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Research Article

Theoretical basis for Nuclear-waste Remediation with Femto-atoms and Femto-molecules

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Abstract

The relativistic quantum mechanics equations for atoms predict deep electron orbits with radii in the femto-meter range in addition to the known atomic orbitals. In prior papers, we have explored a model for the deep-orbit solutions of these relativistic equations and of the resulting hydrogen and helium femto-atoms (and even femto-molecules). One prediction of this model, based on observations from successful cold fusion (CF) results and previously mentioned, is that of hard-radiation-free transmutation. An extension of this important feature is that of the relativistic long-range electromagnetic forces of the deep-orbit electrons that can draw a femto-atom or molecule through a lattice to an excited or unstable nucleus. The earlier papers on this topic assumed the deep-orbit electrons to have kinetic energies in the 1–2 MeV range. Our recent work has replaced and/or augmented the low-MeV range with ∼100 MeV values. These highly relativistic electrons create basically the same remediation characteristics as those at 1–2 MeV. The selective attraction of mobile femto-atoms or molecules to radionuclides means that, not only their transmutation products but, all radioactive materials in the vicinity are preferentially made to decay by multi-particle, but fast, processes. This ability to so neutralize such materials explains some of the outstanding questions about low-energy nuclear reaction (LENR) results, such as why known characteristic decay products of observed neutron-activated transmutations are not seen. Presently, the model is only a possible explanation of observations. This paper is not a "how-to" document. It seeks to consolidate, update, and expand our prior theoretical material on selective transmutation and nuclear-waste remediation that could lead to suggestions for experimental testing and possible confirmation of the proposed model.
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1. Introduction

The s-orbits of atomic electrons pass through the atoms' nuclear region in which the kinetic energy gained from the Coulomb potential of the nuclear and electron charges briefly makes such electrons relativistic. The relativistic

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Schrödinger (Klein–Gordon or K–G) and Dirac equations predict deep electron orbits with radii in the femto-meter range In such orbits, the electrons are continuously relativistic; but, no standard models predict how electrons can get there or what happens when/if they do so. In prior papers, we have explored the nature of deep-orbit solutions of the relativistic equations [1–4] and of the resulting femto-atoms (and even femto-molecules) [5–7]. Since the existence of the deep-orbits has not been experimentally observed and the mathematics of the relativistic-quantum-mechanics equations leading to the deep orbits has been contested, this whole topic could be considered speculative. Nevertheless, the "normal" solutions to these equations are fundamental to quantum mechanics (QM) because they have been validated experimentally. Analysis shows the deep orbits, if populated, to be both self-consistent and consistent with experimental observations in Cold Fusion (CF)

One prediction of our electron deep-orbit (EDO) model, based on observations from successful cold fusion results and mentioned in several of the above references, is that of hard-radiation-free transmutation. An extension of this important feature is that of the relativistic long-range electromagnetic (EM) forces of the deep-orbit electrons [8,9], which can draw a femto-atom or molecule through a lattice to an excited or unstable nucleus. This attraction provides the basis for selective remediation of radioactive waste.

The selective attraction of mobile femto-atoms or molecules to radionuclides means that, not only transmutation products but, all radioactive materials near the source of neutral femto-atoms are preferentially made to decay by multi-particle, but fast, processes.[a] This ability to so neutralize such materials explains some of the outstanding questions about low-energy nuclear reaction (LENR) results, such as why characteristic decay products of known transmutations (e.g., those by neutron activation) are not seen. It is also a means of further validating the electron deep-orbit model of Cold Fusion. Presently, the model is only a possible explanation of observations. But, confirmation of transmutation in biological systems [10] introduces other possibilities that may, or may not [11], be consistent with the EDO model.

If the substrate in a CF-active system is intentionally doped (with specific isotopes and radioactive elements), it should be possible to direct, and thereby determine and quantify details: of the CF processes, of the subsequent transmutation pathways and of hard-radiation mitigation. This paper[b] seeks to consolidate and expand our prior survey [12], which includes references to our work on selective transmutation and nuclear-waste remediation and to introduce into the topic a recent finding of much higher kinetic-energy deep-orbit electrons [3] (and the references therein) than had been considered in prior works on the topic.

Section 2 provides some further background as to why early cold fusion results have led to thoughts of a different process for transmutation. Section 3 (and its subsections) provides details on the specific mechanisms involved with a model of cold fusion that invokes the existence of deep-orbit electrons and resulting femto-atoms as the principal actors in the different fusion process, the high mobility of an active agent, the transmutation of lattice nuclei without expected radiation, and the greater attraction of the active agent to radionuclides within the lattice. This is followed by a brief discussion of the heuristics and limitations of quantum mechanical models to address these mechanisms and a summary list of the key points of the paper.

[a]Multi-particle interactions are generally low probability because of the timing requirement that all interacting particles must be together at the same place and time (or, at least, within a narrow window). The EDO, when populated, provides constant proximity of multiple bodies and therefore fulfils this simultaneity requirement 100% of the time. Furthermore, it will provide additional reaction pathways and will often increase reaction rates by reducing or eliminating barriers in the normal interactions. Often, the model used here is a semi-classical picture of a point-like particle. Thus, an $l = 0$ electron will transit the nuclear region; but, over time, this trajectory (which has a frequency dependent on electron velocity and orbit and which has no angular dependence) will trace out the isotropic distribution function, with a peak at $r = 0$, generally pictured for the s-orbital.

[b]Work presented at ICCF-21, The 21st International Conference for Condensed Matter Nuclear Science, 3–8 June, 2018, Fort Collins, CO, USA.

2. Basis for CMNS Nuclear-waste Remediation

We have proposed that relativistic deep-orbit electrons are the basis for all CF results. The ability of such electrons to initiate and participate in nuclear fusion and radiative decay processes, generally without the normally-observed processes of conventional nuclear physics, leads us to the topic of this paper. The path to this proposal begins with the Pons and Fleischman electrochemical work with deuterium [13] that led to the observation of heat in excess of that possible from chemical reactions. In subsequent experiments, it was found that, associated with this excess heat, the expected product ratio of fusion of two deuterons was not the same as was well-known for the D+D reaction. Instead of the normal neutron to proton ratio, n/p = ~50/50, results for D+D $\rightarrow$ ^{3}He + n and ^{3}H + p, the neutron decay path was suppressed by many orders of magnitude (6–8) relative to the proton decay path. Furthermore, even the tritium results of the proton decay path of D+D were orders of magnitude lower than would be expected for the excess heat measured. Thus was demonstrated the first examples of altered-decay processes associated with transmutation via Cold Fusion. Almost from the beginning of Cold Fusion, the topic was publicly rejected by those who "knew" what could happen at the atomic, the molecular, and the nuclear levels. Their major arguments have now been countered on the theoretical level (e.g., [14]) and by thousands of experiments. The theoretical models and experimental results open up a new approach to the transition region between atomic and nuclear physics. Their understanding can now be extended into other areas.

In the years of experimental efforts to reliably reproduce the Cold Fusion heat effect and to understand its operative mechanism, it became clear that other transmutations were also taking place [15]. Again, the expected gamma-decay radiations from transmutation products (i.e., those known from neutron activation) were not observed. Initially, this lack of observables was used by skeptics to deny that transmutation had occurred or to claim that the "strange" isotopes found in CF experiments were due to contamination. It was attributed by some to the low rates of cold fusion. This latter attribution was despite the many comments (generally to debunk the claims of measured excess heat) about radiation killing everybody in the laboratory, if the measured heat was really from transmutation. With the accumulated evidence for ^{4}He being a dominant product of cold fusion and having excess heat produced being proportional to the determined production of ^{4}He [16], the standard model for DD fusion had to be recognized as limited in scope. Thus, DD fusion (the transmutation of D+D $\rightarrow$^{4}He) became a key source of information about both the fusion/fission processes and the suppression of radiation and nuclear-fragmentation processes in CF-induced transmutation. Moving beyond the "anomaly" of ^{4}He production, isotopic profiles of cathodes from excess-heat-producing experiments showed both the decrease in certain "natural" isotopes of the substrate elements and the increase in others that would be considered logical transmutation products [15]. This led to the thought that, associated with heat production in cold fusion, nuclear remediation might be possible. *The further observations (particularly in H+H $\rightarrow$ D cold fusion results with NiH) that the "substrate isotopic distribution did not show proportionate changes" pointed to selective transmutation*. Was this a result of differences in capture cross sections for some "product" of Cold Fusion? What mechanism(s) can be considered to be responsible for such selectivity?

