Tunneling beneath the $^4He^*$ fragmentation energy

A. Meulenberg[a] and K. P. Sinha[b]

[a] *HiPi Consulting, Frederick, MD, USA*
[b] *Department of Physics, IISc, Bangalore 560012, India*

E-mail: mules333@gmail.com

Abstract. The repulsive Coulomb barrier between deuterium nuclei is reduced in length and height by a catalytic mechanism involving optical phonons and electric fields in a lattice. If the mechanism induces the formation of $D^- D^+$ pairs, the tightly-bound and energetic electron pair (in the D^- ion) becomes a binding force between the nuclei. The lattice constraints and **slow** collision processes**,** force the ions into a near 1-D configuration that deepens the electron ground-state potential well. This permits the electron pair to remain closely bound to one deuteron and to do work in bringing the $D^- D^+$ pair together. These tightly-bound electrons may remain as a pair, attached to a single deuteron, during the fusion process. In reducing the Coulomb repulsion of the nuclear protons, these electrons bring down the total energy of the fusing $D^- D^+$ pair and raise the fragmentation energy level. This process accounts for the observations in CMNS of excess heat (in both p-p and d-d reactions) and for the differing observations (or their absence) of tritium, ^3He, neutrons, and ^4He in the d-d reaction. Thus, all major observed CMNS processes are explained.

1. Introduction

At ICCF-14, we presented the means whereby the repulsive Coulomb barrier between hydrogen (deuterium) nuclei is reduced in length, perhaps by orders of magnitude [1]. This mechanism, involving optical phonons and electric fields (internally or externally generated) in a lattice that induce the formation of $D^- D^+$ pairs, increases the tunneling probability by more than 100 orders of magnitude [2]. It has additional major consequences described below.

In brief: the lattice constraints and collision processes force the interstitial deuterium ions into a temporary, but cyclic, nearly one-dimensional (1-D) configuration that greatly deepens the D-D and electron ground-state potential well. The proposed tightly-bound and energetic-electron pair (a local-charged Boson - the lochon) results in sub-lattice $D^- D^+$ pairs and becomes more than strong screening; it becomes a binding force between the nuclei [3]. Thus, the Coulomb-barrier height is reduced as well as its length. With this greatly enhanced barrier-penetration probability, the energy level of nuclei with reasonable tunneling probability drops from the multi-100 keV range down into the eV range.

In this earlier version of our model (only concerned with the barrier-penetration problem), normal tunneling is into resonant states above the fragmentation levels [4]. Thus, even if the Coulomb barrier is overcome by the tightly-bound electron pair and fusion is possible, the major observations of LENR (e.g. more heat than neutrons) are not accounted for. This requirement of tunneling into states above fragmentation is dictated by the mass deficit [5] between the two colliding D atoms and the resultant ^4He atom (2D - ^4He = Q = 23.8 MeV). Therefore, even with zero incident energy, a deuteron pair will have too much energy to tunnel beneath the fragmentation levels at 20.6 and 19.8 MeV above the ^4He ground state. Nevertheless, the model was successful in providing a mechanism to overcome a major argument against LENR. The present work shows how its extension also explains most of the experimental results observed in the field.

2. Extended Lochon Model

In a more detailed study of the model, new and unexpected effects are found. Just as slow-motion photography can reveal unsuspected processes, low-energy collisions (i. e., eV compared to MeV) have provided some surprises. It is the non-equilibrium conditions of a "slow" D^- D+ collision in a linear sub-lattice that provides an answer to the "nuclear ash" problem of CMNS. The deuteron motion is slow; but, the bound-electron motion is not. This distinction allows us to separate the actions and use the Born-Oppenheimer approximation [6] (common in quantum chemistry) to solve for the electron quasi-steady-state parameters, step-by-step, as the D^- D^+ pair approach each other over the PdD lattice barrier separating them.

