ON THE POSSIBILITY OF A NUCLEAR MASS-ENERGY RESONANCE IN D + D REACTIONS AT LOW ENERGY

J. RAND McNALLY, Jr. Fusion Energy Consultant
103 Norman Lane, Oak Ridge, Tennessee 37830

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The possibility of a nuclear mass-energy resonance is offered to explain recent "cold fusion" results.

Numerous recent newspaper stories have reported of neutron and tritium production being observed in deuterium + deuterium (D + D) reactions and an energy output four times the energy input via an electrolysis cell containing deuterated water operated at low temperatures.¹

University of Utah scientists, Pons and Fleischmann, report this discovery occurs in what appears to be an ~8-in.-long x 3-in.-diam glass electrolytic cell containing a platinum coiled wire anode and a palladium tube cathode with ~6 to 8 V applied to the cell, which contains deuterated water (D₂O) (Ref. 1). Lithium hydroxide at 0.1 M is added to aid electrolysis. Television pictures of the cell in operation reveal copious bubbles, which suggest the current is of the order of an ampere, possibly more. The nuclear fusion events presumably occur at the cathode to which the deuterons are accelerated with up to 8-eV energies. Palladium has a tremendous affinity for deuterium. Cast palladium is better suited than extruded palladium.

Jones of Brigham Young University and others also are reported to have observed "cold fusion" in a deuterated water electrolysis cell but with no substantial energy output.² His report is said to have been accepted by the British journal Nature, while the paper by Pons and Fleischmann is reportedly still under review. Pons is chairman of the chemistry department at the University of Utah, and he and Fleischmann (Southampton University in England) have been working on this electrolysis of heavy water for ~5 yr in search of possible D-D nuclear reactions at high densities and low temperatures.

Some years ago, this author published Ref. 3. Having noted that most nuclear cross-section increases occur near a nuclear mass-energy resonance,³ a few possibly interesting resonances were selected that might take place with a favorable cross section at low temperatures giving a significant reaction rate at high fuel densities.

The principle of a nuclear mass-energy resonance in D + D at low temperature would involve

\[ M_D c^2 + M_D c^2 - M_{^4He} c^2 = \Delta E_{\text{excitation}} \text{ of } ^4\text{He} \]

or

\[ \Delta M_D + \Delta M_D - \Delta M_{^4He} = \Delta E_{\text{excitation}} \text{ of } ^4\text{He} \]

\[ = 23.85 \text{ MeV} \]

where

- \( M \) = mass of the specific isotopic species
- \( c \) = velocity of light
- \( \Delta M \) = mass excess energy⁴ (MeV)
- \( \Delta E \) = excitation level in \(^4\text{He} \), which can couple strongly with the D + D reaction.

The 1973 report of Fiarman and Meyerhof⁶ on excitation levels in \(^4\text{He} \) lists the closest levels at 22.1 and 25.5 MeV, which apparently are not close enough to 23.85 MeV to arouse interest. In a telephone call to Hale at Los Alamos National Laboratory (LANL), however, he informed me that there are closer possible resonances calculated by R-matrix theory at 23.6 and 24.4 MeV. The former level would not couple strongly with D-D, but the latter level at 24.4 MeV would couple quite strongly and has a broad level width of several mega-electron-volts, thus overlapping the 23.85-MeV excitation value. This suggests that the 24.4-MeV level may give a nuclear mass-energy resonance at low deuteron energies.

The D + D reaction then could proceed as follows:

\[ \text{D + D} \rightarrow \text{He}^* \rightarrow n(2.450 \text{ MeV}) + ^1\text{He}(0.817 \text{ MeV}) \]

or \( p(3.024 \text{ MeV}) + \gamma(1.008 \text{ MeV}) \)

or \(^4\text{He}_{\text{ground state}} + \gamma(23.85 \text{ MeV}) \)

or \(^4\text{He}_{\text{ground state}} + \text{matrix energy} (23.85 \text{ MeV}) \).
McNally  MASS-ENERGY RESONANCE

The latter process seems unlikely but should be considered as an improbable but potential process in which the PdD lattice absorbs the excitation energy as heat energy. The gamma production is less probable (and is actually a forbidden transition directly to the ground state) than the particle emission that is given in the first two possibilities, which proceed with about equal probability in higher temperature fusion.

The theoretical reaction probability for the neutron channel for D + D reactions at 10 eV has been calculated by Thompson as \( (\sigma v) = 2.61 \times 10^{-55} \text{cm}^2/\text{s} \), too small to account for any significant neutron production even at solid densities. Also, the deuterons presumably have a maximum energy of 8 eV rather than a Maxwellian kinetic temperature. One can estimate optimistically that the neutron production rate \( R \) is

\[
R = \frac{1}{2} n_D^2(\sigma v) \text{ (or } n_{\text{beam}} n_{\text{D lattice}} \sigma v) 
\approx 1.3 \times 10^{-8} \text{ reaction/s cm}^{-3},
\]

where the deuteron density is assumed to be \( 10^{22} \text{ d/cm}^3 \). The actual deuteron beam density will depend on the current in the cell, which together with the effective penetration depth in the PdD lattice, may correspond to a much lower density product. Thus, normal thermonuclear reactions at a kinetic temperature of 10 eV and even less (reactions at \( E = 8 \text{ eV} \) maximum energy) cannot account for any appreciable neutron production, and one must rely on a nuclear resonance or some other process that increases the reaction probability quite substantially.