3. Deep-orbit Electrons and their Interactions

The relativistic QM equations give an electron deep orbit (EDO) with a binding energy for hydrogen at BE = –509 to –507 keV [17] when an electron with or without spin and a point nucleus is assumed. However, the equations do not provide specific information on the electron energies (kinetic and potential). This must be found based on other considerations. Therefore, the proposed deep-orbit electrons are relativistic with model-dependent kinetic energies of $1 < \text{KE} \leq \sim$100 MeV. The lower limit is established by the minimum requirements for D + D $\rightarrow$ ^{4}He with reduced or zero fragmentation. It is what had been assumed in our prior work. The upper limit is established by recent work with the assumption that the equality in the Heisenberg Uncertainty Relation (HUR) is obeyed [1,18]. Values of KE = ~100 MeV are possible based on both the virial theorem for a $1/r$ Coulomb potential and on the inequality in the

HUR; but, for our present purposes, the 100 MeV value is representative of a high-KE deep-orbit electron. The failure of the low-MeV KE values (representative of a low-KE deep-orbit electron) to obey the HUR is to be addressed in detail elsewhere.

Our prior work on nuclear remediation was based on the lower limit value of KE. In the present work, we extend that and include the high-KE option of the EDOs to see if it is also consistent with the prior work. The recent work looks at additional effects that are only 2nd and 3rd order for atomic electrons. However, for femto-atoms, they could dominate the orbits. A deep-orbit electron's proximity to the nucleus greatly lowers the electric-dipole moment (but not the spin effects? See below and in [18]) of the electron/nucleus pair. The small orbital-dipole moments reduce both the far-field magnetic effects and the electric-dipole effects of these electrons relative to those from atomic electrons.

If nuclear spin is included in the relativistic model, then there are additional attractive and a repulsive potentials to consider [18]. An additional attractive potential draws the electron closer to the center of the nucleus, but may raise the actual potential at that location since any repulsive centrifugal potential must be overcome to shrink the EDO toward the center. Both effects alter the virial theorem for stable orbits.

In the present model, we assume that spin requires a finite size "body" and, as a test point (a relativistic charged body with spin) is moved close to the center of that body, its effects are diminished from those based on the standard radial dependence of the spin–spin interaction. The "overlap" of two such spinning bodies will more rapidly diminish the spin–spin, S–S, interaction as $d > 0$. The centrifugal force on a deep-orbit electron, a non-zero perturbation of the $l = 0$ atomic quantum number, also diminishes with overlap of the orbiting body with the center of rotation. Nevertheless, this latter is only a single-body effect and therefore does not decrease as rapidly as does the two-body S–S effect.

The high-energy option [18] of the model would allow the deep-orbit electrons to be energetic enough to fit the Heisenberg Uncertainty Relation (HUR). Since the relativistic equations do not specify the KE and PE of the deep-orbit electrons, but only the binding energy, BE, it is possible to have a relatively low BE (e.g., ~ -500 keV) , when both KE and |PE| are large (e.g., $\sim$100 MeV). This condition is also consistent with the relativistic virial theorem [19] that specifies, for stable Coulomb orbits, a condition KE $\rightarrow$ PE as $v \rightarrow c$. Thus, the extreme energies might exist within the same orbit (i.e. one with the same binding energy, but not necessarily the same orbital geometry and average radius) and still satisfy the relativistic equations.

The relativistic virial theorem for a pure $1/r$ Coulomb potential gives a relationship between its orbital kinetic and potential energies of KE = –(γ/(γ+1))PE. For an electron with KE = $\sim$100 MeV and $\gamma = \sim$200, then PE = –KE/(γ/(γ+1)) = –(201/200)KE. Thus, |BE| = |PE| − KE =~ 0.5 MeV. For an electron with only KE = $\sim$1 MeV, then $\gamma = \sim$3 and |PE| = KE/$(3/(3+1)) = 4$KE/3. Thus, |BE| = |PE| − KE <~ 0.35 MeV. This is not consistent with the virial theorem for a Coulomb potential. However, for an orbit within the multi-fermi range of a nucleus, there are too many additional forces to consider before assuming a 1/r potential in the near-nuclear region.

The interactions of the deep-orbit electrons with the charged nucleon components have never been significantly explored because this deep-orbit has not been accepted since early rejection of the neutron model as a "proton plus electron". That rejection preceded, by many decades, more-elaborate models for the internal structure of the nucleon. Nevertheless, if quarks (and their components?) are charged, then it would be impossible for the deep-orbit electrons not to interact strongly with them. However, if the vibration or orbital frequency[c] of these electrons is so high that it

[c]In the K–G deep orbits, the $l = 0$ orbital electron transits the nuclear region and thus may be said to vibrate through the nucleus rather than orbit it. In the Dirac solutions, EDO electrons never fully transit the nucleus. Nevertheless, it might be said to vibrate, as it reflects between the attractive and repulsive potentials about the nucleus, even as it moves about it in a rosette rather than in an elliptical orbit. The vibrational frequency can be higher than the rotational frequency and it could be very much higher than the deBroglie frequency. This is the basis for considering lower kinetic energy EDOs (e.g., KE $<$ 2 MeV) that might violate the HUR based on $\hbar$. The deBroglie frequency would only be a perturbation on this non-HUR deep orbit.

might greatly exceed that of quarks, then it might not be "seen" by them. In this case, it is unlikely that any effective dynamic interaction would be with the nucleon or even its quarks rather than with any charged sub-components. Without knowledge of the frequency nature of spin and its source, we cannot say that the deep-orbit electron's S–S interactions with the nucleons or quarks can be dominant, diminished, or ruled out. Thus, speculation as to the nature of sub-nuclear components, based on coincidences encountered in trying to explain observed CF phenomena, may not be out of place.

The orbital or vibrational frequencies of the deep-orbit electron level(s) could be comparable to that of the nucleons, quarks, and/or subcomponents. Thus, they would interact with the nucleons and components to explain the transfer of energy from the nucleus to the deep-orbit electron. This transfer of energy from the potential energies of a nucleon to the kinetic energy of the electron is basic to the change in mass of the deuterons that is needed to model the new pathway to ^{4}He from D–D Cold Fusion [8]. *It also explains the mechanism of energy transfer from excited nucleons to the lattice and the mechanism of transmutation without emission of energetic radiation or particles* [6]. The following sections provide details of how this transfer may take place and why it is a unique property of the deep-orbit electrons.

3.1. Deep-orbit electrons and their interactions outside of the nucleus

Relativistic deep-orbit (EDO or deep Dirac level, DDL) electrons have strong long-range electromagnetic (EM) forces and fields [8,9]. We look at the maximum-strength **E**-fields based on some assumptions[d] for application of the Liénard–Wiechert potentials [20] and for calculating the maximum values of the fields. One assumption is that the static potential and fields of the nucleus are small relative to those of the relativistic electron's high velocity and acceleration. Therefore, we can generally ignore the proton's essentially static charge and the dipole nature of the electron/nucleus pair. The general expression for the electric field is:

$$\overrightarrow{E}(\overrightarrow{x},t) = q\left(\frac{\overrightarrow{n}-\overrightarrow{\beta}}{\gamma^2(1-\overrightarrow{\beta}\cdot\overrightarrow{n})^3R^2}\right)_{\text{ret}} + \frac{q}{c}\left(\frac{\overrightarrow{n}\times[(\overrightarrow{n}-\overrightarrow{\beta})\times\overrightarrow{\dot{\beta}}]}{(1-\overrightarrow{\beta}\cdot\overrightarrow{n})^3R}\right)_{\text{net}}. \tag{1}$$

The maximum value for the first term on the right-hand side (RHS) depends strongly on the velocity relative to c ($\boldsymbol{\beta}$ =**v**/c) and on the direction the electron is moving relative to the unit vector ***n*** pointing from the "retarded" source toward the maximum field. For highly relativistic orbital motion under these assumptions, which include: the velocity being parallel to ***n***; $v \to c$; $\boldsymbol{\beta} = \mathbf{v}/c \to \boldsymbol{n}$; and $\boldsymbol{\beta}\cdot\mathbf{n} \to 1$. Since $\gamma^2 = 1/(1-\beta^2) = 1/(1-\beta)(1+\beta)$, the first term reduces to $q(1+\beta)/(1-\beta)R^2$, where R is the distance from the charge to the test point when the energy was emitted.

