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Research Article

Composite Model(s) for Low Energy Nuclear Reactions in the Solid State: II

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Abstract

Three partial models for Low-Energy Nuclear Fusion (LENR) of hydrogen, H, or deuterium, D, are brought together in the context of 30 years of searching for the answer to the source of nuclear fusion without the requisite kinetic energy to overcome a nuclear Coulomb barrier. The earliest of these D+D cold fusion (CF) models is Julian Schwinger's proposal (1990) to combine, in a single Hamiltonian, the attractive nuclear potential with the repulsive Coulomb potential to reach an excited state of ^{4}He. The second was a pair of papers by Maly and Vavra (M&V) that, a few years later, provided a relativistic quantum mechanical model basis for deep electron orbits. A third was K.P. Sinha's 1999 model to use a natural electron pairing in a lattice to form charge-polarized D_+ D_- pairs in a linear defect that is attractive rather than repulsive. Critical in Schwinger's model is the ability to dissipate nuclear energy before the actual fusion of the nuclei takes place. Critical to M&V's model is a deep-electron orbit predicted by relativistic quantum mechanics that, if occupied in deuterium, assured nuclear fusion. Critical in Sinha's model is the ability to free the hydrogen sub-lattice spacing in a linear defect from the encompassing crystal's lattice spacing. This present paper includes a connection with the more recently developed model (post-2015) of the deep-electron orbits and even more recent information (2019 and 2020) on new PdD phases and on models of properties of the hydrogen "chain". The importance and connection of each model's contributions with recent information are highlighted. We are not proposing a specific model supported with detailed calculations. We are suggesting that (aspects of) prior models can be combined to form a unified (composite) model that would be more convincing to the other members of the Condensed Matter Nuclear Science (CMNS) community (and others) than they would be individually.
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1. Introduction

Different models of the Low-Energy Nuclear Reaction have come and gone. Some were wrong and died a natural death, or are still being developed and 'pushed'. Some did not properly or fully represent the data available. Some were just premature and were not able to be appreciated at the time. We will address three of the last type and indicate how presentation and analysis of more recent models have brought them together. The present paper is an updated version of the unpublished text [1] of an oral presentation at ICCF-18. A poster presentation [2] in 2013 at that conference, provided a pictorial description of phonon activity in a linear array of D or H atoms that could be a common basis for the three models.

In 1990, Julian Schwinger, from his broad theoretical-physics background, presented a model for fusion of deuterium atoms into helium [3]. Breaking with the tradition of "non-interaction between nuclear and atomic forces", his model involved a coupling of the nuclear energy of D-D fusion into the PdD lattice, apparently even before the deuterons could be expected to access the non-Coulombic nuclear potential energy. Because of the low-energy conditions of the pre-fusion system and of the zero angular-momentum ^{4}He states available, the energy was only slowly coupled into the PdD lattice phonons while the deuterons were still at large distances (many pico-meters) from each other and long before the expected post-fusion nuclear reactions, e.g., nucleon exchange and subsequent fragmentation, of the excited 4He* nucleus could take place.

In 1993 and 1995, Maly and Vavra showed that the Klein-Gordon and Dirac theories (both accepted relativistic quantum mechanical models) provided the basis for real deep-electron orbits with binding energies for hydrogen in excess of 500 keV [4], [5]. They gave details of such orbits and stated that, if occupied in deuterium, nuclear fusion was assured. More than 20 years later, the validity of this work has been confirmed and its value has become apparent. Its implications and applications have now been explored and greatly extended in the context of CF.

In 2000, K. P. Sinha, from his theoretical and solid-state physics backgrounds, presented a particular model for longitudinal-optical-phonon motion of multiple deuterium atoms in a linear defect [6]. The interaction of their bound electrons with the lattice and sub-lattice provided conditions that created high-effective-mass electrons in an independent deuterium sub-lattice within that defect.[1] These one-dimensional, atomic-orbital, electrons provided super-strong screening that allowed a tightly-bound linear molecule to form and to precipitate D-D fusion. This electron-lattice interaction model has been developed [7], [8] and extended [9], [10], [11] over the intervening years to address, not just the fusion of deuterium in the PdD lattice, but also issues of experimental conditions leading to enhanced LENR results [12], [13]. These extensions led to classical deep-electron transits, which were then supported by relativistic quantum mechanics in the form of deep-electron orbits (see Synthesis 3 below) in solutions of the Klein-Gordon and Dirac equations, e.g., [4]. The deep-electron models include a mechanism for: avoiding the fragmentation products

[1] For many years, the present co-author (AM) thought that Sinha was referring to the "effective" mass of an electron due only to Pd-lattice constraints. Since this solid-state physics concept is related to electron transport between lattice sites, he did not feel that it could be applied to atomic-electron levels. Only with the recognition that Sinha was referring to the linear hydrogen sub-lattice spacing (not that of the palladium lattice) and to the geometric (see ref. [33]) and material (field) constraints imposed by the lattice on the sub-lattice components, did he come to understand the full picture. Just as the effective mass of an electron is altered by the barriers between lattice sites ($m^* = F/a$), it is altered by its coupling with lattice electrons and by the potentials that can confine it to a reduced volume about its nucleus. Sinha's calculation (for his Eq. (21)), estimating the possible effective mass of the bound electron and based on available data, suggested it to be $m^* = 200\ m_e$. At the time, though it was known that strong internal and external fields and relativity could increase the energies and effective mass of bound electrons, this value appeared to be impossibly high. However, this is the range for effective mass of the highly-relativistic, deep-orbit, electrons. Was Sinha's high value; possible, entirely coincidental, a misinterpretation of the equations or parameters involved, or wishful thinking on his part? Relativity is not mentioned in Sinha's paper; but, it becomes very important in the 3rd Synthesis below. With this potential for misunderstanding in mind, these sentences were written hoping to clarify Sinha's intent in reference [6]. While the confinement Δx of an electron is related to its momentum, Δp, (from the Heisenberg Uncertainty Relation, $\Delta p \cdot \Delta x \geq \hbar/2$), the relativistic effect, relating its mass to its energy, increases its effective mass ($m^* = \gamma m_o = E/c^2$) as well as decreasing its minimum size at velocities approaching the speed of light.

of 'hot' fusion [14], [15], [16], the means of coupling the nuclear energy of fusion into the lattice [17], [18]; the LENR results of the NiH system [19]; and the observations of transmutation in both the deuterium and light-hydrogen systems [20], [21].

Thus, by 1999, there was already a theoretical basis for a composite model of cold fusion. Sinha had provided a QM basis for bringing protons closer together in a (perhaps?) unique lattice-enabled solid-state ensemble. Schwinger had provided a nuclear "boost" to the attractive Coulomb potential drawing them closer. Maly and Va'vra had given the relativistic basis for electron stability in near-nuclear orbits. Sinha's lattice-based effective mass of the nuclear-bound electrons (effective at the lattice and atomic levels) was replaced by the relativistic effective mass of the deep-orbit electrons at the near-nuclear level. Sinha's and Schwinger's models provided possible (non-photonic?) mechanisms for populating the deep-orbits of hydrogen atoms; thereby greatly increasing their fusion probability, and that in a manner quite different from that of hot fusion.

Why were the pre-2000, fully-developed, theoretical-modeling papers ignored for so long? Why did it take so many years for these papers and their ideas to come together? Have they actually come together even now? In 1990, the field was new and Schwinger's model was presented to explain one of the major observations and anomalies at that time. A Nobel laureate and one of the best theoretical physicists at the time, Schwinger was publically ridiculed by some physicists for his non-traditional idea. On the experimental side, above-fragmentation deuterium fusion, a normal result of 100 million degree temperatures in the sun or multi-MeV accelerator beams in the laboratory, was known to produce neutrons and protons in equal numbers from d-d collisions. The 'cold' fusion results had already shown that the neutrons could be produced at a rate of less than 10^{-6} that of the protons (most often determined by the level of tritium resulting from the reaction). Thus, Schwinger was proposing a theoretical basis to provide a model to predict data that was being challenged and was already changing at the time. It was presented at a time that cold fusion was already beginning to be classified as "pseudo-science'. The 'moving' target of data, the novelty of his physics, and the changed perception of the field meant that his work appeared to have been misdirected and that, already, the small community of physicists capable of understanding and appreciating his work had nearly disappeared from this new field.

