron emission.

3. Cold fusion phenomena are enhanced by stimulation with thermal neutrons.

4. Neutron-assisted D-D cold fusion is partially masked by the fusion of directly formed $(dd)2e$ binuclear atoms.

CONCLUSIONS

The hypothesized mechanism for neutron-assisted D-D cold fusion consists of the formation of a $(dd)2e$ binuclear

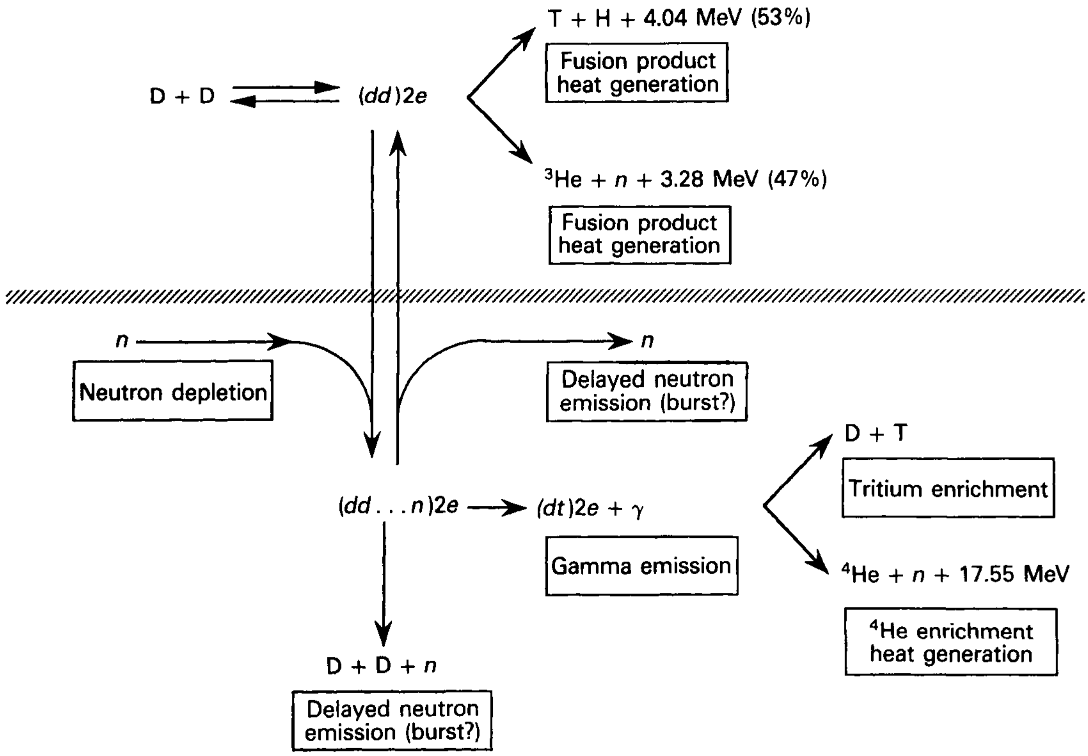

Fig. 1. Pathway of reactions of free and neutron-trapping deuterium-deuterium binuclear atoms.