The last term depends on both the velocity *and* on the acceleration of the electron as vectors. [e]

The maximum value for the second term becomes $2^{1/2}q\,\dot{\boldsymbol{\beta}}/c(1-\boldsymbol{\beta}\cdot\mathbf{n})^{3/2}R$. Thus this term increases, relative to the velocity term, as the velocity, the acceleration, and the decrease in R. We need not concern ourselves with the retarded (ret) values of the two terms because we have assumed circular orbits, only maximum values, and R is much greater than either the dipole moment or the orbital radius r. Therefore, neither $\boldsymbol{\beta}\cdot\boldsymbol{n}$ nor R change much with the retarded-time correction. Since the following description of fields provides only a crude approximation to the real world at these dimensions, these assumptions are also loose. In particular for near-field values, the dipole moment established by the electron orbit may be comparable to the distance from the dipole center to the test point and thus the

[d] As we use the semi-classical model of the electron for the orbital picture, we use classical electrodynamics here for the description of electric fields generated by moving and accelerating point-like relativistic electrons.

[e] With the same assumptions as above and also assuming the (circular-orbital) acceleration $\dot{\boldsymbol{\beta}}$ to be at right angles to the velocity (and thus to ***n***), then the second term becomes $(\boldsymbol{n}\times\boldsymbol{\beta})q\,\dot{\boldsymbol{\beta}}/c(1-\boldsymbol{\beta})\cdot\boldsymbol{n})^2R$. At small angles between **n** and $\boldsymbol{\beta}$ and $\boldsymbol{\beta}\to\mathbf{n}$, then $(\mathbf{n}\ \boldsymbol{\beta})/(1-\boldsymbol{\beta}\cdot\mathbf{n}) \to\sim (2/(1-\boldsymbol{\beta}\cdot\mathbf{n})^{1/2}$ (calculated) and $(\mathbf{n}\times\boldsymbol{\beta})/(1-\boldsymbol{\beta}\cdot\mathbf{n}) \to\sim (2/(1-\ \boldsymbol{\beta}\cdot\boldsymbol{n}))^{1/2}$ $(\boldsymbol{n}\times\boldsymbol{\beta}\ /(1-\boldsymbol{\beta}\cdot\boldsymbol{n})^2 \to 2^{1/2}/(1-\boldsymbol{\beta}\cdot\boldsymbol{n})^{3/2}$.

distances and directions from the electron to the test point are not properly defined as assumed for $R \gg r$. Just as the applicability of the $1/r$ Coulomb potential must become suspect at nuclear distances, the size of the electron becomes important and must also enter consideration, particularly when $R \leq \sim R_c$ (the classical-electron radius at ~2.8 fm).[f]

The first RHS term in Eq. (1) (giving the static Coulomb term when $v \ll c$) has a $1/R^2$ dependence and the second (including the radiation fields) has a longer-range $1/R$ dependence. Thus, the second term dominates for the far-field (large-R) effects from near-nuclear deep-orbit electrons with their near-c velocities and femto-meter-range (high-acceleration) orbits. The normal interpretation of the radiation far-field is where the **E**-field has become independent of the source (i.e., as a photon). However, we now make a different assumption. Since, in the source region of the maximum $1/R$ **E**-field, the electron has a acceleration component in the ***n*** direction, the radial decay of field strength is not strictly $1/R^2$, it is faster. Thus, this far-field energy is actually still bound to the charge [21]. This assumption is supported by the fact that no (photonic) radiation is observed from ground states (where there is not enough angular momentum in any decay to form a photon) or states with only filled states below them. Electrons in such states have a strong dynamic (relativistic?) EM field about them that is in addition to the static-charge field. This bound-field energy is included in the effective mass of the electron [22]. Decay, via photonic radiation of this dynamic energy, from excited states has a probabilistic nature, not a continuous one as the equations and classical electrodynamics might imply. (However, significant change in field strength is continuous during electron transits of the nuclear region and periods of transition between states.) Again, this bound dynamic field, represented by the $1/R$ term, while an energy source, is not generally radiant. When there is no radiation loss from this field, then, it must form a standing wave (evanescent wave) with an EM return wave to balance the outgoing wave and the second term must be considered as a source of far-field energy. Again, the field energy is still bound to the source charge unless/until it is absorbed by a nearby charge or radiated away as a photon. We will thus use this term (variously called the EM, the radiation, and the far-field term) to determine, below, the intense **E**-fields from relativistic deep-orbit electrons.

To gain some perspective on the relative electric-field strengths of the two terms, we can look at the approximate ratios for different orbits and particles. By comparing the two terms of eq. 1 for various conditions, thus using the extremes (Coulomb vs. radiation, velocity vs. acceleration, or near-field vs. far-field terms), it is possible to get a feel for why some things can be ignored when doing atomic physics; but, they become important for the deep-orbit electrons. For our approximations here, we will assume: that near-nuclear orbits are circular; that we can ignore non-Coulomb forces; that the "hidden" γ's cancel in the "$\dot{\boldsymbol{\beta}} = \mathbf{a}/c = \gamma$ F/$\gamma m_0 c = (e^2/R^2)(1/m_0 c)$" term; and that the classical-electron radius $R_c = e^2/m_0 c^2$. Thus, $\dot{\boldsymbol{\beta}} = cR_c R^2$. For example, in comparing the two terms for atomic-electron **E**-fields in the atomic or Angstrom range, R_a, comparable to the Bohr orbit, $R_{\mathbf{B}}$,we have (ignoring factors of 2 and with $v \ll c$):

$$\frac{\text{Atomic Coulomb}}{\text{Atomic EM near-field}} = \frac{\sim q/\gamma^2(1-\beta)^2 R_a^2}{2^{1/2} q\dot{\beta}/c(1-\boldsymbol{\beta}\cdot\boldsymbol{n})^{3/2} R_a} = \frac{\sim R_a}{R_c} = \frac{\sim 10^{-10}}{3\times 10{-}15} = \sim 3\times 10^4. \tag{2}$$

For an atomic electron, the large dominance of the Coulomb field over the non-relativistic radiation field at atomic/lattice distances (e.g. ~100 pm), with the ratio of the two terms mathematically reducing to the distance

[f] Defining electrons as being point-like may become a problem when its infinite-range electric fields are being considered. However, if we consider 99% of its rest mass to being within the classical radius and the **E**-field amplitude being reduced to ~1% at the Compton radius of the stationary electron, then we have some idea of the range of validity for our calculations. If the electron is within a Compton wavelength of a proton, the joint **E**-field is already distorted and a dipole representation may be useful. If the deep electron orbit is only a classical-electron radius from a proton, then the sum of Coulomb potentials drops quickly and there is relatively little mono-pole **E**-field left outside the 10 fm range. For most purposes, in the far field, the combination appears neutral. How the acceleration term, in this extreme near-field location, fits reality (and the Liénard–Wiechert potentials) must be left for others to determine. It even raises the question of "when does a pair of leptons become a boson?"

of the test point from the charge relative to the classical electron radius, or R_a/R_c, indicates why the latter term can generally be ignored in the lattice.

A similar comparison, but one for the **E**-field of a deep-orbit electron (in the deep-Dirac level, DDL) with a near-nuclear test point, indicates that the Coulomb and EM terms are nearly of the same order of magnitude in the near field. In this very rough approximation, we have: assumed a near-circular orbit, $R_c/2 < R_{DDL} <\sim R_c$, and used a gamma of 3–4 (as in the earlier publications). Thus, from Eq. (2), modified for the deep orbit (and still cancelling the velocity terms and using $\dot{\boldsymbol{\beta}} = cR_c/R^2$ with $R = R_c$:

$$\frac{\text{DDL Coulomb}}{\text{DDL EM near-field}}(\gamma = 3) \;=\; \frac{\sim q/\gamma^2(1-\beta)^2 R_c^2}{q\dot{\beta}/c(1-\beta)^{3/2}R_c} \;=\; \frac{\sim c}{\gamma^2(1-\beta)^{1/2}\dot{\beta}R_c} \;=\; \frac{\sim 1}{3^2(1-0.94)^{1/2}} \;=\; \sim 0.5. \quad \text{(3a)}$$

For the deep-orbit electron, the two terms are of the same order-of-magnitude. Updating the results from our more recent work [18], which gives an average gamma of ∼200 to make the deep-orbit electrons obey the HUR, complicates things because the actual orbit of the electron is unknown and, if not circular, the velocity (and thus gamma) changes cyclically, rapidly, and greatly. Nevertheless, with the same assumption of a circular orbit as above, the ratio of near-fields decreases by nearly two orders-of-magnitude. From (3a), with $\gamma = 200$:

$$\frac{\text{DDL Coulomb}}{\text{DDL EM near-field}}(\gamma = 200) \;=\; \frac{\sim c}{\gamma^2(1-\beta)^{1/2}\dot{\beta}R_c} \;=\; \frac{\sim 1}{200^2(1-0.9999876)^{1/2}} \;=\; \sim 7\times 10^{-3}. \quad \text{(3b)}$$

On the other hand, the effective Coulomb potential for the highly relativistic DDL electron is increased relative to the nearly static potential of (3a) by ∼70 times, while the acceleration changes very little.[g] Whatever the details, it is clear that, in the near-field case for deep-orbit electrons, the acceleration term nearly equals or exceeds the velocity term. At large R, the $1/R$ EM field is correspondingly much greater than the $1/R^2$ Coulomb field. *This "long-reach" of the DDL-electron electric field is critical information when trying to explain both the energy transfer from the nuclear region to the lattice and the mechanism for selective remediation*.