By 1993, when Maly and Vavra first published their work, there were few left in the CF field who could understand it, even if they had seen it and had time away from their own work to digest it (both are problems even today). In Sinha's case, the difficult description of a new concept in solid-state physics and the problems with combining terminology from three published versions (by 3 different authors) of a controversial development [22], [23], [24] in that field blurred the mathematical implications and obscured some of the descriptive statements that are important in this synthesis. The model that Sinha proposed is not expressed in modern physics. Therefore, from either the description or the mathematics, there is a problem of misinterpretation on the part of a reader because of a "language barrier". Sinha tried to express the problem mathematically by taking appropriate limits of a basic equation. However, in that activity and in those "words", there appeared to be a violation of accepted solid-state physics (the constancy of average crystal-lattice spacing). The co-author (AM) of this paper recognized this issue and he fought long and hard over it with Sinha in 2006. They worked together on many papers since then and did not revisit the issue until Schwinger's paper was found and Ed Storms expressed what appeared to be a similar thought in 2012 [25].

The key to the Sinha picture that differs from conventional solid-state models involves the average spacing between local atomic oscillators in a crystal. Since the physics models were developed in the context of a crystal with a fixed periodic structure, the Einstein oscillations [26] are considered to be about fixed points/spacing within the lattice. Sinha's insight came from the limit equations for a linear system of oscillators indicating that the system energy diminished with the lattice spacing. Since lower total energy means greater stability, the natural result would be a collapse of the spacing to zero. What is different about the Sinha system that allows it to do this when no other system does so? The difference is in the defects within the lattice. If the defects are "filled" with H or D, then the distance between these "hydrons" may not be tightly bound by the lattice spacing. If the hydrons form a sub-lattice, then the

quantum mechanical description can be applied to it as a unique structure, influenced by the supporting lattice - but not defined by it.

This paper is not a review of the field of Low-Energy Nuclear Reaction (LENR) theory. It is more of a directed perspective. It provides the mathematical and physical basis that combines the concepts expressed in the Schwinger-Sinha (SS) and the relativistic QM models. It also describes how some other LENR models have contributed to this fuller picture that could perhaps become the theoretical foundation for explaining, among other things, the phenomenon of generating heat without energetic particles from the fusion of two deuterons.

The Schwinger model was specific to the PdD system. Nevertheless, the concept of combining the nuclear and Coulomb potentials in a common Hamiltonian to describe the low-energy, but complex, system applies to the NiH system (and others) as well. The Sinha model is generic. It applies equally to the deuterium and hydrogen (D and H) systems. Therefore, the use of H and D, or p and d for the atoms and ions under discussion throughout the paper, will be interchangeable (unless specifically noted).

2. Background

2.1. Overcoming the Coulomb barrier

One of the major problems with trying to achieve fusion of two nuclei is overcoming their mutual Coulomb barrier. When far apart, the neutral atoms have no repulsion. When the atoms are very close, their atomic-electron clouds, which cannot be readily shrunk beyond certain limits but can join to become a common molecular cloud, extend beyond both nuclei. As a result, the effective negative charge between the nuclei decreases with their reduced spacing. Kinetic energy of the electrons keeps them too far from the deuterons, on average, to counter even the screened nuclear-Coulomb barrier when the deuterons get too close together. This loss of compensating charge is the source of the transition from a zero to a strong repulsion with decreasing nuclear separation and is the reason that molecules have a nominally fixed spacing between atoms ($\sim 2\mathrm{A} = 0.2\ \mathrm{nm} = 200$ pm).

If two nuclei can be brought closer together (e.g., 1500 fm = 1.5 pm) within the confines of a lattice and by their mutual oscillations, the electron distribution becomes less isotropic as the electrons are forced into alignment along the nuclear axis. For s-orbital electrons, it is not just a shift in average position of the electron cloud relative to its protons, altering a dipole moment. Lattice confinement can provide an alignment force shifting the axis of the instantaneously linear orbits. Any such alignment of the electron orbits along the axis between the nuclei further reduces the net distance between electrons and protons because it increases the average electron density between the protons.

Figures 1, from [27], indicate the effects of these alignments and proximity in the form of their electron probability distribution. The order-of-magnitude scale difference in the axes shows the strong compression of electron distribution into a cylindrical geometry and the concentration of the electrons into the nuclear regions. This greatly increases the percent of total time electrons spend between the nuclei. Nevertheless, the nuclear Coulomb repulsion has also greatly increased with proton proximity. Much of the time there is with no electron between the nuclei to provide screening of the repulsive barrier and the nuclei are kept apart.

In free space at normal molecular distances, the electron's kinetic energy prevents the electron cloud from being tightly 'packed' into the positive potential between the nuclei. The charge dipole-dipole polarization of the protons adds to some extent as an attractive force; but, once the wave functions of the two electrons overlap sufficiently, further 'self-compression' is not possible and the potential barrier remains. Thus, even this short-range $1/r^4$ attraction disappears for small r in normal atoms because, beyond a certain point, charge polarization is no longer as effective. This leaves the relatively large spacing (comparable to the average electron orbital radii) between nuclei in a molecule.

Akito Takahashi proposed a technique for overcoming this problem via a tetrahedral deuterium configuration [28] that counters the bound-electron's tendency to provide insufficient screening. The tight clustering of multiple atoms and their electrons means that the electron orbits overlap in the central region and are thus able to greatly compensate the

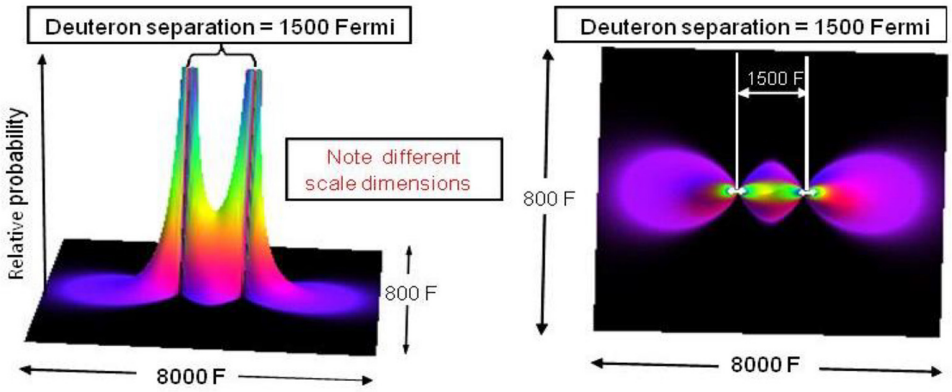

Figure 1. An example of the probability distribution of an electron bound to a pair of protons separated far below the normal molecular spacing [27].

accumulating positive nuclear charge when the atoms come together. In free space, and in most materials, the negative-charge distribution of nearly-isotropic, overlapping, electron clouds is not adequate to compensate the repulsive charge of the protons of the net-neutral atoms. Takahashi's concept of embedding the deuterium cluster within a lattice provided two benefits. By sharing their bound electrons with the lattice atoms, the deuterium atoms have less electron-cloud repulsion to overcome and the concentrated and oriented negative charge of the overlapping electron clouds is able to better screen the charge of the deuterons. By being in a sub-lattice, the deuterons can benefit from both the energy and, possibly, the coherent displacements of the collective modes of lattice oscillation (phonons) to help push the deuterium atoms together.

