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Research Article

Lochon-mediated Low-energy Nuclear Reactions

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Abstract

In heavily hydrogenated (deuterated) palladium crystals, the crystallinity is degraded. This non-uniformity results in phonon modes that are localized and of higher frequency than for unloaded lattices. These modes create dynamic electrostatic fields that couple strongly with both bound and free electrons and the hydrogen (H and D) sub-lattice. A consequent potential inversion leads to the formation of "lochons" (local-charged bosons–electron pairs in the singlet state) and results in H^- or D^- ions in the sub-lattice. The nuclear-Coulomb repulsion between colliding D^+ D^- ion pairs in the sub-lattice is considerably reduced by the resultant "strong screening" and "lochon-drag" effects. Furthermore, work is done, by the bound lochon in a D^- ion attracting an adjacent D^+ ion. This results in reductions: of the deuteron's electron-orbital radii, as the ion pair approaches; of the mass deficit between the deuteron pair and a ^{4}He atom (or a proton pair and a ^{2}He/^{2}H atom); and finally of the Coulomb repulsion between nuclear protons in a helium nucleus. Thus, the end product of such a deuteron-pair fusion is an excited-helium nucleus (^{4}He*) with lower energy relative to that resulting from energetic deuteron collisions. This reduced energy of the excited nucleus may be lower than its new fragmentation levels. The effect of lochon mediation, to alter the nuclear potential-well and fragmentation energies, allows decay to the ^{4}He ground states to be free of particulate radiation. This decay process, of "neutral" ^{2}He (from p+p) or ^{4}He excited nuclei, is also a basis for observed transmutation.

Keywords: Deep orbital, Fragmentation, LENR, Lochon, Strong screening

1. Introduction

It is now established by sustained experimental work that low-energy nuclear reaction (LENR) occurs in PdD_x or PdH_x after considerable loading when x attains a minimum value ($x > 0.8$) [1]. However, this heavy-loading process results in the degradation of crystallinity [2]. For this situation one has to consider the newly created interface-phonon modes. The solutions correspond to localized (longitudinal optical, Fig. 1) phonon modes near the interface. With particular

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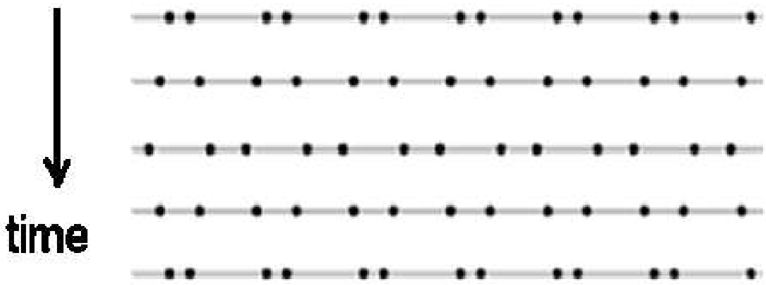

Figure 1. Longitudinal optical modes where adjacent lattice atoms/ions move in opposite directions along a common axis.