How does the DDL far-field compare with atomic electron near-fields? The far-field vs. near-field regime is determined by the distance relation to the orbit. Thus, the atomic near-field, at $R_a =\sim 10^{-10}$ m, is in the deep-orbit far-field. The classical-electron radius ($R_c < 3$ F) is still the DDL near field. The atomic electrons for light nuclei are non-relativistic and therefore are controlled by Coulomb's law in both near- and far-field. The DDL-electron far-field is dominated by the $1/r$ acceleration term. If this is primarily dependent on the Coulomb potential, there are still two things to consider. For a relativistic orbit and assuming $\mathbf{a} = \mathbf{f}/\gamma m_0$ (with the acceleration normal to the velocity vector), then the force can be from the relativistic Coulomb potential, $V_{eff} = \gamma V + V^2/2m_0c^2$, and the effective, or Lorentz, mass (γm_0) is also increased. However, the relativistic effect on force and effective mass would be strongly dependent on the shape of the orbit and the other potentials within this region. With $R_a =\sim R_{\mathbf{B}}$ and $R_{ddl} = \sim R_c = \sim R_{\mathbf{B}}/137^2$:

$$\frac{\text{DDL EM far-field}}{\text{Atomic Coulomb}} \;=\; \frac{q\dot{\beta}/c(1-\beta)^{3/2}R_a}{q/R_a^2} \;=\; \frac{cR_c}{R_{DDL}^2}\frac{R_a}{c(1-0.9)^{3/2}} \;=\; \frac{\sim 137^2}{0.1^{3/2}} \;=\; \sim 6\times 10^5. \quad \text{(4)}$$

Thus, at lattice dimensions ($>R_a$), the DDL-electron influence is nearly a million times stronger than that of the atomic-electron Coulomb potential. Furthermore, at its ultra-high frequencies (at nuclear levels), this E-field strength cannot be as easily screened by bound lattice electrons as at atomic frequencies. Therefore, while one can generally

[g]Since this factor of ∼70 is close to the difference in γ's between the two cases, it is possible that one of the relativistic conversions (e.g., $\dot{\boldsymbol{\beta}} = a/c = f/mc$) needed one more or less γ than used in the above calculations.

ignore atomic-electron effects beyond their nearest neighbors, *the influence of a DDL electron can be seen for a significant volume of the lattice about it.* For the case of a DDL electron obeying the HUR, e.g., for a highly relativistic DDL electron in the near-nuclear region, it is necessary to consider the effective Coulomb potential, $V_{\rm eff} = \gamma V + V^2/2mc^2 =\sim \gamma V_{\rm cb}$, for $\gamma =\sim 200$ [1]. For this large gamma, $v/c =\sim 0.99999$ and the $1/(1-\beta)^{3/2}$ term increases from that of Eq. (4) (of ∼32) to over 30 million. Assuming the gammas cancel in the acceleration term, it does not change much (perhaps $R_{\rm ddl}$ reduces to $\sim R_{\rm c}/2$) and the ratio of the two fields of Eq. (4) becomes $\sim 10^{12}$.

If calculations based on these equations and assumptions are valid, the maximum DDL **E**-field from $\sim 1 <$ KE < 2 MeV and from 100 MeV electrons are, respectively, very large and extremely so. Both are at such a high frequency that they will only cause a dither in the lattice-electron orbitals [8]; thus, there is generally no net energy transfer. Nevertheless, if timed and oriented correctly, such a dither in a lattice atomic-electron orbit passing through its nuclear region could shift an electron to a much different orbital. This huge **E**-field could excite, or even strip from their nuclei, a small portion of s-orbit atomic electrons throughout a macroscopic lattice. Such a scenario would account for the large-volume dissipation of excited-nuclear energy needed to explain some of the observed cold-fusion experimental results (such as the low-energy X-ray distribution). If, in a much smaller local lattice volume, the s-orbital electrons are continually (but briefly) removed from their orbits, then state inversion and consequential lasing is possible. Such lasing has been observed in cold-fusion experiments.

Because the DDL orbital frequencies are so high, such electrons would interact with nucleons (directly or via their sub-components) more readily than with lattice electrons. However, because of the mass differences between the DDL electron and nucleons, the energy transfer at each interaction is not great unless resonant conditions exist between the nucleons and/or their sub-components and the DDL electrons. The many and diverse nuclear forces and interactions may permit conditions that produce such resonances. The various shapes of these nuclear potentials alter the probability of significant non-photonic energy transfer [9]. *Such resonances become the basis for the transmutation and selective-remediation models*.

The interaction of DDL electrons with charged and spinning relativistic sub-nucleon components (i.e., quarks and their parts) would perhaps be the greatest interaction of the deep-orbit electrons with both the parent nucleus and the lattice nuclei. This interaction introduces a new perspective on nuclear physics and must be examined closely in terms of what is known from decades of experimental results. It may require an adjustment of, or modification to, the present models of nuclear forces and interactions. A major consideration must be that of the nature of the nucleon charge and its response to a deep-orbit electron. Polarization of the nuclear charge by the proximate electron produces a modified dipole, rather than the monopole fields calculated above. This greatly reduces (perhaps by orders of magnitude) both the amplitude and range of the fields described. The actual amount of reduction cannot be calculated based on present information for the nucleons. Nevertheless, *the residual peak-field intensities in the lattice from the DDL electrons, relative to those normally experienced from atomic electrons, should still be immense* and are the basis of this paper.

3.2. Neutral femto-atoms and molecules

The proposed neutral femto-atoms and -molecules can explain the different processes of cold fusion in both the palladium (Pd) and nickel (Ni) systems. Their deep-orbit electrons provide the means for allowing hydrogen femto-atoms and paired femto-D 'molecules' to penetrate both the electron cloud and the Coulomb barrier about lattice atoms and nuclei, respectively. Nevertheless, there are both similarities and differences in the production and activity of the proton- and deuteron-based femto-bodies [6,7].

A single femto-atom can be formed if the atomic electron of a hydrogen atom (H or D) can tunnel[h] or decay into

[h]Tunneling may be a misnomer here. There is neither physical-potential nor centrifugal barrier between the atomic s-orbital levels and the DDLs. However, there is a barrier of sorts in the inability of the atomic ground state's (an $l = 0$, $k = 1$) s-orbital to provide the angular momentum required

the deep orbit about its nucleus. Such femto-atoms can either fuse with lattice nuclei or combine in a new chemistry to form neutral femto-molecules or positive femto-molecular ions. It is also possible for femto-atoms to fuse with atomic nuclei or perhaps to combine with normal atoms to form mixed, neutral molecules. Thus, hydrogen-based femto-bodies can be femto-atoms H# and D#, femto-molecules H##2 and D##2, or the femto-molecular ions H#p+, H#d+, D#p+, and D#d+, where each # indicates a deep-orbit electron in the atom, ion, or molecule. The mixed molecules, H#2, D#2, HD#, and H#D, contain femto-atoms, but are atomic-scale quasi-molecules because the femto-atoms share an atomic electron in addition to their single deep-orbit electron. These mixed molecules could be the simplest of the halo nuclei that have been observed and measured for several decades. Deuterium could be considered to have the lightest halo nucleus since the two nucleons spend more time outside the nuclear potential than inside.