While Takahashi's model is a valid means of reducing or overcoming the nuclear Coulomb barrier, of overcoming the weaker, but significant, electron barrier, and of using the lattice phonon motions to provide sufficient energy to overcome the remaining barriers, a problem remains. The probability of bound nucleons in 4 separate sub-lattices achieving the synchronous motion necessary to simultaneously induce and take advantage of the lowered barrier seems low. Nevertheless, Takahashi has identified a means of overcoming the Coulomb barrier within the framework of a low-temperature environment. Remember, 1 eV is equivalent to ~11,000°C and the compression alone of a hydrogen atom to a 1-D configuration, during the phonon-induced cycling, reduces the electron ground-state energy by over 40 eV. **This is an example of a geometric multiplier acting as a catalyst.**

K. P. Sinha, in his 2000 Infinite Energy paper [6], proposed the lochon model to produce D^+ D^- pairs that are attractive rather than repulsive - at least for sufficient time for fusion to take place. This pairing concept goes back to a 1963 paper of his [29] (and to other authors also exploring the phonon-electron interaction at the time) to explain experimentally observed aspects of superconductivity. The pairing, in physical space (rather than in momentum space), is allowed by spin-spin coupling between the s-orbital electrons. Furthermore, the increased polarization of the local host lattice provides an increase in effective mass, m*, of the bound electrons [30]. The increased effective mass leads to a deepening of the electron orbits and thus to a reduction in the 'size' of the atom. This can equivalently be attributed to the alteration of the shape of the local potential well confining the atom and its electrons. This shrinkage of the atom size produces an energy component due to localization effects. The extra energy means that the electron energy level for the D^- or H^- ion in the lattice is lowered relative to the Fermi level or to the neutral-ion level and this negative state becomes more populated.

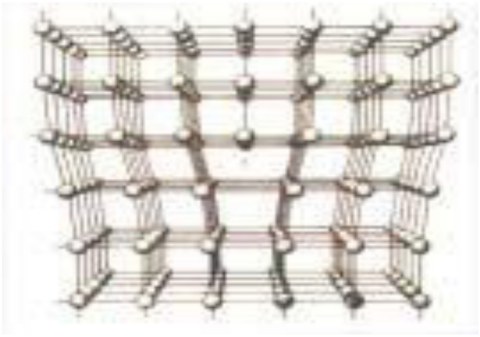

Figure 2. Example of a linear defect that could constrain a linear H_n sub-lattice with less than the normal sub-lattice barriers, interposed lattice atoms, and lattice constraints.

Sinha's model depended on a reduction of the 'effective spacing' within the linear array of deuterium atoms to increase the effective mass of the electrons when treating the array as a linear lattice. Sinha's quantum mechanics appeared to provide the numbers supporting his claim as long as the spacing of the linear array, l, could decrease significantly in a regular manner (see Eq. (1)). This cannot happen within a PdD lattice. However, Sinha had considered that point and wrote that "When the atoms are located on regular crystal lattices, the shrinking in their size ... is constrained by the lattice constants." He continued by stating that, "... when the chains of deuterons lie in crevices, voids or empty channels of the matrix, the conditions are different. They will have their own spacing in the chain."

Is it possible to find such conditions within the Pd lattice? Fig. 2 shows one such possibility. However, a recent study [31] suggests that this type of dislocation defect might be more important as a source of vacancies in forming and leading to islands of delta δ and delta δ' phase in Pd that may be an even better fit to our requirements for a 1-D channel or "tube". This δ-phase possibility is explored further and is proposed to be a site for the linear defect as needed for CF [32].

What Sinha apparently realized was that, even given an appropriate defect, the situation was extremely complicated and the system energy (Eq. (1), now modified to include a dependence on l as a variable) depended on multiple variables that were not independent. When he tried to establish the energy dependencies on the multiple parameters, he did not fully appreciate that not only were the two standard variables (x, the displacement of the nuclei from their equilibrium location, and r, the distance between the nuclei and the nearest electron) interelated, but all of the parameters in the equation were actually variable within different dimensional regimes and had a non-linear interdependence as well. The energy terms that depend on the proton-electron, the electron-electron, and the electron-lattice interactions, include a displaced oscillator mass, M_d, that produces a displaced oscillator energy, E_d, with an oscillator frequency, ω_d, and displacement, x; the radius of influence of a bound charge (from polarization of the lattice), r_i; the distance between the electrons and their nearest proton, r; the effective dielectric constant of the local lattice region between the proton and electron, ε^*; the sub-lattice spacing, ℓ; the displacement from this spacing, x; and the effective mass, m*, of a bare electron within the surrounding lattice. Thus,

$$E(x, \ell, r) = \hbar^2/2m^* r^2 - e^2/\varepsilon^* r - x\omega_d(2M_d E_d)^{1/2} + 1/2x^2\omega_d^2 M_d(r_i/\ell)^3, \quad (1)$$

with $\hbar = h/2\pi$ (h* is used for $\hbar$ in Sinha's paper). The first two terms on the right are repectively the electron kinetic and potential energies of the hydrogen atom (perhaps extended by bond sharing) in the lattice. The kinetic energy is expressed in terms of the momentum related to the deBroglie wavelength. The last two terms are the 'displaced'

oscillator kinetic and potential energies tying the hydrogen atom's kinetic and potential energy to the lattice. In this latter case, the ratio of the range of influence r_i within the lattice to its spacing, ℓ, within the sub-lattice is critical.

When the electron gets close to the nucleus, then $r_i => r$, the atomic radius, and this becomes a limiting factor in determining the sub-lattice spacing. The atomic radius in the hydrogen sub-lattice is not isotropic. It is compressed by the lattice defect walls and becomes 2-D [33] or 1-D like, even at low hydron concentrations within the sub-lattice. However, as more hydrogen atoms are 'crammed' into the defect by lattice loading, their high concentration further compresses and deepens the Coulomb potential well for the electrons. Thus, r can shrink toward 1-D values or even be reduced in all three dimensions (as in Fig. 1). This shrinkage and change from monopole- (of the seperated electrons and nuclei) to dipole-field distributions (of the closely-coupled pairs) alters the charge interaction with the lattice and thus the dielectric constant and effective mass of the electrons. So, the 'constants' of Eq. (1), including the displacement energy and oscillator mass and frequencies, have interdependences that are defect and loading dependent and can change at several levels of loading and at each of the several spatial regimes to be considered.

It was an almost impossible task to treat the equation without assuming that all of the 'constants' would be constant over the distance of interest from the host-lattice spacing to the near nuclear regime. But, with that assumption, strange effects were observed. Furthermore, this QM model does not include relativitic effects or even electron-spin coupling (which includes the Pauli exclusion principle). While this coupling leads to dimerization in the longitudinal-optical-phonon mode of the deuteron sub-lattice, it prevents significant shrinking of the sub-lattice spacing if the D-bound electrons remain in s-orbitals. However, recent modeling of the linear-H chain [34] has shown that for a 40 atom chain, the metal-insulator transition (MIT) occurs at an inter-proton distance of R = ~1.7 Bohr radii (or about 4/3 of the free-space H_2-molecule spacing). The transition is attributed to the "mixing" of the 1s, 2s and 2p states. The 2n states have a high enough density-of-states and radius that, if partially populated, will allow ready transfer of electrons along the chain without violating the Pauli principle. The paper suggests that significant non-thermal population of these 2p states begins at R = ~ 1 Bohr radii (a_B), which, at ~53 pm, is much greater than the spacing chosen for Fig. 1. Thus, with the hydron sub-lattice spacing controlled by the Pd lattice (d_{PdD} = ~405 pm $>7.5a_B$) and the large energy difference between the ground state and excited levels, there should be little probability of significant bound-electron transport along the linear-D chain even with further considerations. It is this transport that could allow greater screening of the repulsive Coulomb forces between the sub-lattice nuclei.

The further considerations, in the present model, include a Pd lattice structure defect that confines the D-chain to linearity without "forcing" the sub-lattice spacing to that of the lattice. It is highly unlikely that this lateral confinement alone will reduce the sub-lattice spacing by the factor of 4 to 7 needed to fit the modeled 2p initial-filling condition for PdD. Nevertheless, it can confine the filling of 2p orbitals to only the ones along the D-chain axis. Since the transverse size of the 2p orbitals are calculated (for a linear chain without lateral confinement) to be about 5 a_B [34], the aligned orbitals should be capable of forming sigma bonds between the hydrons (initially about 7.5 a_B apart) as electrons begin to move into the 2p orbitals.