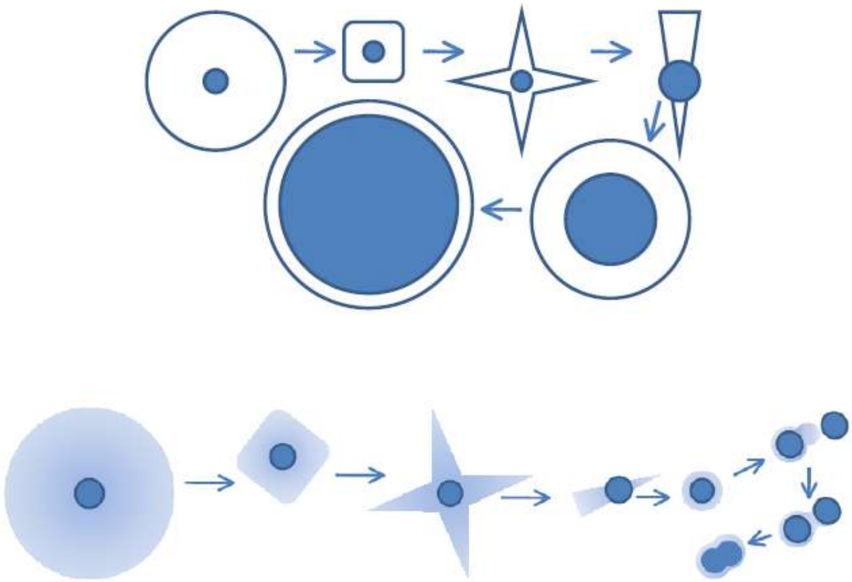

Figure 2. Schematic representation of the electron distribution (size) relative to that of a nucleus (at 1000× magnification relative to electron orbit) as a hydrogen atom moves within its PdD_x sub-lattice site (see text).

interface orientations, the major phonon modes are reduced from three dimensions to one. Further, the frequency (ω) of the localized mode is above that of the highest phonon mode of the bulk PdD lattice.

The expectation value of the number of such local phonons $\langle n_{q\omega}\rangle$ and the expectation value of their amplitude $\langle A_{q\omega}\rangle$ are related by $\langle n_{q\omega}\rangle = 2M\omega\langle A_{q\omega}\rangle^2/\hbar$, where M is the mass of the D atom (ion) and $\hbar$ is the Planck constant divided by 2π. With $M = 3.34 \times 10^{-24}$ g, $\omega \sim 5 \times 10^{14}$ per second, and $A = 3 \times 10^{-8}$ cm, the number of phonons is of the order of a few thousands. The total energy of the local phonons could thus be in the multi-eV range.

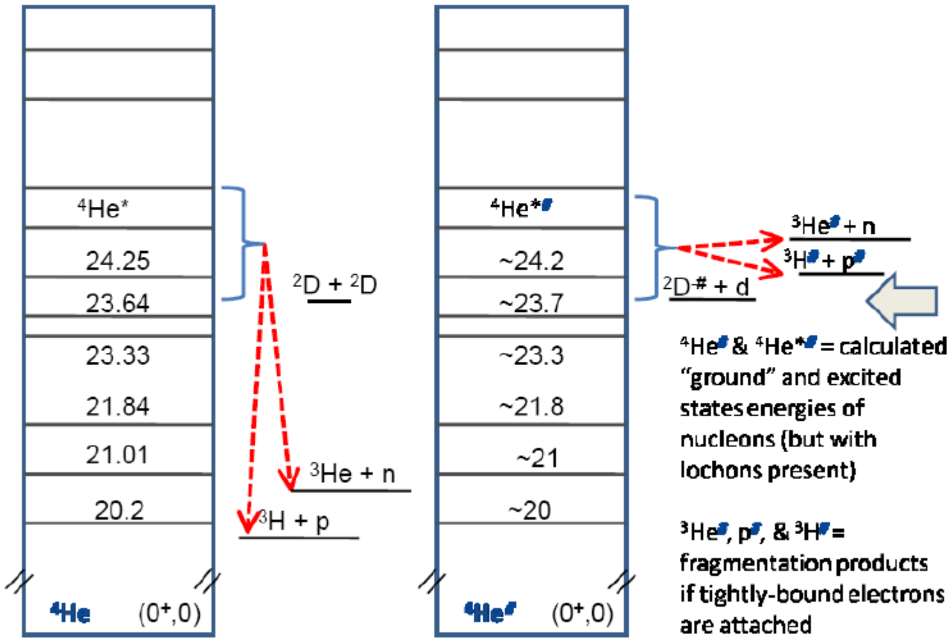

Figure 3. Energy levels for ^{4}He with normal atomic electrons (left side) and with tightly-bound electrons (right side).