HD# and H#D are the same mixed-molecule because both the atomic and deep-orbit electrons are shared equally between the two nuclei. They will act, and be measured, as ^{3}H unless very accurate (e.g., spectroscopic) measurements are made. The neutral femto-atoms or femto-molecules will act as stable, but strong, transmutants. They would move through the lattice and into a nucleus as easily as would free neutrons or poly-neutron bodies. *It is this high mobility of the femto-particles that would make them so important in nuclear-waste remediation*. However, there are differences between femto-atoms or molecules and neutrons or poly-neutrons in both their lattice transport and in their interaction with nuclei.

The deep-orbit electron model of CF for D–D fusion proposes that deuterium atoms either come together as femto-deuterides, D# + D#, or form these femto-atoms in the fusion process. Either way, formation of the helium femto-molecule D#D# is a probable mechanism. The question here is whether and how the DDL electrons are shared. If they are not paired by spin or another mechanism, then the positive femto-molecular ion, D#D+, with the deuterons sharing a single DDL electron is the probable configuration. While this ion would attract an electron to form the mixed molecule D#2, neither ion nor molecule is a transmutant without sufficient kinetic energy to initiate the process. The ion is mobile in a lattice, but can't overcome the Coulomb barrier of another nucleus. The mixed molecule is neither mobile nor able to fuse with a nucleus.

Since D–D cold fusion produces transmutation, but the expected mixed molecules are not transmutants, some other entity or mechanism must be involved. The femto-D atom *is* a strong transmutant, so it would act as the femto-H atoms do, until it enters another nucleus. However, because of its greater mass, the mobility and attraction of femto-D to other nuclei is less than that of femto-H. Thus, it will not have the range about the source of femto-atoms that femto-H has and it will have a higher probability of fusing with a like femto-atom in the process. The D#D# entity could be a short-lived femto-molecule and/or some form of diatomic femto-structure. The yet-to-be-discovered nature of the binding and orbit(s) of the paired deep-molecular-electrons as the paired deuterons sink to the lowest potential (the ^{4}He nuclear ground state) would be the determining factor. Until one of the deep-orbit electrons leaves the D#D# entity (a femto-He atom?), it is a short-lived, strong, local transmutant. Thus, d*ifferences between D#D# and H#H# in the lattice are in their lifetime and the type of transmutations observed*.

3.3. Neutral femto-atoms and femto-molecules in the lattice

Selective transmutation begins in the motion of, and forces on, a femto-atom or -molecule in the lattice. As neutral near-nuclear-size bodies, there might not appear to be any major differences in their transport through the lattice

to form a photon in the transition to the (near-zero-angular-momentum, $k = -1$, $l = 1$) DDL region. (The change in quantum number, Δk, representing the change in total angular momentum from atomic to DDL, would be 2. If this translates into an E2, or electric-quadrupole, transition then its probability is greatly reduced relative to that of the normal E1, or electric dipole.) Were the deep-level electron KE to approach 100 MeV, then the $k = -2$ ($l = 2$), DDL might be available for photonic decay, via E3; but, again at a further large reduction in transition probability. The possibility of an atomic electron entering the relativistic Coulomb potential regime required to reach these high kinetic energies, via photonic interaction, has not yet been validated or rejected.

compared to that of neutrons (both have high mobility). However, when considering the deep-electron orbits and the internal structure of femto-atoms or -molecule and neutrons, it appears that there may be considerable differences in their ability to interact with lattice electrons and nuclei.

The primary neutral femto-atoms (femto-hydrogen or femto-helium) include one or two protons and zero, one, or two neutrons. Thus, there are common structures between them and neutrons (if one considers the quark model of the nucleus). However, the femto-atoms also contain one or two DDL electrons that make a major difference. Along with the relativistic fields from the deep-orbit electrons, a comparison of the quarks (and their possible sub-components) with deep-orbit and atomic electrons may be key to understanding the selective interaction with the lattice.

Atomic electrons are primarily non-relativistic; but, they have large orbits and therefore may have large dipole moments. The large orbits, with low-electron acceleration and the charge "cloud" they represent, both screen the nuclear charges and prevent close interaction between lattice nuclei. The electron bonds, with and between, nuclei also prevent a ready motion of atoms through the lattice. This restriction of movement negates much of the influence of the large dipole moments that the atomic electron's orbit could provide.

The deep-orbit electrons are relativistic, perhaps highly so; but, they have small orbits and therefore small dipole moments (the spin dipole moments are a separate issue). Their near-nuclear orbits, with high acceleration and the tightly bound charge "cloud" they represent, completely screen the nuclear charges down to the multi-femtometer level and make the femto-atoms and -molecules act as neutrons (neutral bodies) with their ready motion (high mobility) through the lattice. Only when a femto-atom gets to the multi-femtometer distance from a nucleus does the complete screening break down and allow the deep-orbit electron and the nucleus to act as separate charges. However, the tight-binding energy of a deep-orbit electron to its nucleus ($|\mathrm{BE}| < 511$ keV) allows the formation of femto-molecules (or halo nuclei?) and allows such nuclei to get close enough for their nuclear forces to overcome any nuclear-Coulomb repulsion.

As shown above, the relativistic velocities and extreme acceleration of the deep-orbit electrons make the last term in Eq. (1) become dominant in their interaction with lattice electrons and nuclei. Their interaction with lattice electrons are phase related, therefore stochastic (random), and strong interactions are statistical, just as are radioactive decay or photoemission. Their interaction with lattice nuclei are frequency related and strong interactions therefore occur primarily for resonant conditions. The ability of a DDL electron to alter nuclear energy states is dependent on the shape of the nuclear Coulomb-potential well. Since these electrons do not normally have sufficient angular momentum to form a photon and, with the near-field interactions, transverse photons are not able to form in the limited volume between the nucleus and its DDL electron [9] to act as the energy-transfer mechanism. Therefore, energy transfer between an excited nucleus and the lattice is through direct, near-field, EM interaction (or longitudinal photons?) between the nucleus and its DDL electron and, then, between the DDL electron and the lattice electrons (via far-field, EM interaction). However, these same EM fields can also interact with lattice nuclei to cause an attraction of femto-atoms to them.

The strong fields of a DDL electron can shift and split degenerate nuclear and sub-nuclear energy levels without changing any nuclear states. Even a small change in the energy of levels means that a potential can be altered and thereby a force generated. Since the relativistic-electron far-fields are so strong, they can affect nuclei over a large volume in the lattice. The nuclei most affected by these fields will generate the greatest force. All things being equal, the nearest nuclei will have the greatest attraction for the deep-orbit electron and the femto-atoms. However, radioactive nuclei are likely to have the largest changes and, if resonant, might even have state changes induced by the relativistic electrons. *This greater attraction of the DDL electrons for radioisotopes, compared to stable nuclei, is a basis for selective transmutation, a first step in nuclear-waste remediation.*

3.4. Deep-orbit electron as nuclear attractor

As an intermediary between a lattice nucleus and a nucleus with deep-orbit electron, the electron itself may be attracted to both nuclei. If either atom is mobile within the lattice, the electron will draw them together, even over many lattice sites, without any static-charge effects that can be easily shielded by the lattice electrons. The neutral femto-atom may be drawn to any nucleus; but, the lattice, as an isotropic sea of nuclei may not give a particular direction for this motion induced by long-range forces. It is also drawn by any lattice s-orbital electrons that can respond inelastically to the bound EM radiation of the DDL electron. However, as a stochastic process, this effect is also isotropic. So, while there is a preferred motion toward nearby nuclei, the effect is not strong unless there is something special about the interaction.

It is proposed that radioactive nuclei, not being in a lowest-energy configuration and having various modes of getting there, are more susceptible to absorbing and emitting energy in response to the strong fields of the DDL electron. A major reason for this susceptibility is the near-nuclear frequencies of the DDL electron and its fields. If these frequencies are resonant with decay modes of an excited nucleus, then, induced emission is one means by which radioactive decay paths are altered ($F = -\mathrm{d}V/\mathrm{d}x$ from reduction of system potential energy.) Nevertheless, this process is not likely to be one that would create an attraction between femto-atom and radioactive nucleus for long enough to bring two nuclei together. Radioactive nuclei in the lattice are not generally in excited states unless they have already begun their decay process. The more likely process is one of an unstable nucleus having one or more nucleons in less tightly bound states. Such nucleons will respond more strongly to the DDL electric-fields, particularly if they are near resonance. *Any energy transfer between the DDL electron and these weakly bound nucleons will draw the femto-atom toward, and/or induce decay of, the radionuclide.*

In another strong EM process, the case of a fusing pair of deuterons with one or more DDL electrons present, the transfer of nuclear energy to the lattice from the decay to ^{4}He is the change in total energy that defines the attractive force. In the case of a fusing pair of protons with one or more DDL electrons, the transfer of nuclear energy to the lattice is from the weak interaction changing a proton and electron into a neutron and forming the deuteron. The excitation of atomic s-orbital electrons in the lattice would be nearly isotropic; however, that of nucleons in randomly distributed radioactive nuclides would be a directional attractor. It is these states that will more readily respond strongly to the DDL electron(s) and therefore become more attractive to the femto-atoms.