As the nuclear potential well deepens while a D_2 molecule is being confined to 2 dimensions, so does the electron potential well. A deepening of the electron potential wells does not necessarily mean that the electrons go deeper into the well; they must lose total energy to do that (although they gain kinetic energy as they move into the well, they lose it again on the way back out). However, being in a ground state (l = 0), they cannot directly radiate photons or induce phonon excitation. Nevertheless, in a critical concept provided online by Tom Barnard, a mechanism is provided whereby they may dissipate energy as the separation of the electron and D^- D^+ pairs is reduced. Since work is done by the electrons during this motion (they transfer energy to the deuterons), they fall deeper into the deuteron's Coulomb potential well. Being deeper in the well means that neither of the paired electrons is likely to transfer to the potential well of the other deuteron during this process. **This is a critical assumption of the model.**[i] Since this electron pairing is a possible state, quantum mechanics can calculate the probability of a 2-electron deuterium sub-lattice state relative to that of zero or single-electron occupancy. However, the probability depends on the energy of the electron pair and the local Fermi levels, and those depend on the recent history of the D^- D^+ pair.

Collisions in nuclear physics experiments are so fast that, except for the electrons directly involved, equilibrium electron-energy levels do not have time to change before the event is over. On the other hand, during the critical portion of the D^- D^+ interaction in a lattice, the "slow" motion of the converging deuterons allows the electrons to orbit hundreds of time during each increment of deuteron closing and therefore allows the electrons to experience and respond to the changing fields - and to do work. As the electrons move deeper into the D^- Coulomb potential well, the cancellation of electric fields (electron and proton) reduces the total field energy (potential energy) and therefore (initially very slightly) the mass of the particles. Since energy is conserved, part of this loss in field energy goes into the increased kinetic energy of the electrons (T_e), part into the increased kinetic energy of the deuterons (T_d), and part into increasing the e-e and d-d electric field strengths as the like-charge particles move closer together. (Just as the electrons do work in bringing the deuterons together, the deuterons and electrons have work done on them to move them closer together.) The net result of this 4-body interaction is that the paired, tightly-bound, energetic, electrons (e*) remain at nearly constant total energy (more KE and deeper in Coulomb well), the D^+ gains some total energy, and the D^- loses total energy.

As the colliding deuterons move still closer together (and climb the barrier between the deuteron sites), the screening from the lattice electrons and the residual barrier between the deuterons becomes smaller. The D^- D^+ Coulomb potential grows and the collapse of the D^- D^+ pair is accelerated. However, the energy expended in overcoming the lattice barrier keeps the D^- D^+ pair moving slowly until the pair gets very close (~1 picometer). As the pair gets even closer together, the D^- D^+ potential dominates the lattice barrier and the closing velocity increases.

The electron's kinetic-energy increase and its movement deeper into the Coulomb well about the deuteron causes the electron orbit to "shrink." Its deBroglie wavelength decreases with increased velocity and, as it spirals in, its field energy is further "cancelled" and concentrated by that of the proton (within the deuteron). With an increase in energy from the T_e = 10 eV range of the electron in the "free" deuterium atoms to a 1 keV of a bound electron as it approaches the deuteron, the deBroglie wavelength is reduced by an order of magnitude. As the energy of this "shrinking-orbit" electron, e*, increases to the 100 keV range, its wavelength drops by 10x again and approaches that of an electron's Compton wavelength. However, by this time, the electron field (and therefore the electron center of "mass") has shifted to within 10s of Fermi of the nucleus. The e* may no longer be a separate entity. The e*-proton pair has become a relativistic rotating dipole field (quadrapole field, if two bound electrons are present). The cancelled charge-field energy has been transformed to electromagnetic and relativistic-mass energy.

---

[i] The existence of D^- D^+ pairs in a lattice is accepted physics ([2] and references therein). Their existence in a PdD lattice must still be verified.

3. Nuclear Interactions

The reduced Coulomb repulsion between the protons (resulting from the shrunken e* or lochon orbits) increases the total nuclear attraction between them relative to that of normal ^{4}He. Thus, the nucleons spend more time closer together and therefore more time in the nuclear-potential well. This increases the effective "depth" of the well and decreases the energy of the excited states of the ^{2}He* or ^{4}He* structures formed. There are other reasons why the nucleus might shrink even further. Both the closer binding of the nucleons and the deeper potential well reduces the probability of fragmentation.