These modes, in an ionized lattice or sublattice, create electrodynamic fields that are strongly coupled with electrons confined in the layer. This coupling and the disorder due to degradation of crystallinity lead to a localization of the electrons on some D^+ ions. The concomitant potential inversion makes it possible to produce electron pairs (in the singlet state; local charged bosons, acronym "lochons") at some deuterons to give D^- ions [3,4]. The lochons formed by this mechanism and by phonon-induced charge polarization provide strong screening for the static and dynamically induced ion pairs D^-D^+. As the deuterons approach each other closely and penetrate the distributed-electron Coulomb field, the residual proton–proton repulsive barrier is considerably reduced in height as well as in length by this strong screening.

The presence of lochons results in enhanced barrier-penetration probability [4] and it has been shown in our earlier papers that fusion is possible [3,4]. However, dictated by mass deficit ($Q = 23.8$ MeV), the resultant excited nuclear state, ^{4}He*, will emerge above the fragmentation levels at 20.6 and 19.8 MeV above the ^{4}He ground state. Thus, ^{4}He* will likely fragment into energetic particles rather than decay to the ^{4}He ground state. The work done by the bound lochon, in a D^- ion attracting an adjacent D^+ ion during a phonon cycle, results in reductions of the deuteron's electron-orbital radii, as the ion pair converges. If the lochon remains attached during a collision/fusion process, this reduced orbit lowers the mass deficit and raises the energy required for fragmentation. Thus, the lochon-modified ^{4}He* can emerge below one, or both, of the fragmentation levels. The present work addresses this problem. The resulting extended "lochon" model may thus explain all the major observations of LENR.

2. Lochon Model and Strong Screening

Consider a chainlet of deuterons surrounded by an equal number of electrons in the interface regions of PdD_x. The Hamiltonian for this system [$H = H_e + H_L + H_{eL} + A$ will comprise the electronic part H_e, the sub-lattice H_L of D^+ ions that execute Einstein oscillations, and an electron–phonon interaction H_{eL}. "A" is a constant negative energy due to space charge in the channel. After a suitable unitary transformation (diagonalizing the matrix and thus establishing the system resonances), one gets a displaced harmonic oscillator and a reduced on-site electron energy, a hopping integral, and an enhanced effective mass (by being dressed with a large number of phonons – details are given in [3,4]).

The enhanced effective mass of the electron (m^*), resulting from the interaction of an electron with the phonon field, may be critical to the present argument.

$$m^* = m_e \exp(E_d/\hbar\omega_D) = m_e \exp(g^2), \tag{1}$$

where the contribution from a single electron is $E_d = g^2\hbar\omega_D$, $\hbar\omega_D$ is the energy of the Einstein oscillator of deuteron; and g is the dimensionless electron–phonon coupling constant. The on-site electron energy is $E_m^* = E_m - E_d$ (the bare electron energy as modified by the phonon field). For the case of two electrons in a site, the Coulomb repulsion between a pair of electrons, U_e, is similarly modified (but now with $2E_d$).

$$U_e^* = U_e - 2E_d. \tag{2}$$

We see that for $U_e < 2E_d$, U_e^* becomes negative and there is potential inversion (e.g., a pair of electrons in the singlet state and localized at a D^- ion). Note that in such a lattice, a D^- state will be more stable and will have lower energy than a neutral D atom. Thus one can visualize the existence of D^+ D^- pairs in the PdD_x system. Under the influence of phonon fields, such pairs may undergo dynamical oscillations in which lochons will hop from one to the other deuteron, D^- - $D^+ \leftrightarrow D^+$ - D^- dragging each other to closer proximity. This will result in considerable reduction in the Coulomb repulsion between the two nuclei. The screened effective potential is now described by