3.5. Neutral femto-atoms and molecules in their interaction with nuclei

If the femto-atoms/molecules were only drawn to radioactive nuclides and then fused in the manner of neutron activation, then this would only be a lower form of nuclear-remediation. Long-term radioactivity would be reduced; but, radioactivity would be increased in the short-term. However, this radioactivity is not what has been observed in cold fusion. Why not?

The deep-orbit electron model is one explanation for fusion with few or no energetic particles/photons being observed. This model was initially created as an explanation for how D–D fusion could proceed to ^{4}He by a pathway never observed (or recognized, if observed) previously in such fusion [23]. When applied to H–H fusion, a variant of the model leads to the formation of femto-H atoms and molecules [5] and also to deuterium (via an accelerated version of the weak-nuclear reaction). Together, these processes further provide an explanation and understanding of radiation-free transmutation that differs significantly from transmutation via neutron activation. Both processes depend on the deep-orbit electron concept and on the fact that the interaction is multi-body [6,7] as in beta decay, rather than two body (see Appendix A) as in neutron activation. The relativistic DDL electron is able to absorb nuclear energy and transmit it much more efficiently to the lattice than can the heavier nuclear components themselves. The continued presence of a third body increases the possible pathways to a lower-energy state. This increases the potential for finding a faster way to "ground" and for a nucleus decaying with particle-energy distributions (such as in beta decay) rather

than the observed spectral lines of gamma decay for most neutron activation processes.

The H–H and D–D fusion processes, the simplest of transmutations, often begin with the creation of one or more femto-atoms. Models for this creation are described elsewhere [24–26] and will be assumed here. We begin here with a brief review of the femto-atom, H# or D#, entering a H or D nucleus. This entrance into a nucleus is where differences begin. For H+H# to fuse into a stable deuterium atom, it is necessary for a weak interaction to convert a proton into a neutron. This is normally a low-probability interaction since the two protons normally do not spend much time together. The Coulomb repulsion almost always forces the interaction to be one of scattering rather than of fusion. The deep-orbit electron of cold fusion allows the formation of a meta-stable femto-H molecule or molecular ion, which keeps the protons within femtometers of each other until fusion or some other interaction occurs. The proximity of the energetic electron to the internal charges of the nucleon alters the energy levels of the nucleons and their components via electromagnetic interactions. But, the short-range nuclear force between protons is not normally adequate to bind them against their centrifugal and longer-range Coulomb repulsion. However, the deep-orbit electron reduces this repulsion (actually makes the charge interaction attractive up to a point) [5] and therefore gives time and proximity for the weak interaction needed for the H+H $\rightarrow$ (H + n) $\rightarrow$ D transition to occur. Further details of this nuclear interaction for H+H and for that of D+D $\rightarrow$^{4}He are to be described in a later paper.

For D+D# to fuse, the additional strong nuclear interaction provided by the presence and proximity of neutrons means that fusion is rapid and limited only by the strong centrifugal forces when the deuterons get close enough together.[i] Since there is no weak interaction required in this fusion process, this centrifugal barrier to fusion is not much of a limitation in the presence of nucleon probability overlap, and the femto-molecular state does not last long before it transitions to the fully-fused state. Because no stable nuclear-energy level exists below the ^{3}He + p fragmentation level, the transition from D–D# femto-molecule to excited ^{4}He# to ^{4}He ground state is a continual (non-photonic, but still radiative?) process rather than a quantum "jump" associated with single photons. Thus, in this model of the Cold Fusion process, the initial binding of the two deuterons is by femto-molecule formation mediated by one or two deep-orbit electrons. *The proximity of the energetic DDL electron(s) and the nucleon charges alters the energy levels of the nucleons and their charged sub-components via electromagnetic interactions*. The nuclear forces, strongly enhanced by those EM interactions, greatly speed the fusion process. Nevertheless, *it is the reduction in nuclear mass energy, associated with the presence of the deep-orbit electrons and their influence on (excitation of) nuclear components, that is a likely cause of nuclear remediation*.

This reduction in nuclear mass energy is a result of the transfer of the mass deficit of the nucleus of the incident femto atom or molecule to the target nucleus. This energy comes from the change in potential energy (increase in absolute value of perhaps up to 100 MeV) brought about by the presence of the intense fields of the relativistic deep-orbit electron as it moves from the femto-atom DDL to the new nucleus. These fields alter all energy levels within the nucleus in a random manner. This rattling of the nuclear "cage" until the energies equilibrate and dissipate makes and breaks internal nuclear bonds and allows fusion or fission of the nucleus to a lower energy state. The relativistic deep-bound electron acts as a stirring rod and energy-transfer mechanism at the same time. While the nucleus settles down to a generally lowest state, it transfers energy to the electron which can, in turn, transfer it to the lattice. Thus, this chaotically bound electron can dissipate most or all of the excess energy of the radionuclide, including that which

[i]While the quantum number, $l = 0$, is required to obtain a near-nuclear orbit, this does not necessarily mean that the electron has no angular momentum. For that to happen, the electron must transit the origin exactly and that has a low relative probability. However, when considering all possible $l = 0$ paths through the nuclear region, as many may pass on one side of the nucleus as the other. Thus, centrifugal forces would not be a limitation to rapid fusion. On the other hand, the perturbation theory of QM allows there to be a net offset from this $l = 0$ balance that would provide a centrifugal barrier; albeit one that is much smaller than the h of $l = 1$. Again, the multipath model allows for such transits and barriers within the nuclear region even when the primary orbit does not. This would provide for a "porous" barrier (and tunneling) that decreases as the perturbation increases. Are there resonances within the $l = 0$, $\Delta l \geq 1/100$, picture (i.e., angular momentum $\geq h/100$) that would allow a metastable state that violates the HUR?

would normally be stored in excited levels pending departure as gamma radiation. If the electron ultimately leaves (as it slows down), it takes with it the remains of the excited nucleus energy minus the initial binding energy with which the femto-particle entered. Thus, *the femto-particles not only reduce the radioactivity of impurities (native or introduced) in the lattice, they convert the excess energy of these radionuclides into potentially useful heat*.

Mark Davidson, in his papers on variable mass, e.g., [27] and the references therein, has described the mass changes in a quantum mechanical model. His use of Fock–Stueckelberg theories of off-mass–shell interactions is the only other attempt to explain CF and its consequences in this context. However, that model does not include the concept of deep-orbit electrons, which provides a classical basis for such mass changes. The existence of these electrons should be considered as a constant interaction with a nucleus and therefore it both limits and extends the QM model.

It is precisely at this point that classical physics may provide information that QM does not yet "see". Non-relativistic QM, through the HUR, allows violation of the conservation of energy for brief periods of time during an interaction. Classical physics does not allow that violation; but, through relativity and deep-orbit electrons, it can provide a reason for why such apparent events might occur. While a change in nuclear-mass energy of a few MeV would have a major impact on the decay mode of the excited state of ^{4}He in the D–D fusion process, *the change of ∼100 MeV, associated with a HUR-compliant deep-orbit electron, would have a major impact on fusion processes and products of any nucleus*.