The sigma bonds (with both s and p electrons, if populated) will provide electron transport along the D chain to reduce the repulsive nuclear-charge effects and allow the chain to shrink together under the right circumstances (e.g., a high local Fermi level, a high hydron loading, and sufficiently weak coupling to the Pd lattice). The local fermi level is affected by both the sub-lattice spacing and the substrate itself (e.g., material, temperature, and doping). The higher the fermi level, the greater the electron population within the sub-lattice; then, the greater the screening of the protons' Coulomb barrier. In the reduced sub-lattice spacing as the hydrons move closer together in their phonon-driven oscillations, momentarily leaving gaps, more hydrons can be injected from the lattice if the hydrogen population is high enough. New modeling of a lattice-bound linear chain in a lattice defect would be required to determine the rate of filling the 2p orbital and its temperature dependence, since results depend on the selected boundary conditions.

2.2. Dissipation of nuclear energy without fragmentation

In addition to the problem related to lattice spacing, the present co-author was also unable to accept what he thought was Sinha's means of obtaining the high "effective-mass" electrons that would allow sufficient tunneling to achieve fusion by a muon-like induced-fusion mode. Nevertheless, he was attracted by the D^+D^- model of tunneling through the nuclear-Coulomb barrier and, together, the two of us did the calculations necessary to show that this was possible and produced a result on the order observed in CF experiments [9]. However, like muon-induced fusion, this lochon model would produce fusion with fragmentation. Thus, an extended-lochon model was developed to get beneath the fragmentation levels [14], [16]. This latter effort found support in the decades-long pre-Cold-Fusion struggle over the deep-electron levels predicted by the relativistic Schrodinger equations of quantum mechanics and best expressed in [4].

Early in the history of Cold Fusion, a different approach was proposed (1990) to provide deuterium fusion without neutron emission. When Schwinger proposed a model for a phonon-induced transition between the D-D pair and the 1st excited state of ^{4}He* [3], he stated that, unlike the standard 2-step process of tunneling to within the nuclear-potential well and then decay to the excited state(s), a single coherent process, rather than an event, could be considered for the transition. His idea did not gain much traction because it was very theoretical; it required a transfer of nuclear energy to the involved atoms prior to fusion. And, while it explained the dearth of neutrons in the CF process, it still provided fragmentation via the tritium plus proton (t+p) products. Soon thereafter, data started to indicate that the end product of the D-D CF process was almost entirely ^{4}He and not tritium. This recognition of an important feature of CF was not integrated into a published model by Schwinger before his death in 1994. Nevertheless, such an extension is trivial.

Peter Hagelstein, for quite a while, logically advocated the decay of ^{4}He* to below the fragmentation level, or to the ground state, via phonons from a recoiling nucleus to the lattice [35]. A problem with this model was the need to dispose of a very high level of energy (>20 MeV) in a very short time, via an extremely high number of coherent low-energy phonons, to be able to compete with the extremely-rapid fragmentation process. On the other hand, this model could almost fit with an extension of Schwinger's model that would permit phonon decay to the ^{4}He ground state or to an arbitrary level beneath the fragmentation levels, via lattice-atom oscillation, before fusion actually occurred. Ed Storms also proposed such a pre-fusion decay process, but via nuclear photons[2] in a nuclear-active environment (NAE) of the lattice [25].

After ICCF-18, a theoretical effort of getting an electron close enough, for long enough, between a proton pair to draw them close enough for fusion to occur, was devoted to developing the relativistic quantum models that predicted near-nuclear electron orbits (see [36] and the references therein). Such an orbit could contain an electron with kinetic energies and effective mass in the 1 - 100 MeV range. These deep-orbit electrons would automatically lead to nuclear fusion and transmutations, along with the myriad other results observed in cold fusion. In the reviewing of these older models, a mechanism for populating the deep orbits from lattice confinement and distorted atomic- or molecular-electron orbits presented itself. This is further discussed below as Synthesis 3.

2.3. Lattice confinement effects

The reduction of the hydrogen sub-lattice volume (via confinement) due to localization in a linear lattice defect, is primarily in the direction of neighboring lattice-array atom(s). It forms the sub-lattice toward a 1- or 2-dimensional structure. This means that orientation of the bound sub-lattice electrons will be preferentially directed along the linear- or planar-array axes. As the population of hydrogen atoms in the 'gap' exceeds its first 'saturation' point, where the

[2]The present authors consider such nuclear photons to be unlikely since there are no known energy levels to provide them. However, the linear-H array would, as a molecule, have molecular levels that would provide a basis for photoemission as the H atoms move closer together on average.

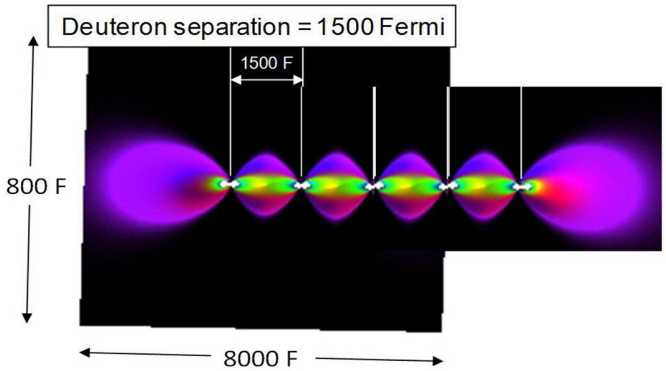

Figure 3. A linear-H_n 'molecule'/sub-lattice with reduced spacing and increased linearity (based on an extension of Fig. 1).

number of lattice-provided potential minima are filled, the hydrogen electrons will begin to show a preference for bonding to other hydrogen atoms (dimerisation [37]), rather than to the host-lattice atoms. The molecular spacing will still be affected, but not defined, by the host lattice. Thus, oriented diatomic molecules may begin to form and interact within the confines of the gap. As more hydrogen is 'expressed' into the gap from the host during the H-loading step, the gap population becomes less and less dependent on the host-lattice spacing. A second 'saturation' point occurs when the lattice is filled with diatomic molecules oriented along the common axis (e.g., making the transition from Fig. 1 to Fig. 3). At this point, in a 1-D defect, a second phonon mode becomes dominant, in which pairs of atoms (the diatomic molecules) form a polymer (the linear array) and alternating pairs are cyclically squeezed together in a longitudinal-optical-phonon mode [38].

Ideally, each additional atom in a linear-H array, which is now an n-atom molecule not strongly bound by the lattice, reduces the array's average atomic spacing. The atoms at the end may be less tightly bound than average in this sub-lattice; but, at some point, the inner atoms can come together because there is always an electron between pairs of nuclei. The ability to maintain linearity is reduced by higher temperatures that increase intrusion of the lattice atoms into the linear-defect space and by the off-axis motion of the sub-lattice atoms. On the other hand, the amplitudes of linear-array phonon modes and the population of excited-electron orbitals increase with temperature. This means that at the phonon frequency, which depends on the sub-lattice modes, two or more hydrogen nuclei can come together close enough to greatly increase the probability of fusing.

This new mode, consisting of oriented molecules colliding in alternating pairs, has its own spacing conditions. They are not dependent on the host lattice and not even strongly dependent on the linear-lattice spacing of the hydrogen atoms in the gap. However, as pairs of pairs colliding in a line, its electron distribution has an unusual property. In the normal, molecular-hydrogen configuration (as in Fig. 1), the atoms and molecules are kept apart because the electron population density cannot be confined between the nuclei. It extends in all directions beyond that of the proton-pair spacing. Thus, the nuclear-Coulomb barrier rises as each nucleus moves inside the other's electron cloud and sees a reduced screening. In a linear chain of H atoms (e.g., the 5-atom chain of Fig. 3), when the atoms are close enough, the very electron overlap that prevented collapse of the molecule in the diatomic case, is now concentrated and aligned along the linear-chain axis. It therefore is able to provide additional charge compensation for the adjacent pair. As a consequence, **the inner pairs of nuclei in a linear array have a greatly reduced Coulomb barrier keeping them apart.** The level of approximation to linearity determines the extent of potential-well deepening [33], [39], the probability of electrons decaying to a near-nuclear deep-level [4], and then the probability of paired nuclei fusing.