$$U_{dd}^* = (e^*)^2/r = (e^2)(1 - \exp{-a_s/\lambda_L})/r, \tag{3}$$

where e^* is the effective charge, a_s is the strong-electron screening length, $\lambda_L = \hbar/m_L * \nu_L$is the effective lochon dimension (orbit radius from the deBroglie wavelength), m_L^* its effective mass, and ν_L its speed. The screening produced by lochons (bound-electron pairs) extends to short range and is much more effective in reducing the repulsive Coulomb potential between reacting nuclei (deuterons) relative to the screening effect of itinerant electrons of the system that can be ignored [5]. An important point to note is that the barrier to the penetration by quantum mechanical tunneling is associated with composite units in which not only the bare deuterons but the lochons are involved.

In the low-energy situation (e.g., LENR), the low orbital angular momentum state ($l = 0$) of the nuclei contributes most. The tunneling factor for $l = 0$, turns out to be

$$P(0, E_a) = (e^{*2}/R)\exp(-e^{*2}/\hbar v_r)/E_a, \tag{4}$$

v_r being the relative velocity and E_a the total energy; R is the effective radius of the nuclear well.

The d–d fusion reaction rate per unit area on a surface or in a defect-plane is given by [4]

$$R_{dd} = r_{dd}^* k_B T \lambda_L (N_s^2/\hbar)(e^{*2}/\hbar v_r)\exp(-e^{*2}/\hbar v_r), \tag{5}$$

where $r_{dd}^* = \hbar^2/2M_N e^2$ is the nuclear Bohr radius of a deuteron; $M_N \approx 1.66 \times 10^{-24}$ g, the mass per nucleon, k_B the Boltzmann constant, T the absolute temperature, and N_s is the number of deuterons per unit area. The calculation of the reaction rate as a function of internuclear distance is given in [4].

3. Lochons: Deepening on the Atomic Potential Well

The crucial point is that the lochon formation (D^-) and the presence of D^-D^+ pairs with attractive interaction provide a mechanism for energy transfer at the atomic level [9]. The lochon drag, involved in the movement of D^+ and D^- toward each other, results in work done and transfer of corresponding potential energy from lochons to D^+ deuterons. Since the ground-state electrons (lochon) have inadequate angular momentum to form photons, this energy loss required for them to move to deeper levels in a conventional manner must result from doing work rather than by radiation.

Figure 2 gives a symbolic representation of the electron size and distribution relative to that of the nucleus. The nucleus has been scaled at 1000× that of the electron to better represent the change in size of the electron orbit. The left-most pictogram represents the electron distribution for an atom in free space. The electron distribution, as seen by a slow-moving nucleus, is that of the whole spherical s-orbit. Therefore, the electron "size" is represented by the Bohr radius determined from the deBroglie wavelength divided by 2π ($= \lambda_{\mathrm{dB}}$). A fast-moving electron (free or bound) sees the fluctuating electric dipole of the electron–proton pair. The electron "size" is therefore strongly dependent on the observer. What does a tunneling proton see? How is this vision shaped by the environment which affects the electron distribution?

Starting as it is seen in free space, the electron 'size/shape' progresses to that: as confined in a Pd-interstitial site, as modified by the sub-lattice phonon field, as constricted during passage between lattice sites, as having done work greatly-in-excess of lattice-barrier height, as moving toward a nought orbit and to a nought-orbit molecule.

The square distribution symbolically represents the effects of the bound Pd-lattice electrons on confining the hydrogen-bound electron cloud. The star-shaped distribution represents the effects (on the bound-electron distribution) of 3-dimensional, phonon-induced, motion of the hydrogen atom within its sub-lattice site and of the phonon electric fields. Given the proper lattice parameters, standard quantum mechanics can represent these electron distributions.

The wedge-shaped pictogram represents the shrinking and oriented electron distribution as the atom moves into the denser Pd-electron clouds of the Pd-lattice barrier region. Next, with work being done in overcoming the barrier and bringing the D^- D^+ pair closer together, the D^- electron orbit shrinks further and becomes deep enough that it is no longer influenced by the lattice. Since these and the succeeding conditions are not average, a Born–Oppenheimer approximation must be used to determine the electron distributions, in steps, as the D^- mounts the lattice barrier and moves closer to the approaching D^+.