4. Discussion

In prior papers, we have described how the nuclear charges, in an excited state of ^{4}He, transfer excess energy to the relativistic deep-Dirac-level electrons with $3 < \gamma < 4$ [28]. For the same process, but one modified to be consistent with the Heisenberg Uncertainty Relation (giving γ =∼200) [3], the transfer of such energy from DDL to lattice electrons is much faster because the fields generated are much more intense. The energy transfer from nucleons to DDL electron is not a strong function of deep-electron velocity (being nearly a constant at $v \sim c$); but, it would still be dominated by the near-field term of Eq. (1). All of the energy transferred from the nucleons to the DDL electron is rapidly dissipated to the lattice primarily via the far-field term of Eq. (1), which does not contain a gamma in the denominator. Because of their high KE (∼100 MeV), the DDL electrons may not change their relative energy levels much in the process. This is somewhat different from the scenario proposed earlier [28–30] for $\gamma < 4$ (where the DDL electron, with KE = ∼1.5 MeV, may change its relative energy level and orbital frequency dramatically) and, if valid, the higher-γ DDL model could result in a harder continuum X-ray spectrum generated within the lattice. Nevertheless, the process is the same for both electron-energy ranges and applies to other nuclei during transmutations when a femto-atom fuses with a lattice (or lattice contaminant) nucleus. The DDL electrons, being close to (both inside and outside of) a nucleus, can accept the very-strong, but short-ranged, nuclear-generated fields and can convert their energy into strong fields in the distance. *This ready transfer of nuclear energies to deep-orbit electrons, with the DDL frequencies being on the order of nucleon-component frequencies, is also a basis for DDL-electron-mediated internuclear interactions*.

With this background, it is possible to picture what happens in general when a femto-atom enters a lattice nucleus. The DDL-electron binding energy, on the order of BE = 0.5 MeV (even if its KE = ∼100 MeV), is much less than that binding the nucleons (>5 MeV). Therefore, on entering the nucleus, a femto-H will split and the deep-orbit electron now becomes "shared" with all of the nucleons. This sharing, whether the electron is inside or outside the nucleus, distributes the local Coulomb field. The electron's binding energy and potential energy, with respect to the initial proton, are correspondingly reduced in magnitude. The proton that initially bound a deep-orbit electron will thus regain most of the energy (mass) that it had previously shared only with the electron.

In the process of redistributing the new and old energies of the transmuting nucleus, both the incoming proton and the deep-orbit electron have multiple, and competing, choices for the transition. Many, most,

or even all, of the paths would not be available to a single proton or neutron entering the nucleus. *These new decay paths are provided by the deep-orbit electron, its effects on nuclear mass, and its ability to mediate energy transfer within the nucleus and from the nucleus to the lattice*. The actual transition will be a result of statistical (competing) processes. Possible mechanisms and examples of the new pathways are taught in the examination of cold-fusion results for D–D fusion, H–H fusion, and transmutations [6,7,29].

In almost all nuclear processes, multiple paths are possible. The observed paths are often just the most probable; but, the differences in probability can be nearly zero or many orders of magnitude. Over the years, many techniques have been discovered and developed to explore, explain, and alter these probabilities. The known energy-levels and decay probabilities of ^{4}He are instructive in explaining how D–D fusion results can be so greatly altered by the cold-fusion process [12,29]. The pathway from the excited state of helium (^{4}He*), just after D–D fusion, to the ^{4}He ground state (via >20 MeV gamma emission) exists; but, it has low probability in the hot-fusion process because fragmentation is so much more probable. Cold fusion results (with ^{4}He#), which show very little fragmentation, might be thought to indicate a suppression of that mode of decay. This would leave energetic gamma decay as the dominant path to ground. However, since such radiation is not observed:

(1) it also must be suppressed by some process *or*,
(2) another faster pathway, perhaps even faster than fragmentation, must be found or,
(3) an entirely different fusion mode must exist (e.g., [31,32] and the references therein).

The present model of deep-orbit electrons satisfies (1) and/or (2). Thus, this mechanism for cold fusion in D–D interactions can be applied to the CF-transmutation results, which, as in the D–D cold-fusion case, do not show the well-known results of hot fusion. The two different fusion models in item (3) of Storms and of Takahashi, both still evolving as is the present model, also contain the concept of confining electrons between pairs (one or more) of resonant hydrogen atoms. Therefore, they have been selected (from the many CF models proposed over the years) to represent different, yet likely, contenders.

Even a comparison of three different theoretical QM models for the hydrogen atom has provided important information as to what different approximations mean in predicted results. The simple QM model, the Schrödinger equation without inclusion of electron spin or relativity, does not show any deep (nor negative-energy) orbits. The Dirac model, with both spin and relativity does show the deep orbits. The Klein-Gordon model (a relativistic version of the simple model, but still without spin) also shows the deep-orbits, but at slightly different binding energies. So the key to the deep-orbits is relativity [3]. Nevertheless, relativistic effects have not been fully explored and exploited because no evidence of deep-electron orbits has been accepted and therefore no results, from experiments specifically designed to seek deep-orbit-electron characteristics, have been provided for any models to work with. While high-atomic-number elements have atomic-electron orbits that are relativistic and some effects have been calculated and confirmed by models, details of the transient nuclear interactions with these electrons are seldom explored [33].

All three QM models generally assume a point-source, infinite-mass, positive charge as the center of attraction. Deviation from these assumptions is generally in the perturbation model, since the integrated effects of nuclear interaction with atomic electrons is small relative to the Coulomb energies involved. While corrections for the finite nuclear mass are made by use of a "reduced" mass, *changes* in the nuclear masses with electron proximity are not considered. Other than as an explanation for cold fusion results, we have not seen where this known effect has been proposed even when physics has been trying for years to understand the difference between calculated proton radii from atomic-electron and muonic-atom experiments.

Arguments have been made [34] that challenge the several presently 'accepted' versions of the internal structure and nature of a nucleus, its nucleons, and their constituent parts. It is difficult to go beyond a number of assumptions when making predictions or calculations regarding nuclear interactions. Introduction of a relativistic electron into the near-nuclear region complicates things even further. However, if relativistic DDL electrons exist, their dynamic EM

fields at the nucleus would be much stronger than those of any nucleon, or externally applied field, and major effects would be expected. These electron-based fields could have a greater influence during the transmutation process than those of a femto-atom's nucleus. Introduction of a DDL electron reversibly alters nuclear (nucleon and quark) energy levels, masses, and processes even before fusion begins. Furthermore, relative to the motion of such an electron, *the fusion process (a rearrangement of nucleons) is not instantaneous; it is a transition (generally the source of gammas). The final product is a result of statistical (competing) processes mediated by the fields of the DDL electron*.

5. Summary of Deep-orbit Electron Effects on Selective Radioactivity Remediation

We have covered a lot of territory to provide a basis for this topic. We will try to organize the major points here. The key points are in italics.

(1) Because of their relativistic velocities and very-strong acceleration toward the center of charge, the DDL EM fields, if present, *dominate the fields* about an atom (Section 3.1).
(2) In cold fusion, *direct transfer* of nuclear energy to lattice s-orbit electrons is via DDL electrons (Section 3.1: "Thus, this huge **E**-field could excite ... a small portion of s-orbit atomic electrons throughout a macroscopic lattice").
(3) *Neutral femto-atoms* and molecules allow protons to avoid a nuclear-Coulomb barrier (Sections 3.2 and 3.3). This charge neutrality and small size permits their unobstructed mobility through a lattice and into a nucleus.
(4) *Near-field attraction* (induced-dipole to induced-dipole) of femto-atoms and molecules to lattice atoms and nuclei is strong (Sections 3.2 and 3.3).
(5) Even *attraction of femto-atoms and molecules to distant excited lattice nuclei, or to radionuclide* impurities, is possible via far-field forces (Section 3.2 and 3.3).
(6) Deep-orbit electrons inside a nuclear region can produce *neutrons* via "fast" weak interactions (electron capture in Sections 3.4 and 3.5).
(7) *Multiple possible paths* exist for femto-atom transmutation (Section 4).
(8) Deep-orbit electrons give *m multiple decay paths* for excited transmutation products (Section 4).
(9) *Multi-body interaction* may eliminate gamma "spectral" lines (Section 3.5 and Appendix A).
(10) *The relativistic deep-orbit electron* is a basis for all the above.

Appendix A. Three-body Vs. Two-body Atomic-electron Energy Transfer

This appendix is an attempt (by A. Meulenberg) to provide a physical description of energy transfer that is not expressed in the mathematical formulations of the process. Energy transfer mechanisms are considered critical to cold fusion processes, to the observed transmutations, and to the selectivity of such transmutations. Such an interpretation should not change the mathematics and, it is hoped that, it might give some insight into mechanisms that must otherwise just be accepted on faith. It is not expected to be a complete picture, fully proven. However, it is thought to be self-consistent and with sufficient references to be considered plausible.