Any residual barrier is a consequence of the deviation of the electron distribution from the 1-D ideal. However, as the growing phonon oscillations bring the hydrogen atoms closer together the resultant potential well of three (or more) nuclei (i.e., that dominated by the sub-lattice rather than by the lattice) becomes deeper and more one dimensional (Fig. 3). As the bound electrons move in this deepening potential well, they gain kinetic energy that comes from the nuclear Coulomb potential. As the electron orbits are changed by the confinement and motion, the atomic and molecular energy levels become distorted, spread out, and overlapped. Thus, as the electron orbitals begin to overlap, the electron concentration between the sub-lattice protons are free to increase despite the increased mutual repulsive potentials. The Pauli exclusion principle no longer precludes this increase since the extra electrons are not in the same state. In addition, when the nuclei get close enough during their phonon cycle, they experience a small portion of their nuclear attraction and this is a 'boost' in the direction of increased attraction. The extent of boost is dependent on the increase in number of phonons in the driving mode and this addition is distributed along the linear chain and into the lattice. Even if only the Coulomb attraction between nuclei and electrons is considered, this change in nuclear-Coulomb potential energy and fields will alter the average internal structure spacings (and thus mass) of the protons.[3]

The energy transfer from the nuclear potential to the linear chain initially is weaker than the Coulomb potential energy being transferred to the electrons. Nevertheless, both come from the same source, the sub-lattice nuclei. The energy gain to the sub-lattice from both the nuclear and the Coulomb forces increases with time. However, as soon as the nuclear potential begins to contribute significantly to the system's kinetic energy, the process becomes irreversible because that energy is not stored (e.g., in the electron's relativistic and kinetic energy). It is distributed into the lattice phonon field. We now have multiple answers (e.g., Synthesis 3 below) to the question about how atomic electrons can decay to the deep-Dirac levels without single-photon emission.

3. Bringing past models together

3.1. Synthesis 1: Atomic proximity effects and nuclear-to-lattice energy transfer

Common elements in much of present CMNS thinking on the subject are the longitudinal-optical-phonon motion of a linear-hydrogen sub-lattice and/or a deep-orbit- or multiple-electron presence to provide sufficient screening to aid tunneling/fusion. Sinha and Storms have specifically identified linear defects or voids within the lattice (or at the surface) as logical sites for a special action needed for CF. Sinha had specifically considered the D^+D^- interaction that leads to D-D fusion [6]. Meulenberg identified the longitudinal-optical-phonon mode as a means of forming such pairs as resonant transients in the sub-lattice [2]. Storms considered a centrally located 'electron' as the 'attractor' that initiates a process of continuous photon emission ($\sim$24 MeV worth of IR radiation) leading to the ^{4}He ground state. Staker identified negatively-charged vacancies within linear "tubes" of deuterium in the δ and δ' phases of PdD that might fit all these requirements [32].

Without identifying a specific structure, Schwinger calculated the probability of phonon coupling/emission adequate to make a transition from the D + D state directly to an excited ^{4}He* nuclear state. This differs from Hagelstein's phonon-dissipation model of nuclear energies [35] in several ways:

- Schwinger's model does not provide details on a physical mechanism for the coupling of the nucleus to the lattice. It only provides the theoretical/mathematical connection.
- his energy transfer is a relatively 'slow' process; but, being pre-fusion, there is no competing decay process that would prescribe or proscribe the dissipation rate.

[3]Within the charged-quark model, polarization of the nucleus increases the average distance between the positive and negative quarks. This reduces the internal energy and thus the mass of the nucleons.

- it does not require tunneling through a Coulomb barrier (or a strong overlap of nuclear wave functions), to initiate the fusion process, until the nuclear energy levels are reduced below the neutron fragmentation level.
    - Tunneling is still possible. However, it has a very low probability until the nuclei get closer together later in the process. Early tunneling provides aspects of the known fusion-fragmentation results. Late tunneling gives the cold fusion results. In-between tunneling, would be the source of the greatly-reduced neutron fragmentation and the reduced proton fragmentation that has been observed in many CF experiments.

Therefore, with the above considerations, we can draw out a synthesis of the thoughts:

- Sinha's lochon model, leading to D-D fusion, provides a basis for fusion above the fragmentation levels and may account for the minor neutron emission observed in some of the CF experiments. It also provides the early stages leading to fragmentation-free LENR: the longitudinal optical-phonon mode bringing the lattice-bound hydrogen atoms closer together; the charge separation and increased effective electron mass resulting from coupling to the lattice; and the possibility of decreased spacing of the deuterium ions in a linear defect. These are probably valid and important concepts; but, the basic model must be extended to get below the ^{4}He fragmentation levels that identify the conventional fusion process.
- The present authors have explored an approach to satisfying that requirement in the Extended Lochon Model [14], [15].
- The Schwinger, Takahashi, and Storms processes are alternative approaches to getting beneath the fragmentation level and are particularly appropriate to Sinha's defect-based, linear sub-lattice, model.
- Staker's exploration of the δ and δ' phases of PdD, perhaps, provides the best location for all of the models to come together.

3.2. Synthesis 2: Multi-atomic, linear sub-lattice, interactions

Variations on Storms' model of the central electron and Sinha's lochon model may reflect a real scenario whereby a linear constraint (the crevice, void, or defect) confines the hydrons (the hydrogen species under consideration, H or D). The defect 'walls' and the linear hydrogen structure further reduces the dimensionality of the electron paths/orbits about the defect nuclei. The electrons become even more confined to a 1-D path as the hydrogen atoms get closer together and the screened nuclear-Coulomb potentials overlap (e.g., Fig.1). The summed proton potentials build up a Coulomb barrier between the protons; but, at the same time, this becomes a more one-dimensional 'trap' for the bound electrons.

The bound electrons are still in near ground-state 1s orbitals (zero angular momentum). Thus, they follow near-linear paths that are now oriented by the 1-D confinement. How does this linear, multi-H, structure differ from that of a H_2 molecule? As a near 1-D molecule, it has much deeper ground-state energies [33], [39]. Therefore, the average spacing is less than that for a 3-D H_2 molecule. Since the longitudinal, optical-phonon modes include multiple atoms coming together in pairs, repeatedly, opportunity exists for additional H-atoms to be inserted into the defect to begin the formation of a higher H-atom-density sub-lattice. The linear sub-lattice could be a H_3, ..., H_m molecule (e.g., $m = 5$ in Fig. 3) or a linear structure with alternating H and vacancies, e.g., [32]. The bound 2-s and 2-p electrons can be shared among the multiple paired nuclei and within the sub-lattice as a whole. However, since the 'shrinking' of the molecule increases the electrons' kinetic energies, some/many of them can shift to their higher n-levels (all of which have had their energy levels 'spread' from the compression and proximity) to form a chain of sigma bonds and, possibly, compressed pi bonds. This provides the basis for a localized 'metallic' hydrogen [34].

The fact that multiple hydrogen atoms can come together in a linear formation means that the shared electrons maintain their screening capability to much smaller spacing than is possible if only two atoms come together (as

described in Figs. 1 and 3). Thus, as in Takahashi's tetrahedral-hydrogen cluster model [28], the Coulomb barrier between nuclei is greatly reduced in length and height. The electron concentration initially provides strong screening for the nuclei. As the average sub-lattice spacing decreases, the potential well seen by the electrons gets more one-dimensional and the average of one electron between each nucleus gives a net attraction until the nuclear-Coulomb barrier emerges to dominate at very close sub-lattice spacing ($\ell < 100$ fm?) and at even smaller inter-nuclear distances during oscillations. This potential well and barrier for the nuclei provides a basis for the oscillatory motion proposed by Schwinger and Sinha.

The radiation from this oscillation of charges (s-orbital electrons and nuclei in the linear molecules) may not be photonic in the normal sense, if none of the charges has sufficient angular momentum to form photons. Neither may the combined sub-lattice have this, if in a highly-linear array. Furthermore, the only electron orbits below the atomic ground states are those of the deep-electron orbits with binding energies in the 500 keV range (and the basis for Synthesis 3). Thus, energy transfer from the combined Coulomb and nuclear potentials would be primarily in the form of numerous low-energy phonons from the hydrogen atoms in molecular-vibrational modes. Nevertheless, the photon radiation that has been reported does have possible source modes. Double-photon emission can occur with a net zero change in angular momentum. It is highly forbidden ($\sim 10^{-8}$ times the normal dipole radiation probability, which puts it in the same range as the zero-to-zero angular momentum transition); but, in the slow, repetitive, phonon-emission environment, with no competition from normal single-photon radiation, larger energy steps could be taken occasionally by this double-photon process. Such emission, if aligned with the excited linear molecule, could stimulate laser-like pulses.