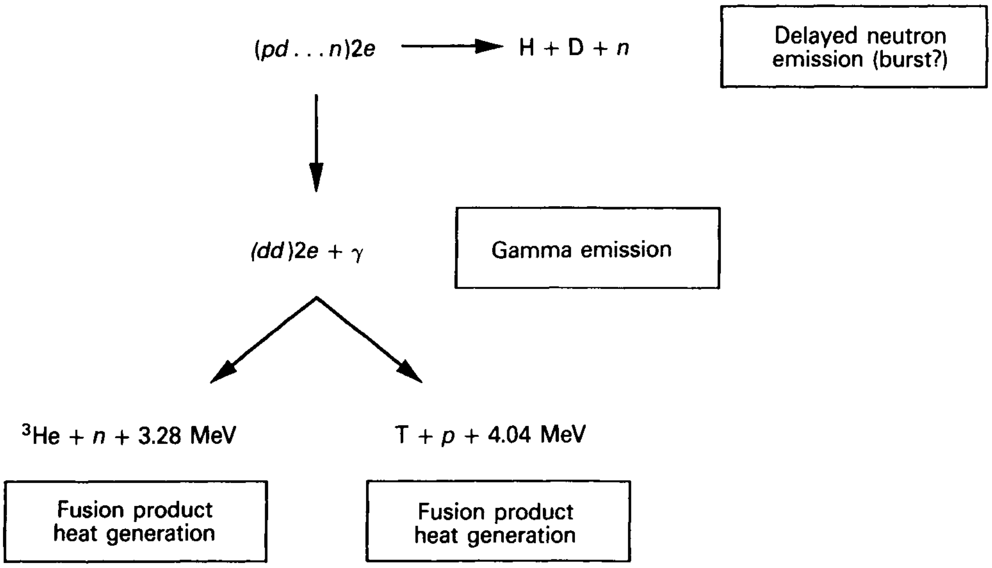

Fig. 2. Pathway of reactions of neutron-trapping deuterium-hydrogen binuclear atoms. The free deuterium-hydrogen binuclear atom is able to fuse directly, $(pd)2e \rightarrow {}^3\mathrm{He} + \gamma(1.06\ \mathrm{MeV})$, without neutron emission or heat production.

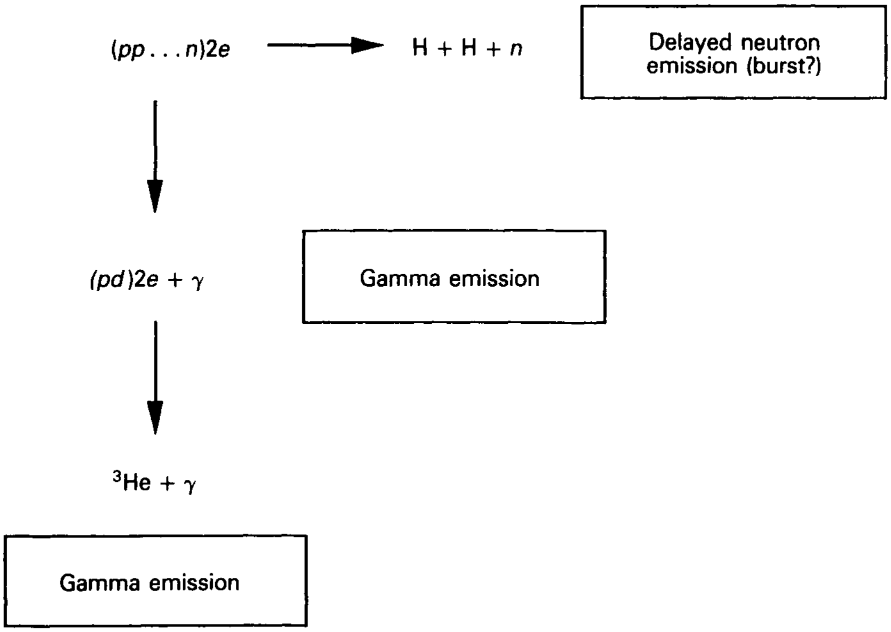

Fig. 3. Pathway of reactions of neutron-trapping hydrogen-hydrogen binuclear atoms.

atom and capture in a stable orbit of a thermal neutron to form the complex $(dd\cdots n)2e$, $(dd)2e + n \rightarrow (dd\cdots n)2e$.

This hypothesis allows the following facts to be explained:

1. increased tritium enrichment without neutron production, the mechanism being

$$(dd\cdots n)2e \rightarrow (dt)2e + \gamma(6.27\ \mathrm{MeV})$$

and

$$(dt)2e \rightarrow \mathrm{D} + \mathrm{T}$$

2. ^{4}He production without 23.84-MeV gamma emission, the mechanism being a kind of neutron-catalyzed fusion:

$$(dd\cdots n)2e \rightarrow (dt)2e + \gamma(6.27\ \mathrm{MeV})$$

and

$$(dt)2e \rightarrow {}^4\mathrm{He} + n + 17.55\ \mathrm{MeV}$$

3. delayed neutron emission (possibly resulting in bursts if the decay of one binuclear atom is able to produce the decay of other neutron-trapping binuclear atoms), the mechanisms being

$$(dd\cdots n)2e \rightarrow (dd)2e + n$$

and

$$(dd\cdots n)2e \rightarrow \mathrm{D} + \mathrm{D} + n\ .$$

This hypothesis is perhaps a key in removing the anomalies of cold fusion. It is worthwhile to note that the major predictions of the proposed model, delayed neutron emission and neutron-stimulated cold fusion, have already been reported. For instance, we quote the paper on neutron-stimulated cold fusion by Celani et al.[29] and a few results, which, although not explicitly observed, can be interpreted as evidence of delayed neutron emission (Figs. 2 and 3 of Ref. 8 and Fig. 3 of Ref. 17) even in papers claiming null results for cold fusion (see Fig. 4 of Ref. 21). The model predicts that tritium and ^{4}He enrichment in a thermal neutron field is higher when the neutron field is more intense and is accompanied by gamma emission; these combined predictions allow the model to be verified.

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