The normal process for atomic-energy transfer between two atoms (with both electron excitation and orbital decay) is radiative, via a photon. This can be considered to be a three-body process, two electrons with the third body, a photon, considered to be the exchange medium. An important function of this medium is that of reversing a change in frequency during a transition. This is equivalent to reversing rotation direction in a mechanical system with an idler wheel [35]. In the energy exchange between the electron and the photon, even the process of forming or absorbing a photon is a three-body process, with a third "body", the bound electromagnetic (EM) field[j] considered to be a buffering

[j] The bound EM field is a charge's static electric field plus its velocity- and acceleration-dependent distortions, the measurable **E**- and **B**-fields of an

exchange medium that is coupled to and encompasses both. Why do these processes work, when a simple two-body interaction does not? The following is offered as a possible explanation.

The atomic-energy absorption process can be considered to be a low-energy, resonant (or harmonic), version of Compton (inelastic) scattering [36]. Using a model of the photoelectric effect [37] and a classical view of the atomic electron as being a bound, charged, particle, we see a resonant interaction between the photon and electron. We look at the development of the EM field and the photon in a non-relativistic, atomic-orbital, decay process to see the resonances between electron and bound field and between bound field and forming photon [38]. As an atomic electron decays from one orbit to a greater binding-energy state (i.e., to one with a higher absolute value, $|\ \mathrm{BE}|$), both its kinetic energy and orbital frequency (not its spectral frequency, which is related to energy differences) increase. This means that its bound EM field increases in amplitude. Furthermore, being driven by the electron's motion, the dynamic EM-field frequency increases as well. This process is critical to the energy conservation of the system and to the formation of a photon [38].

Similarly, when a photon is absorbed by an atomic electron, it is initially coupled (quasi-bound) to it through the electrostatic charge and the phase-related, bound, dynamic-EM field. Cycle-by-cycle it raises the electron to a higher-orbit with a lower binding energy (i.e., $|\mathrm{BE}|$ is lower) and with a higher potential energy (V_2, where $V_1 < V < V_2 < 0$). The point in each case is that, in a *decay* process, the nascent photon (a subset of the bound dynamic-EM field) increases frequency (and energy) along with the orbital electron. In an *excitation* process, the quasi-bound-photon frequency decreases and it loses energy as the electron gains energy (reduces its binding energy $|\mathrm{BE}|$ in the Coulomb field). This process preserves energy and momentum conservation in a continuous transition instead of in a "magical" and instantaneous quantum jump that depends on "off-shell", non-conservative, components of an interaction to define the process.

The photon and electron frequencies do not change at the same rate and the difference is tied up in the remainder of the bound EM field of the local interaction between nucleus, electron, and bound photon. When the nascent- or quasi-bound-photon and electron orbital frequencies (or their harmonics) are resonant, a photon can be respectively released from, or absorbed into, this bound EM field.[k] Thus, this field may be considered a buffering body, just as a bound electron is a body inside an atom. Without mention of this physical buffering field, the photo-electric process is just a quantum-mechanical description (grey box model [39]) of an observable effect.[l]

Just as the free (or bound) electron transition to (deeper) atomic orbitals requires an intermediary, the transfer of energy from an excited atomic electron to another bound electron (in the same or another atom) requires a third body. This process cannot happen as readily by a two-body mechanism because of frequency mismatches. If an excited bound electron tries to transfer energy to another charged body, via its electric or magnetic fields, it will be poorly coupled (non-resonant) if the frequencies do not match. If they do match and energy transfer begins, then the "sending" bound electron will go to higher orbital frequencies as it decays. Similarly, a "receiving" bound electron

electron in motion. Unless/until, the dynamic portion of this EM field forms into a photon and leaves, it is bound to the source and acts as part of its distributed mass energy. Nevertheless, in some of this discussion, it can be considered a separate (but coupled) body. In the present standard model, virtual photons are considered to be the force-exchange medium of charge. When equated to evanescent waves or the energy associated with **E**-field lines, they are also bound energy with effective mass and this perhaps becomes a many-body problem. Thus, in this regard, the present model differs little from this aspect of the standard model.

[k]The standard model would say that a virtual photon has become "real".

[l]The connection between the continuous process described here and the quantum mechanical description of a quantum "jump" is that of two coupled oscillators. QM only compares the initial and final states, nothing in between. Determining the eigenvalue of the transition is equivalent to finding the oscillation frequency between the two states from the diagonalization of a matrix representing the classical simultaneous equations for the two oscillators. This Heisenberg representation of QM is thus equivalent to the classical problem with the additional insight of identifying the mutual-oscillation frequency with the difference in energies between the oscillators and its relationship with the photon that is emitted or absorbed in the process. While QM greatly simplifies the description of the process, it loses information on the transition process and the function and importance of the bound EM field as a third "body".

will go to lower frequencies. Thus, an initial frequency match will rapidly lose resonance and coupling strength. This process eliminates a net-energy transfer between two electrons in the same energy state even though there will be a cyclic (reversible) energy exchange between coupled oscillators.

On the other hand, if an excited bound electron tries to directly transfer energy to another atom's electron with a higher orbital frequency (i.e., more tightly bound), via its electric and/or magnetic fields, it will be poorly coupled (non-resonant) initially. However, it will slowly move toward resonance and a more rapid transfer of energy as its frequency increases and that of the receiving electron decreases. Nevertheless, there is no net energy transfer at the mutual resonance point where their frequencies are the same. This is because both electrons are radiating the same amount of energy and they simply act as coupled oscillators changing their energy levels at a frequency that is lower than that of either of their orbits. The probability of a net exchange of energy is very low because bound electrons are unlike simple harmonic oscillators with fixed frequencies as their kinetic energy changes. In a Coulomb potential, before reaching the end point of a decay to a stable orbit from an excited state, the lower level of the sending electron has a higher frequency than that of the receiving electron and will not be able to stimulate it to even lower frequencies. In the standard model, the two states will simply exchange energy back and forth via "virtual" photons.

The photon, as a third body, is able to maintain near-resonance conditions (frequencies) between two different bound-electron states throughout the exchange of energies (but not necessarily simultaneously). Even if the bound-electron states of different atoms have the same energies and no net-energy transfer takes place, there is an ongoing interaction that can raise and/or lower the system energy. This is perhaps why virtual photon exchange (evanescent waves [39]) is considered to be a model for the charge interactions of the Coulomb potential. Based on a standing-wave model of the photon and electron [41,42] and a more detailed knowledge of the nature of the internal fields (i.e., gradients of potentials) of the photon [43], a mechanism for the attractive and repulsive forces induced by these virtual photons is proposed elsewhere.

The deep-orbit electron, as a third body, is also able to maintain near-resonance conditions between two different nuclei throughout an exchange of energies. In addition, it has the capability to exchange energy between a nucleus and an atomic electron. While it does this by creating photons from energy it receives from an excited nucleus or by direct excitation of lattice-atom s-orbital electrons, it can also cause a physical attraction between nuclei and between nuclei and nearby atoms (via their bound electrons).

Most interactions of nuclei with atomic electrons, via deep-orbit-electron fields, are not strong because of the differences in orbital frequencies (e.g., $> 10^{19}$ vs. $\sim 10^{10}$ Hz). The deep-orbit-electron frequencies become comparable to those of the lattice electrons only when (and as), the nuclear-decay-energy transfer exceeds the deep-orbit-electron's ability to transfer energy to the lattice. With this condition, the deep-orbit electron will be raised in its potential well and its orbital frequency will generally decrease as it is forced toward ionization.[m]

Direct excitation/ionization of lattice electrons by intense deep-orbit-electron near-fields is a relatively short-range effect because of its rapid drop in field intensity with distance. The initially lower-intensity far-fields of deep-orbit-electrons can, at greater distances, still interact with nuclei (and their components) because the frequencies are comparable. This interaction can produce long-range forces between nuclei that may be similar to that of the Coulomb potential. However, because of their disproportionately high frequency, they may be only weakly screened by the atomic electrons of the lattice.

The point of this appendix is to indicate that simultaneous multi-body interactions have characteristics different from two-body interactions, which are generally the cause of spectral lines rather than of a spectral continuum. Thus,

[m] An important property of the DDL electron is its ability to absorb energy and rise out of the potential well by decreasing its average orbital radius as well as by increasing it. These are not photonic transitions. They are non-quantized transients, related to a transition process itself, and therefore not addressed by QM accept as virtual photons. This ability, normally ignored for atomic electrons, is important in its interactions with the nuclear potential [9], which has varying slopes at different energies and distances.

any nuclear-reaction products expected, based on experience with two-body reactions, will be only second-order effects in the presence of deep-orbit electrons.

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