Other photo-emission mechanisms may also come into play. What happens when the stability of the electron orbits is strongly disturbed? Any photo emission will not now provide the clean spectral lines of the stable orbits (line broadening is characteristic). At the collision points of the defect oscillations described, many orbits, previously with energy levels separated by electron volts, now overlap. This allows electron-orbit transitions and a means of establishing a new energy and angular momentum balance without photo-emission. At the high-separation points of the sub-lattice atoms, the energy levels would have returned toward their atomic states and could then radiate the energy that they had collected earlier. This energy could be released at nearly any point in the orbit so that there would be a large energy and angular distribution of radiation (including radio-frequency that has been observed). Furthermore, since all of the H or D atoms in the sub-lattice are synchronized, if one emits a photon in the direction of the linear array then by stimulated emission many of the other atoms, which would have populated the same orbital(s), can emit in one direction or the other along that axis. This becomes a single-shot laser-like EM burst that could repeatedly occur at or near the sub-lattice oscillation frequency. Again, the EM frequency of the bursts may not be fixed between bursts. Nevertheless, the pumping action of a collapsing sub-lattice will constantly feed electrons into orbits from which they will radiate. While the radiation may be focused along the direction of electron motion by the coupled EM fields, the timing of emission and its ability to trigger a cascade is still random. Bidirectional, laser-like, optical bursts have also been observed in CF experiments.

As mentioned in a footnote above, the linear-H array is an excited molecule seeking a ground state. It can decay via photonic radiation. In the thermal environment of a lattice, "collisions" between lattice and sub-lattice atoms would assure sufficient angular momentum to provide that necessary for photonic emission.

At some point in the coming together of the hydrogen atoms in an oscillatory mode that radiates nuclear (and electron) potential energy in the form of phonons and photons, fusion is inevitable. If D-D fusion occurs below the fragmentation levels, both the deeply bound electrons and nuclei are in potential wells that have no internal resonances. The deuterons have formed an excited helium nucleus below the fragmentation or excited nuclear-energy levels. The electrons are much deeper than the atomic-electron ground-state energies of H, D, or ^{4}He. The energy transfer from this excited nucleus down to the ^{4}He nuclear-ground state is the same as was described in ICCF-17 and ICCF-18 papers [17], [18]. Once below the fragmentation level, Hagelstein's phonon transfer process from the nucleus to the

lattice may no longer have a time-constraint problem (without a deep-orbit electron, there is no competing rapid-decay mechanism) and his QM calculations may be more appropriate to the system than the relative field-strength numbers provided in above references.

3.3. Synthesis 3: Deep-orbit electrons and their effects

The relativistic-electron deep-orbit (EDO) model [36] solves many problems associated with the general acceptance of cold fusion. However, it has its own problems with acceptance by mainstream physics. These include: the lack of experimental evidence for orbits below the atomic ground state; the apparent violation of the Heisenberg Uncertainty Relation (HUR); and the failure of electrons to automatically decay from atomic levels down to the empty deep levels. Each of these problems (and others) may have now been satisfactorily resolved. For example, the ~100 MeV nuclear-bound electron of the EDO model (based on the accepted relativistic Quantum-Mechanics Klein-Gordon and Dirac equations) satisfies both the virial theorem (for stable orbits) and the HUR (for size and momentum constraints).

The linear-defect model has been proposed as a means of overcoming the EDO problems, but without providing details. Initially, the reason for non-decay from the atomic ground state of hydrogen to the deep orbits was the highly-forbidden photo transition of zero-to-zero angular momentum states. A two-level model of quantum mechanics predicts the relative probability of the deep-orbit population in hydrogen relative to that of the atomic levels at only ~2 parts in 10^9 [40], which is consistent with the forbidden nature of the transition. However, the relativistic Dirac equation does not have such $l = 0$ angular momentum deep-orbit levels, so other reasons for preventing photodecay had to be sufficient, e.g., [40]. They also had to be uniquely resolved in cold-fusion experiments.

The lack of photodecay of atomic electrons to an EDO greatly slows the process(es) for formation of the deep-orbit electrons. Nevertheless, in a two-state model, there would be an easily measured EDO population. In reality, we cannot consider EDO calculations for a two-state system since it appears that the decay process to the EDOs requires a medium and that, in turn, provides a rapid "sink" (via transmutation, e.g., [19], [20], & [21]) for the resulting femto-hydrogen or femto-helium atoms. Populating EDOs in higher-atomic number (e.g., $Z > 8$) nuclei, if possible, would be at a much lower rate. They would result in isotopes with Z-1 and with atomic mass almost indistinguishable from that of the original atoms (e.g., <2 keV out of >16 GeV).

The prior two Syntheses have provided a basis for the proximity between protons or deuterons necessary for fusion. Here we go one step further to look at details when they do get close. The resonant motion in linear and compressive-cluster defects periodically distort the atomic-electron energy levels so that they can overlap. This allows direct electron transfer to different orbitals, including those with angular momentum, and could remove the problem of the angular momentum requirement in photo-emission to the deep orbits. However, no appropriate energetic photons have been observed even in active cold-fusion experiments and there are reasons for that. Nevertheless, new opportunities for energy dissipation present themselves in this highly-compressed, oscillating, environment.

The virial theorem for a 1/r Coulomb potential requires dissipation of excess PE (energy conservation) to establish a stable orbit for an electron decaying from free space or from an excited orbit. Photoemission does this for atomic-electrons. However, there are other processes that will also work. In the highly unstable environment suggested for the above syntheses, photo-emission at characteristic lines cannot be expected. Other means of energy dissipation could include [42]: phonons (the electron between two protons is doing work on both in bringing them together); collision-induced absorption and emission; auger-like processes with nearby electrons; proximity-distortion of energy levels to allow forbidden photo-transitions, and even excitation of low-lying nuclear levels. Some such processes are reversible; most are irreversible. A common feature of the defect models is the periodic proximity effect within the sub-lattice. This characteristic frequency is dependent on the motion of the atoms, not of the much faster electrons as in atomic photo-emission. Does this mean that we should be looking for very-low-energy radiation (e.g. molecular spectra or radio frequencies [43])? Or, is the phonon field the most that we could expect to see?

We have introduced a term in a manner not usually mentioned with calculations of stable atomic energy levels: reversibility. In an s-orbital (with zero angular momentum), the electron passes through the nuclear region every orbit. This periodic change in kinetic and potential energies is reversible. It is reflected in the nuclear structure (and thus in its mass energy) as the velocity-related, bound-electromagnetic, field of the electron changes throughout each orbit. Because the EM energy radiates out from the electron before it is "returned" to the outer limits of its orbit, there is a time lag in the reversible process. This energy is stored as standing waves in the "lagtime" of this oscillating EM field. If conditions are right, this stored energy, along with the new fields associated with the changing KE and PE of the decaying orbit, form a photon that can be emitted from the atom in an irreversible action. Associated with this irreversible action is a reversible action within the nucleus.

The internal structure (and mass) of the nucleus is altered by the change in EM fields of the electron in its new orbit. If the electron is returned to its former orbit by another irreversible action (absorption of a photon), the nucleus can return to its former configuration through a reversible action. Reversibility and irreversibility are defined in this context mainly by timing. This change in nuclear energy is only a small perturbation. However, it is "quantized", not by any resonance within the nucleus, but by the stability of electron orbits outside. Thus, we need to look at magnitudes of changes in electron energy and field strengths, as well as in timing, to see the mechanisms of some of the effects we seek. This is just another form of relativity.