The last three pictograms represent the successive distortion of the D^- electron distribution toward the D^+ ion on which it is working. This distortion (increasing the electron probability between the protons) and eventual overlap has an important effect on the D-D tunneling probability (enhancement is not calculated here). Remembering that the figure has amplified the nucleus size by 1000×, the electron EM-field distribution in the final stages is representative of the nought-orbit size (see Appendix). D–D tunneling probability is already high at this point; but the possibility of sharing the lochon between the nucleons and forming a molecule (based on the nought orbit) is real. This possibility is particularly important for collisions that are not truly $l = 0$. Forming the nought-orbit molecule in collisions that otherwise might not result in fusion greatly enhances the total LENR-fusion cross section. The nature of the fusion process from direct tunneling and that from the nought molecule is still to be described.

Note that at a finite temperature, the tunneling rate between lattice sites is enhanced by thermal fluctuation arising from the presence of damping in imperfect solids due to defects. The enhancement is proportional to T^2 for ohmic damping [6]. In contrast, for undamped systems, the enhancement is exponentially weak [6]. Another important enhancement of the tunneling and subsequent reaction is caused by the laser stimulation of LENR in which the system PdDx has a layer of gold film on top of it. This leads to the formation of surface plasmon polariton modes particularly in the surface region [7]. The optical potential is enhanced by several orders of magnitude. The situation is similar to surface-enhanced Raman scattering [8].

4. Lochons: Nuclear Potential Well and Fragmentation Energy

As colliding deuterons move closer together, the D^-D^+ Coulomb potential grows and the merger of a D^-D^+ pair is accelerated. As the pair comes closer yet, the D^-D^+ potential dominates the lattice barrier and the merging velocity increases. The fall of an electron pair into the Coulomb well of a deuteron causes its orbit to shrink. The field energy of the electron pair (and its centre of "mass") eventually concentrates within tens to hundreds of Fermi of the nucleus. The cancelled charge far-field energy will be replaced by near-field electrostatic and electromagnetic energy. The source of this work, the lochon, moves deeper into the D^- Coulomb potential well. The cancellation of electric fields of electrons by protons reduces the total field energy (potential energy). This will result in a change of the mass of nuclear particles [10].

Once the D^-D^+ pair gets close enough to fuse (tunneling the last distance), then we can calculate the energy levels of the resultant excited compound atom. Let us consider the standard D–D reaction (no lochon) to give $^4He^*$ (where * indicates an excited state). The left-hand side of Fig. 3 shows the normal transition to excited states with total energy (above the ^4He ground state) equal to the kinetic energy (bracket) of the colliding pair plus $Q = 23.8$ MeV (broad arrow). This Q value corresponds to the energy equivalent of the mass difference between a D–D pair and the ^4He atom (same as between $^4He^{++}$ and 2d). These excited states are above the fragmentation levels $\sim$20.6 and 19.8 MeV and will decay preferentially via these paths (dashed arrows).

Experimentally, energetic fragments from both these levels have been reported in LENR experiments. However, the excess heat observed is much greater than would be indicated by the radiation levels seen if fragmentation occurs. Furthermore, the measured amount of ^4He has been found to be orders of magnitude higher than expected from standard nuclear physics theory. More recently, nuclear transmutation of heavier nuclei has also been seen [11]. Clearly, something else must be going on.