Examining the traditional D-D to ^{4}He* transition (Fig. 1), we see the broad transition region > 23.8 MeV above the ^{4}He ground state. This is the energy difference that corresponds to the mass difference between the deuterium pair and ^{4}He. Even with tunneling from zero kinetic energy states (i.e., $E_k = 0$), the excess mass of the deuterium atoms would put the deuterons into this high level. This excited ^{4}He* state is above the fragmentation levels at ~ 20.6 and ~ 19.8 MeV. While fragments from both levels have been observed in LENR experiments, the radiation levels are not nearly high enough to explain the excess heat observed. Furthermore, the levels of ^{4}He measured have been orders of magnitude higher than would be expected and, in some cases, have been high enough to account for the observed heat. How does this happen? Conventional physics sees the overcoming of the Coulomb barrier at low temperatures/energies, the distortion of the normal fragmentation ratio (p:n = 50:50 from E > 22 MeV), the high levels of ^{4}He, and, more recently, transmutation of elements as reasons for considering the Cold Fusion results as impossible.

Since the observed data is not possible within the known framework of nuclear physics, something else must be going on. We have shown how the Coulomb barrier problem is solved and laid a foundation for the D-D nuclear interaction with the help of tightly-bound, high-kinetic-energy electrons. Now we put the parts together.

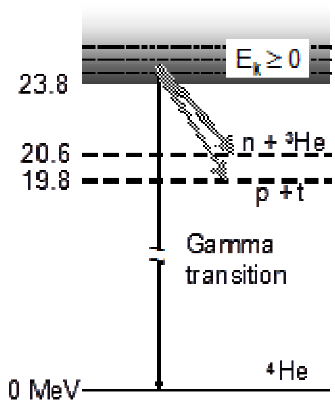

Fig. 1 - Energy levels and decay branches associated with conventional D-D to ^{4}He* fusion reactions.

4. Reduced Energy ^{4}He*

With the ability of deuterons to tunnel from an appropriate PdD lattice site through the nuclear Coulomb barrier of an adjacent **reduced-energy** ($E_t = T + V$) nucleus of a D^- ion, the possibility of a low-energy excited compound nuclei becomes real. If, with the lochon, the excited (but neutralized) helium-4 nucleus does not have sufficient energy to fragment, and gamma decay is highly forbidden, how does it shed the excess energy to get to its ground state? It is proposed that this condition and the subsequent decay process is the basis for the experimental observations of CMNS.

To see how this "new" process can occur, we must take a closer look at Fig. 1. There are no energy levels below the ^{3}H + p (or t+p) fragmentation level. In a d-d interaction, if fusion were to take place, it would be resonance tunneling into one of the many levels above the region at 23.8 MeV. Decay from these excited states would almost always give nearly equal probabilities of fragmenting into the p or n channels. If a state existed below ~20 (or 19) MeV, then n (and p)-channel fragmentation would become unlikely. Unsuccessful attempts have been made specifically to find such an excited state. We propose a non-fragmentation mechanism that does not rely on a new state below 19.8 MeV. It shifts some of the existing states down below that level and it demonstrates how the fragmentation levels are shifted up in energy.

The key to the mechanism is the lochon, which during the collision process attains significant energy (keV to MeV range); but, remaining in an $l = 0$ ground state, it does not radiate. If it survives the final tunneling process of the d^+ through the thin, residual, D^- Coulomb barrier, it may have attained multiple MeV energies from the work done at the expense of the D^- Coulomb potential energy. Thus, it is very-tightly and closely bound and both the lochon and the D^- nucleus have lost electric-field mass. Since the lochon mass and orbital radius is now so small, even in a circular orbit, the orbital angular momentum is less that $\hbar/2$. Therefore, there is little possibility of photonic radiation.