We generally look at photodecay as an instantaneous event. It is not. Even Feynman describes it in one example from his "Lectures" as being a continuous process that might take more than 10^7 cycles per photon (in the decay from excited-electron orbits) to complete. The resulting photon may be considered to be a particle; but, it could be 10^7 cycles long (e.g., 6m by 20ns in the lab frame). Is it a wave or a particle? This has been a silly argument for generations. Again, it is a matter of relativity. The inability to see these effects is an intellectual blindness that can be cured. Nuclear fusion is also considered to be an "instantaneous" event. Is it? Both Schwinger's phonon decay and Storm's "small-photon" decay processes are irreversible "pre-fusion" mechanisms leading to the fusion end-result. Both are encompassed in the above description based on phonon-generated sub-lattice compression-pumping of the bound-electron levels that provides a means of coupling the nuclear-Coulomb energies to the sub-lattice and beyond.

Just as the wave-particle argument has gone unresolved for many people, the "teaching" that nuclear forces are independent of Coulomb forces makes no sense. How can gamma-rays be emitted from excited nuclear levels if electromagnetic effects are divorced from the nuclear effects? Claiming that protons and neutrons are different states of the same particle has a similar problem. These are "stories" that have been embedded in the student's mind for multiple generations now. Experimental evidence alters and even disproves some of these beliefs. However, it appears easier (more efficient?) to accept/believe them than it is to take the time to examine new data and to think things through. After all, it may not be too difficult to assume that the proton is just an excited-state of a hydrogen atom (one with an infinite-orbit, i.e. free, electron). But, it may be even easier for one to accept that electrons cannot exist within a near-nuclear region (because of the Heisenberg Uncertainty Principle) than to look at relativistic effects that can overcome this excuse and open new areas to explore.[4]

As the average linear-H sub-lattice spacing decreases, it also alters the electrons' orbital radii, thus increasing their binding energies. This progressive energy-transfer process can be used to complete a transition from the atomic ground state to a deep-electron orbit for one or more of the bound electrons in the sub-lattice.[5] If this were to happen, the

[4]Nevertheless, in a following paper, one of the present authors (AM) will propose that the neutron might be a highly-relativistic excited-electron state of the hydrogen atom with sub-nuclear orbital radius. Thus, the neutron, proton, and hydrogen atom are all different states of the same atom (particle?).

[5]One reason that atomic electrons may not photonically decay to the deep-orbits is proposed to result from the deep-orbit electrons approaching an anapole configuration with no external EM fields from which to form a photon [41]. Phonon generation may avoid this requirement of external fields.

fusion process follows immediately as pairs of atoms in the affected portion(s) of the sub-lattice collapse together. It is also possible that the energy release of one fusion within the sub-lattice would initiate others (as in stimulated emission). Thus, we see how all of the models mentioned in this paper can participate in an observable cold-fusion result. Nevertheless, since the possible paths are so difficult to quantify over the large range of time, space, and energies, it is difficult to assign relative importance to each of them without more data specific to the proposed processes.

4. Conclusions

(1) Cold fusion could occur in or on the lattice, if a linear defect (or another mechanism) provides a means of multiple hydrogen atoms coming together simultaneously.

- Hydrons (hydrogen or deuterium atoms) in a host-bound, linear, sub-lattice (perhaps as in the δ- and δ'-phases of heavily-H-doped Pd [31], [32]) continually come close together as pairs (longitudinal optical-phonon mode).
- This cyclical pairing of nuclei allows the bound-electron screening of nuclear repulsion to be more effective, over time, than that possible when multiple hydrons come together randomly as in a quasi-free linear array [2] or in Takahashi's Tetrahedral Cluster array [28].

(2) Sinha's calculations of the increase in electron effective mass from lattice effects, as multiple hydron pairs repeatedly come together in a linear defect, gives a much greater depth to the attractive Coulomb potential well (electron/proton) before the repulsive Coulomb barrier (proton/proton) grows at close inter-nuclear distances. This strongly affects the shape of the average potential well experienced by the hydrogen nuclei, which, from Schwinger's paper, can include both the Coulomb contributions of the electrons and protons and the nuclear wells of the nuclei and their components.

(3) Schwinger's model for getting from the D-D pairs in a lattice to an excited ^{4}He nuclear level without the normal neutron fragmentation (to n + ^{3}He) can easily be extrapolated to the ground state. The fact that it could temporarily stabilize at or resonantly tunnel to the known excited states gives a mechanism for the t+p reaction observed in CF experiments where tritium or protons are measured. Nevertheless, this fragmentation result is still much reduced in CF results relative to the fragmentation of normal D-D fusion. Thus, tritium could be a natural result of the CF process, but its relative concentrations would depend on a number of parameters, details of which are yet to be determined. Schwinger's model might have been a first time for a great theoretical-physicist's mind to openly suggest/publish that nuclear forces and electromagnetic forces can couple.

(4) This process could also allow a normal fragmentation process (n + ^{3}He) of conventional D-D fusion to occur at a very much reduced rate, since such fusion is now dependent on: time spent at tunneling distances, proximity of the bound electron(s) to the nuclei, and the actual tunneling lengths. Early in the process, the hydrons (H or D) are not much closer together at closest approach on average than the host-lattice spacing. The longer the process of sub-lattice shrinking goes on (before fusion), the more energy will have been dissipated to the lattice and the lower into the ^{4}He nuclear potential well will tunneling take place. Thus, for a good CF process, early tunneling rates to the higher ^{4}He nuclear states are highly reduced relative to later tunneling to deeper energies.

In summary, a number of the disparate models for cold fusion are converging to provide a coherent picture of at least one mode, but perhaps several, that seems to fit the data and does not violate any physics and chemistry principles involved. Just as the individual models of CF have evolved, it is expected that even these combined models will also evolve.

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References

[1] A. Meulenberg, K.P. Sinha, "Composite model for LENR in linear defects of a lattice," ICCF-18, 18th Int. Conf. on Cond. Matter Nuclear Science, Columbia, Missouri, 25/07/2013, Abstract and presentation slides at **http://hdl.handle.net/10355/36818**, video at **https://www.youtube.com/watch?v=RcTSUJUCRHE**, Updated text (this paper) to be submitted to JCMNS in 2022 as "Composite Model(s) for Low Energy Nuclear Reactions in the solid state: II".

[2] A. Meulenberg, "Pictorial description for LENR in linear defects of a lattice," ICCF-18, 18th Int. Conf. on Cond. Matter Nuclear Science, Columbia, Missouri, 25/07/2013, J. Condensed Matter Nucl. Sci. **15** (2015), 117-124

[3] J. Schwinger, "Nuclear energy in an atomic lattice," in *The First Annual Conference on Cold Fusion*. 1990, Salt Lake City, Utah pp. 130-136 and Z. Phys. D 15 (1990) 221–225

[4] Maly J.A., Va'vra J., "Electron transitions on deep Dirac levels I," Fusion Science and Technol., **24**, N.3, pp.307-318, 1993, http://www.ans.org/pubs/journals/fst/a_30206

[5] Maly J.A., Va'vra J., "Electron transitions on deep Dirac levels II," Fusion Science and Technology, V.27, N.1, pp.59-70, 1995, http://www.ans.org/pubs/journals/fst/a_30350

[6] K.P. Sinha, "A Theoretical Model for Low-Energy Nuclear Reactions in a Solid Matrix," Infinite Energy 29, 54 (2000)

[7] K.P. Sinha, A. Meulenberg, "Lochon Catalyzed D-D Fusion in Deuterated Palladium in the Solid State," National Academy of Science (India) Letters, Vol.30, No. 7&8, 2007 arXiv:0705.0595v1.

[8] K.P. Sinha and A. Meulenberg, "Lochon-mediated Low-energy Nuclear Reactions," J. Condensed Matter Nucl. Sci. JCMNS-6 (2012) 55–63.