These anomalies can be accounted for within the extended lochon model [10]. This is realized by a non-fragmentation mechanism that does not depend on new states below 20 MeV. The mechanism of tightly-bound electron pairs (lochons) shifts the $^4He^{++}$ nuclear level down by reducing the nuclear-proton repulsion. By the same mechanism, the fragmentation levels are also shifted up in energy. (With less Coulomb repulsion, the nucleon kinetic energy must be greater to overcome the now more-attractive nuclear potential.) In addition, both the lochon and protons have had mass converted into EM-field and kinetic energy. The right side of the figure indicates the change when the extended lochon model is introduced. The D^-D^+ mass at fusion is the same as the D–D mass. The difference is that the mass energy of the electrons (as a lochon) is greater than that of atomic electrons and the deuteron nuclei are correspondingly lighter. The Q value gives a common starting point for the two pictures. The nuclear energy levels are perturbed by the presence of the lochon. However, much of the reduction in nuclear potential is compensated by the extra energy in the lochon. Thus, most of the energy levels in both pictures are close. The major difference is in higher fragmentation levels.

With reduced repulsion between the protons, the nuclear wave functions are more concentrated within the nuclear potential well. This increases the effective depth of the well. Since the nucleons are closer together and the protons have less repulsion for each other, more kinetic energy is required to cause fragmentation and those levels go up.

The levels shown on the right side of the figure include the energetic electrons in the fragmentation product energies. For LENR, with only thermal energies on the input, the energy possible for excited states from D^-D^+ fusion is below the fragmentation levels. If these energetic electrons were "lost," or replaced by normal electrons, the fragmentation energies would be reduced by 1–2 MeV. Thus, if the lochon breaks up before or during the tunneling process, fragmentation becomes a real decay channel again. It is apparent that LENR products (in the Extended Lochon Model) can range from full fragmentation to no fragmentation at all. Fusion at sub-fragmentation energy allows heat-only decay to the ^4He ground state (via near-field coupling to Pd electrons by the tightly bound lochon). Another ramification is that fusion at sub-fragmentation energy (e.g., with lochon intact) provides a neutral "nucleus" during the "slow" decay to ground state. Thus, this model permits transmutation via neutral, internally energetic nuclei.

5. Lochons: Nuclear Decay and Transmutation

If the fusion product ^{4}He* is below the fragmentation level, then the only place it can go is to the ^{4}He ground state. There are not likely to be any excited states below the new fragmentation levels that have allowed gamma transitions to the ground state. But, nuclear-energy loss to and through the tightly bound electrons would be a steady process.

Protons do not radiate well because they are too massive for the large radiative effects that electrons display. Nevertheless, when energetic and confined in the nucleus, they do radiate (in the form of gamma rays – when allowed). Furthermore, a high energy-transfer rate is possible between very-close charge dipoles. The effective interaction of the dipoles drops off as the sixth power of the separation, R_{ij}, and with the sum of the transition energies [12]:

$$\left[U_{\mathrm{NF}}\left(R_{ij}\right)\right]^{(2)} \approx -\frac{2}{3}\,\frac{|\mu_{mn}(2)|^2\ |\mu_{mn}(1)|^2}{R_{ij}^6\, E_{mn}(1)+E_{mn}(2)\,]}, \tag{6}$$

where μ_{mn} are the matrix elements of the transition-dipole moments.

At nuclear separation, despite the small dipole moments of the protons and tightly bound electrons, a steady energy transfer from protons to these electrons prevents the establishment of any nuclear energy "level." These electrons, if provided with angular momentum from the protons will, in turn, radiate. And, because of the proximity effect, they will radiate preferentially to the adjacent Pd electrons. The separations between the tightly bound H electrons and the Pd electrons are larger than the Fermi distances of the nucleus. Nevertheless, radiation from the MeV-level electrons will be much higher than that from the protons and the dipole moments of the Pd electrons will be much higher than that of the tightly bound electrons. Following the energy consideration in the denominator of Eq. (6) and the higher number of outer-orbit Pd electrons, low-energy transfer will dominate. However, any resonance effects of the energetic tightly bound electrons with the high-energy inner Pd electrons might make the latter preferred "targets." A range of X-rays has been measured in LENR experiments [13]. This observed radiation, while informative, does not appear adequate to account for the expected levels of Pd atomic-electron excitation. It may be that these electrons are only a transfer medium between the deep electrons and the phonon field.