5. The new $^4He^*$

Once the D^+ is inside the D^- nuclear-Coulomb barrier, the situation is different from that of the normal d-d scattering problem. The nuclear potential is greatly different, because the Coulomb barrier between the protons is much reduced. Thus, they can be much closer together. Since most of the normal nucleon wavefunction is outside the d-d nuclear well, the depth of the nuclear potential well with which the nucleons are bound is increased by both the loss of Coulomb repulsion and the gain in nucleon time spent in the well (increased wavefunction overlap). As a consequence, the effective depth of the nuclear well is increased; the excited nuclear-state energies become lower; and the energy required to break apart (fragment) the excited nucleus is higher.

If the new $^4He^*$ energy, is too low to fragment and it has an e* or two spending much of their time inside the nuclear region, it cannot form a stable nuclear state (even if one existed in the normal $^4He^*$ nucleus). The continual and extreme proximity of the highly-excited deuterons to these electrons (in the femtometer range) allows resonance transfer of energy between them, via near-field EM coupling, at a frequency associated with, or below that of, soft x-rays. Thus, the nuclear energy is able to be transferred to the shrunken-orbital electron(s) and from there it is radiatively transferred to the lattice, since the e* is also close-coupled (in the nanometer range) to the bound Pd electrons. If the average radiated x-ray energy is in the keV range, it takes little time for most of the nuclear energy to be dissipated. However, as decay progresses, the rate of energy transfer and dissipation decreases, giving more time for the electron(s) to be ejected from the nuclear region ($e^* \Rightarrow e^-$) with the remaining energy. Since e* is deep in the nuclear Coulomb potential this ejection is not as an energetic electron, but as a gradually slowing (and expanding-orbit) electron being driven out of the well by energy from the proton-generated EM field.

This extended fusion / radiation process lasts:

a) until the neutral entity ($^2He^*$ or $^4He^*$) drifts into a neighboring nucleus, resulting in a transmutation process;

b) until one (or more) of the energetic shrunken electrons combines with a proton ($p + e^* \Rightarrow n+\nu$, via the p-e*-p, p-2e*-p, d-e*-d, or d-2e*-d reaction); or,

c) until diproton fragmentation or the ^4He ground state is reached, on ejection of the electron(s).

6. Conclusion

Depending on the actual energy of the excited (compound) nuclei and the number of e* still present (0, 1, or 2) after the nuclear Coulomb barrier has been penetrated, the decay process could include fragmentation, or not. This accounts for the observations in CMNS of excess heat, in both p-p and d-d reactions, and the observations (or absence) of tritium, ^3He, neutrons, and ^4He in the d-d reaction. The ability of the lochon to alter the nuclear potential well and fragmentation energies permits radiation-free decay to the ^2H or the ^4He ground state and transmutation. This variation (apparent unpredictability) of results, heretofore the stumbling block to acceptability of LENR, is now perhaps the greatest validation of its existence. Thus, all major observed CMNS processes are explained, but not necessarily the best means of, or materials for, producing them. That comes next.

Acknowledgments

This work is supported in part by HiPi Consulting, New Market, MD, USA; by the Science for Humanity Trust, Bangalore, 560094, India; by the Science for Humanity Trust, Inc, Tucker, GA, USA; and by the Indian National Science Academy.

7. References

[1] K. P. Sinha and A. Meulenberg, *ICCF-14 International Conference on Condensed Matter Nuclear Science*, 2008, Washington, DC. http://www.lenr-canr.org/acrobat/SinhaKPamodelfore.pdf
[2] K.P. Sinha and A. Meulenberg, *Current Science,* 91, 907 (2006), (arXiv:cond-mat/0603213)
[3] K. P. Sinha and A. Meulenberg, *Nat. Acad. of Sc. (India) Letters*, Vol.30, No. 7&8, 2007, (arXiv:0705.0595v1)
[4] A. Takahashi and N. Yabuuchi, *ICCF-14 International Conference on Condensed Matter Nuclear Science*, 2008, Washington, DC. http://www.lenr-canr.org/acrobat/TakahashiAdeuteronst.pdf
[5] http://en.wikipedia.org/wiki/Mass_deficit
[6] M. Born and K. Huang, *"Dynamical Theory of Crystal Lattices,"* Oxford University Press (1956)