[9] K.P. Sinha and A. Meulenberg, "A Model for Enhanced Fusion Reaction in a Solid Matrix of Metal Deuterides," Proceedings of the 14th International Conference on Cold Fusion (ICCF-14) 10-15 August 2008 Washington DC p. 633, https://www.researchgate.net/publication/344772366_A_model_for_enhanced_fusion_reaction_in_a_solid_matrix_of_metal_deuterides_showFulltext=1&linkId=5f8ed899a6fdccfd7b6ec478

[10] A. Meulenberg and K.P. Sinha, "Lochon and Extended-Lochon Models for LENR in a Lattice," *Infinite Energy Magazine*, pp. 29-32, Issue 112, November/December 2013

[11] K.P. Sinha, "Model of low energy nuclear reactions in a solid matrix with defects," PDF "Special Section: Low Energy Nuclear Reactions," Section editors: Srinivasan, M. and Meulenberg, A., Current Science, Vol. 108, No. 4, p 516, 25 Feb. 2015, http://www.currentscience.ac.in/cs/php/feat.php?feature=Special%20Section:%20Low%20Energy%20Nuclear%20Reactions&featid=10094

[12] K.P. Sinha, A. Meulenberg, "Laser stimulation of low-energy nuclear reactions in deuterated palladium", Current Science Vol. 91, No. 7, pp. 907-912, 10/10/06 (03/06, Ref. No. O232) and included in ArXiv (cond. matter) http://arxiv.org/abs/cond-mat/0603213

[13] K.P. Sinha and A. Meulenberg, "Quantum-Correlated Fluctuations, Enhanced Tunneling and Low-Energy Nuclear Reactions in Condensed Matter," 16th International Conf. on Condensed Matter Nuclear Science, Chennai, Feb. 6-11, 2011, JCMNS-8 (2012) pp. 105-114.

[14] A. Meulenberg and K. P. Sinha, "Tunneling Beneath the $^{4}He*$ Fragmentation Energy," presented at 239th ACS National Meeting, San Francisco, CA March 2010, Journal of Condensed Matter Nucl. Sci., JCMNS, 4 (2011) 241–255.

[15] A. Meulenberg and K P Sinha, "Deep-electron orbits in Cold Fusion," 17th International Conference on Condensed Matter Nuclear Science, Daejeon, Korea, 12-17 August, 2012, J. Condensed Matter Nucl. Sci. **13** (2014), 368-377

[16] A. Meulenberg, "From the Naught Orbit to He4 Ground State" 16th International Conference on Condensed Matter Nuclear Science, Chennai, February 6 -11, 2011, JCMNS-**10** p 15 - 29 (2013),

[17] A. Meulenberg and K.P. Sinha, "Deep-Orbit-Electron Radiation Emission in Decay from 4He*# to 4He," 17th International Conference on Condensed Matter Nuclear Science, Daejeon, Korea, 12-17 August, 2012, J. Condensed Matter Nucl. Sci. **13** (2014), 357-368,

[18] A. Meulenberg, "Radiation Coupling: Nuclear Protons to Deep-Orbit-Electrons, then to the Lattice," ICCF-18, 18th Int. Conf. on Cond. Matter Nuclear Science, Columbia, Missouri, 25/07/2013, J. Condensed Matter Nucl. Sci. **15** (2015), 125 – 136
[19] A. Meulenberg, "Femto-atoms and Transmutation," 17th International Conference on Condensed Matter Nuclear Science, Daejeon, Korea, 12-17 August, 2012, J. Condensed Matter Nucl. Sci. **13** (2014), 346-357,
[20] A. Meulenberg, "Femto-Helium and PdD Transmutation," ICCF-18, 18th Int. Conf. on Cond. Matter Nuclear Sci., Columbia, Missouri, 25/07/2013, J. Cond. Matter Nucl. Sci. **15** (2015), 106-117,
[21] A. Meulenberg and J. L. Paillet, "Basis for femto-molecules and -ions created from femto-atoms," ICCF-19, 19th Int. Conf. on Cond. Matter Nuclear Science, Padua, Italy, 15/05/2015, J. Condensed Matter Nucl. Sci. **19**, pp. 202 – 209, (2016),
[22] A.S. Alexandrov, N.F. Mott, Polarons and Bipolarons, World Scientific, Singapore, 1995
[23] P.W. Anderson, "Model for electronic structures of amorphous semiconductors," Phys. Rev. Lett., 34, p. 953, 1975
[24] R.A.Street and N.F.Mott, "States in the gap in glassy semiconductors," Phys. Rev. Lett. 35, p.1293, 1975
[25] E. Storms, "The role of voids as the location of LENR," J. Condensed Matter Nucl. Sci. **11** (2013), 123-141, http://coldfusioncommunity.net/pdf/jcmns/v11/368_JCMNS-Vol11.pdf
[26] https://en.wikipedia.org/wiki/Einstein_solid
[27] T. Barnard, "Applying the Scientific Method to Understanding Anomalous Heat Effects: High Energy D2 Bond from Feynman's Integral Wave Equation," ICCF 18 July 21-27, 2013, University of Missouri Columbia, MO, USA, Abstract and annotated presentation slides at http://hdl.handle.net/10355/36839
[28] Akito Takahashi, "Background for Condensed Cluster Fusion," Proceedings of JCF15, Nov. 1 - 2, 2014, Sapporo, Japan, https://www.researchgate.net/publication/325807810
[29] A.P.B. Sinha and K.P. Sinha, "Electronic motion in some polar semiconductors," Ind. J. Pure and Appl. Phys. 1, 286 (1963)
[30] I.G. Lang and Yu. A. Firsov, "Kinetic theory of semiconductors with low mobility," Sov. Phys. JETP, 16, 1301 (1963)
[31] M.R. Staker, "Coupled calorimetry and resistivity measurements, in conjunction with an emended and more complete phase diagram of the palladium - isotopic hydrogen system," J. Cond. Matter Nucl. Sci. **29** (2019) 129-168.
[32] M.R. Staker, "A Model and simulation of lattice vibrations in a superabundant vacancy phase of palladium-deuterium," Mod. Sim. in Mat. Sci & Engr 28. (2020) https://doi.org/10.1088/1361-651X/ab9994
[33] S.H. Patil, "Hydrogen molecular ion and molecule in two dimensions," J. Chem. Phys. 118, 2197 (2003).
[34] M. Motta et al., (Simons Collaboration on the Many-Electron Problem), "Ground-State Properties of the Hydrogen Chain: Dimerisation, Insulator-to-Metal Transition, and Magnetic Phases," Physical Review X 10, 031058 (2020)
[35] P.L. Hagelstein, "Bird's eye view of phonon models for excess heat in the Fleischmann–Pons experiment," *J. Cond. Mat. Nucl. Sci.***6** (2011) 169
[36] J.L. Paillet, A. Meulenberg, "A study on electron deep orbits by quantum relativistic methods," pp. 301-331, in Cold Fusion, Advances in Condensed Matter Nuclear Science, Edited by Jean-Paul Biberian, 2020 Elsevier Inc. and J.L. Paillet, A. Meulenberg, "Special relativity: the source of electron deep orbits," Foundations of Physics, Feb. 2017, Vol. 47, Issue 2, pp 256–264.
[37] https://en.wikipedia.org/wiki/Dimer_(chemistry)#Covalent_dimers
[38] https://en.wikipedia.org/wiki/Phonon#Acoustic_and_optical_phonons
[39] K. P. Sinha and A. Meulenberg, "A model for enhanced fusion reaction in a solid matrix of metal deuterides," Slide 8 of an annotated copy of presentation at ICCF-14, Aug. 2008, Wash., DC, https://www.researchgate.net/publication/344772366_A_model_for_enhanced_fusion_reaction_in_a_solid_matrix_of_metal_deuterides_showFulltext=1&linkId=5f8ed899a6fdccfd7b6ec478
[40] R. A. Rice, Y. E. Kim, and M. Rabinowitz, "Comment on 'Electron Transitions on Deep Dirac Levels I,"' *Fusion Technol*, 26, 110 (1994).
[41] V. Savinov, "Light emission by accelerated electric, toroidal, and anapole dipolar sources," Phys. Rev. A **97**, 063834 (2018).
[42] see examples in the references of S. X. Hu *et al*., "Interspecies radiative transition in warm and super-dense plasma mixtures, "Nature Communications | (2020) 11:1989 | https://doi.org/10.1038/s41467-020-15916-3 | www.nature.com/naturecommunications.
[43] M.R. Swartz, "Active LANR Systems Emit a 327.37 MHz Maser Line," Journal of Condensed Matter Nuclear Science 33 (2020) 81–110.