The means of decay from ^{4}He* to ^{4}He without particulate radiation is clear. A similar path for ^{2}He* to ^{2}He (from p–p fusion) might be possible. However, a competing path is likely. The three-body reaction, p–e–p $\rightarrow$ $d^+ + \upsilon$ (where υ is a neutrino), in solar physics is well known [14]. In the sun, it is not a major fusion pathway (p–p $\rightarrow$ $d^+ + e^+ + \upsilon$ dominates). However, in stars, the protons and electrons are not nearly as close as in our model and there is never a *pair* of electrons in a tight cluster. If a coupled-electron pair (lochon) is present, the p–2e–p $\rightarrow$ $d^+ + e + \upsilon$ or p–2e–p $\rightarrow$ d^+ + e reactions should be even faster. How fast they are, relative to the decay to the unstable ^{2}He, determines whether the reaction is one of fusion or of scattering.

Both ^{2}He* and ^{4}He* display non-resonant decay paths. This means that the neutral 'atom,' with its tightly bound lochon is 'free' (and has time) to drift through adjacent electron and nuclear potentials with impunity. If it enters another nucleus, then the decay may be instantaneous and the decay products predictable. LENR data indicate the possibility of transmutation with the preferential addition of two and four nucleons to native elemental concentrations in active PdD lattices.

6. Summary

A lattice-specific model has been proposed whereby, negative hydrogen ions attract positive ions rather than experience the normal Coulomb barrier considered to be a major argument against low-energy nuclear reactions. The negative ions are a result of electron–phonon coupling that makes a lattice ion with an electron pair (a localized, doubly charged, boson – lochon) more probable than neutral atoms (those having only a single electron) in the sub-lattice. Specific phonon modes (most likely at linear-defect sites or at interfaces and surfaces) induce near collisions of the D^-D^+ pairs at a high rate ($>10^{14}$/s per pair). As an attractive element in the pair, the lochon does work during collision and falls deeper into its Coulomb-potential well, becoming even more stable in this phonon phase.

If the collision process proceeds far enough that the attractive potential is greater than the lattice barrier, then the D^-D^+ pair continues to converge, the lochon continues to fall deeper into its potential well, and the conditions for the final tunneling and fusion of the deuteron pair is established. As the lochon is spin-paired electrons in a filled orbital, there is no spinflip possible to provide angular momentum to generate photons. Therefore, this excess energy may be converted into work and lochon KE that could be on the order of MeV. Thus, up to the point of fusion, this is a reversible process – even though the deuterons may end up in other than their original lattice sites.

After fusion, when a deuteron is inside the D^- Coulomb barrier with a MeV-type lochon present, the situation is quite different from the normal d–d nuclear scattering with no, or only a single eV-range, bound atomic electron. In the usual d–d scattering of nuclear physics, the mass difference between ^{4}He and 2D is involved. In the present case, the electrons exist in shrunken orbits for the tightly bound paired state in D^-D^+ and, after fusion, in the excited ^{4}He*. The Coulomb far field of these electrons is negligible as it has been compensated by a comparable amount extracted from that of the protons. The far-field energy has been converted into more intense near-fields and kinetic energy. This reduces the apparent size of an electron to that of the shrunken orbit for slow motions and to the classical-electron radius for fast motions (e.g., tunneling). As a consequence of the reduced Coulomb repulsion within the nucleus, the effective depth of the nuclear potential well is increased. The ground and excited state energies become lower; but the fragmentation levels go up.