Researchers von Engel and Goodyear have measured the experimental D-D cross section in the 4- to 16 eV energy range and find that the cross section at 4 eV is a factor of 2 larger than expected by theory (theory and experiment normalized at 15 keV) (Ref. 9). Krauss et al. have measured the D(D,p)T cross section from 2.98 to 162.5 keV and find a 15% increase in the astrophysical S factor [S = \( a(E)E^{-2+s} \) with \( 2s = 31.39/\sqrt{\text{p/cm}} \) with \( E \) in kilo-electron-volts] below \( -10 \text{ keV} \) (Ref. 10). If these two effects are real, it may be that D-D-beam target reactions have a larger increase in reactivity at much lower energies than expected. Electron shielding in the PdD lattice might also play an important role.

The explanation of the larger energy output than expected from neutron observations may be due to a selective D + D branching, which favors the \( p + t \) branch over the \( n + ^3\text{He} \) branch. One watt of heat output would generate \(-10^{12} \text{n/s} \) with equal branching.

At \( T = 1 \text{ MeV} \), the neutron branch is favored by 21% (Ref. 11); Tuck suggests \( \sigma_{\text{D-D}}/\sigma_{\text{D-D}} \) may be 1.07 below 20-keV temperature \(^{12}\); von Engel and Goodyear \(^{8}\) report \( \sigma_{\text{D-D}} = (2 \pm 1)\sigma_{\text{theory}} \text{ at } E = 4 \text{ keV} \); Howerton \(^{13}\) gives \( \langle \sigma v \rangle \text{D-D} / \langle \sigma v \rangle \text{p-p} = 1.72 \) at \( T = 100 \text{ eV} \). Howerton also reports the D + D total reaction probability \( \langle \sigma v \rangle \text{D-D} \approx 0.01 \) of that of deuterium-tritium at \( T = 10 \text{ keV but } -0.15 \) at 100 eV, indicating a possibly significant relative increase of \( \langle \sigma v \rangle \text{D-D} \) at low temperatures. There is some uncertainty in these figures.

These figures suggest that \( \sigma_{\text{D-D}} \) may be much greater than \( \sigma_{\text{p-p}} \) at energies in the 0.1- to 8-eV range of the electrolysis experiments. The coulomb repulsion of the proton in the D + (pn) reaction may greatly favor the \( p + t \) branch at very low energies. More experimental and theoretical work seems justified at these very low energies.

How can D-D react at \( E \leq 8 \text{ eV} \) when apparently it does not react appreciably at 100 eV even with a mass-energy resonance that overlaps this region even better? It is probably due to the de Broglie interaction wavelength, \( \lambda = \hbar/Mv \), giving supporting overlap of the two deuteron's waves, which together with the nuclear mass-energy resonance allows the two deuterons to interact with each other, since the system may not know whether it is D + D or \(^4\text{He} \) because of the very strong coupling between these states.

One has for \( \lambda \), the de Broglie interaction wavelength,

\[
\lambda = \hbar/Mv \\
\approx 2.2 \times 10^{-9} \text{ cm at } E_D = 8 \text{ eV} \\
\approx 1.8 \times 10^{-8} \text{ cm at } E_D = 0.2 \text{ eV}.
\]

Palladium has a tremendous affinity for deuterium and \( n_0 \) may be \(-3 \times 10^{22} \text{ d/cm}^3 \). Using the deuteron volume, \( V = 4\pi r_D^2/3 = 1/n_0 \) in deuterons per cubic centimetre, one obtains for the distance of closest neighbors \( r_{\text{D-D}} \approx 1.8 \times 10^{-8} \text{ cm} \). Thus, two deuterons at 0.4 eV, or one deuteron at \(-0.2 \text{ eV} \) and a cold deuteron, might enhance the resonance by overlap of their de Broglie waves.

It would be of interest to study any very dense deuterium system in which the deuteron energy is only \(-0.1 \text{ to } 0.2 \text{ eV} \) (\( T \approx 1160 \) to 2300 K).

Thus, nuclear mass-energy resonance together with other physics might account for the reactions observed by Pons and Fleischmann, \(^1\) Jones, \(^2\) and others. Experimental and theoretical confirmation of this hypothesis is needed. Should the results be favorable, the scientific study of other nuclear resonances at "low temperature" and high density might be quite promising, possibly ensuring "cold fusion" a valid place in science.

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