The tightly bound electron pairs (lochons) increase the lattice and Coulomb barrier penetration probability necessary for D^+D^- fusion. The bound-electron pairs may remain intact in the tunneling process. The above considerations lead to a conclusion that the energy of the excited state ^{4}He* nucleons could be less than 20 MeV. If so, and/or if the fragmentation level is raised above the excited states, no fragmentation is probable. The slower decay process to the ground state proceeds via radiative proximity coupling of the nuclear potential energy, between the protons and tightly bound electrons and then between the tightly bound electrons and the adjacent Pd electrons. This process provides both a path for conversion of the nuclear energy to thermal energy and, for a brief period, a small, neutral, internally energetic body that can drift (at thermal velocities) into adjacent nuclei during the decay.

The extended lochon model thus is capable of explaining: the realistic probability of low-energy nuclear reactions, normal D–D fusion decay paths with energetic fragments, the existence of a path from hydrogen collision (H^+H^- or D^+D^-) to a ground state (D or ^{4}He) without energetic particles, and a basis for the transmutation products observed in some LENR experiments.

Appendix: Deep Atomic Orbitals

A few remarks regarding a recent reference to the Klein–Gordon (K–G) equation applied to lochons (which have bosonic character) for describing a very small atomic orbital on D^- [10] may be in order. For the K–G equation, the energy states for a singly charged boson are given by (see Naudts) [14]

$$E_n = (n + \gamma^2) m_{\text{eff}}\, c^2 / \sqrt{n^2 + \gamma^2 (2n + 1)}\,, \tag{A.1}$$

where the binding energy of the orbit is $m_{\text{eff}}\, c^2 - E_n$ and $\gamma > \alpha/\sqrt{f}$, $\alpha > 1/137$, and $f > 1$,[a] or ~ 0. The orbit

[a]Naudts uses l for this dummy variable, but we use f to avoid confusion with the angular momentum used in this paper.

radius is

$$r_n = \hbar \sqrt{n^2 + \gamma^2(2n+1)}/m_{\text{eff}}\, c\alpha\ . \tag{A.2}$$

The $f > 1$ state is normally rejected as being non-physical, e.g., not observed. But, for the unique $n = 0$, $f > 1$ (or nought orbit) state,

$$E_{\text{o}} > \alpha m_{\text{eff}}\, c^2, \tag{A.3}$$

$$r_{\text{o}} = \hbar/m_{\text{eff}}\, c\sqrt{f} > \hbar/m_{\text{eff}}\, c. \tag{A.4}$$

Thus, r_{o} is essentially the Compton radius and, for lochons with $q_{\text{eff}} = 2q_{\text{o}}$ and $m_{\text{eff}} = 2m_{\text{o}}$, $r_{\text{o}} \sim 2 \times 10^{-11}$ cm.[b] With a binding energy perhaps close to 1 MeV, we have a very energetic and shrunken orbital for lochons in H^- or D^-. This orbital will produce the same fusion as does a muonic-hydrogen atom. Even if not stable, it could be considered a resonance, rather than a state, and still have a major impact on fusion rates.

Considering the means of attaining this nought orbit, it seems likely that a nought-orbit molecule would form in the process. Depending on the angular momentum of the collision (nominally $l = 0$), the lifetime of the molecule is limited by the fusion of the nuclei or by electron capture by one of the protons. Thus, LENR results may provide support for the existence of a deep atomic orbital that is still controversial and, furthermore, the extended lochon model would suggest that a nought molecule could form as an intermediate step prior to fusion or electron capture.

This deep orbit (∼MeV level, achieved by the work done in bringing the deuterons together) completes the pre-fusion orbit-shrinkage story of Fig. 2 begun with the Pd-lattice confinement of the hydrogen atom, continued as shown earlier [3,4] with the enhanced mass of lochons, and extended further by the reduced dimensionality of the lattice-barrier region being penetrated by colliding hydrogen.

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[b]These values are only approximated because of the charge and nature of the lochon. The effects of a doubly charged, compound boson are not analyzed here because of the complications resulting from the internal-charge repulsion and the uncertainty in its distribution in space and time.