J. Condensed Matter Nucl. Sci. 10 (2013) 15–29

Research Article

From the Naught Orbit to the ^{4}He Excited State

A. Meulenberg *

National Advanced IPv6 Centre, Universiti Sains Malaysia, 11800 Penang, Malaysia

Abstract

An electron pair (lochon) in a deep hydrogen 'naught' orbit ($n = 0$) has similarities to muonic hydrogen in that it has a small orbital radius that allows the protons in molecular hydrogen to be very much closer together than is possible in a normal molecule. There are also significant differences between lochon- and muon-catalyzed fusion (e.g., one leads to 'cold' fusion and the other the 'hot' fusion). However, since muon-catalyzed fusion is an accepted phenomenon and Lattice-assisted Nuclear Reaction (LANR) or Low-energy Nuclear Reaction (LENR) is not, we will examine the similarities and differences in various mechanisms with the fusion of deuterons in mind. We start with the assumption that both solutions of the Klein–Gordon equation are actually real and the one that has here-to-for been rejected correctly identifies a single deep orbit below the $n = 1$ ground state. (It is generally accepted that, at least for spinless bosons such as the lochon, this solution of the Klein–Gordon equation holds.) We then compare the creation model and characteristics of these two naught orbits with those of the muonic orbits (both atomic and molecular). The similarities lead both naught-orbit and muonic-orbit molecules to fusion. The differences lead the non-relativistic (but >100 MeV excess energy) muon-induced fusion of deuterons to the fragmentation of excited helium nuclei and the relativistic (but <10 eV excess energy) lochon-induced D–D fusion to an excited helium ^{4}He* state that is below these fragmentation levels. The reason for this different response to the respective "tight" orbits is described along with some of the consequences, e.g., electron capture. In addition, internal conversion, a known physical process involving nucleon interaction with atomic electrons, is compared with the Extended Lochon Model to provide a means of de-exciting ^{4}He* without production of energetic particles or radiation.

Keywords: Electron-capture, Internal-conversion, LENR, Lochon, Muon-catalysis, Naught-orbit

1. Introduction

Loaded palladium deuteride, PdD_x (with $x = \sim 1$), has a high number of deuterons located in close proximity to one another. Under certain circumstances, these deuterons are cyclically brought still closer together and some of them fuse. Many models have been proposed to identify these circumstances. None has had more than a small group of adherents, and, all of the earlier models had weaknesses identified in a 1994 review [1]. Nevertheless, with experimental evidence proving that at least some of the fusion processes proceed from lattice site to the ^{4}He ground state with release of more

*E-mail: mules333@gmail.com; Tel.: 604-01255 92369, 604-653 4632

heat than can be accounted for by accepted pathways, it is clear that conventional atomic and nuclear physics must be extended beyond their present realms.

Assuming the reality of measured end products (heat and ^{4}He), we have developed a model over the last decade that provides a pathway to these products as well as to the other observed effects and byproducts of this system [2–6]. The individual steps along this path have not yet been validated. However, none of them violates known experimental or theoretical physics. In fact, recent experimental and theoretical work within the mainstream of astrophysics [7,8] and physics [9] supports some hypotheses of the model.

An assumption of our Lochon Model[a] is that the $n = 1$, hydrogen-ground-state energy level is briefly and periodically occupied by a pair of zero-angular momentum,$l = 0$, s-orbit electrons that can lose sufficient energy in doing work to move deeply into a deepening Coulomb potential well so that their orbital radius (wave function) is confined more closely about the nucleus. The pairing of electrons, shared in the hydrogen 1s orbital and the Pd 4d orbitals, depends on the local Fermi level and therefore on the local electric fields. This pair of s electrons, the lochon, will form from, and respond to, the local phonon field and cyclically (at 10^{13} to 10^{14} Hz) move deep into the nuclear-Coulomb potential well, accelerating to high kinetic energies in the process. This modeled action of s electrons is not new; lattice-induced pair formation is standard physics and happens continually in the solid state as a result of phonon or polariton action.

Normally, in the lattice-atom oscillation, the kinetic energy of bound electrons increases to a point and then returns to the initial condition (maintaining constant total energy). If the electrons are in an excited atomic state and are able to radiate energy away as one or more photons or phonons, then the total electron energy drops to a lower level. The $n = 1$ level is the lowest such radiation-accessible level, because electrons in that level do not have sufficient angular momentum to form a photon. However, under the proper nuclear conditions, while the electrons are close to their nucleus, they can be captured by the nucleus. Or, if they can do work that does not require angular momentum, they may be able to drop to a lower potential and total energy. At the atomic level and below, systems are generally conservative. Therefore, the work done goes into stored energy and the process is fully reversible. The electron energy changes are ‘done’ and ‘undone’ in a cyclic manner and no violation of accepted physics and chemistry is observed.

When this process occurs during the collision portion of the longitudinal optical-phonon cycle for deuteron pairs bound in the sub-lattice of a PdD crystal, work *is* performed. If the colliding deuterons do not get close enough for their nuclear forces to overcome the lattice or nuclear Coulomb barriers, they are subsequently drawn back into the sub-lattice sites and the cycle, at about 10^{14} Hz, begins again. If the collision is close enough for fusion to occur, then, the deep-well electrons absorb energy from the accelerating protons and reradiate it. One or both of the electrons can be ejected. The now tightly bound and relativistic electron or pair participates in a nuclear ‘dance’ that leads the excited ^{4}He* to its ground state(s). This latter process is described by the Extended Lochon Model [10].

The Extended Model provides all of the observed effects in low-energy nuclear reactions (LENR). It has been recently reinforced by (and, in turn supports) a theoretical quantum mechanics work of Jan Naudts identifying a deep-level atomic orbital [9,11]. This deep level is not within the normal range of detectability (energy and intensity), is not generally occupied, here-to-fore has not been sought, and therefore has not had any experimental support. (However, actual experimental data for the Halo nucleons [12] can be interpreted to support this model.) The prior deep-orbit theoretical work, while neither fundamental nor essential to the lochon model, may provide a valuable basis for explaining some parts of the model that had been postulated, based on accepted solid-state models and mathematically derived, but not proven rigorously. Similarity of portions of the lochon model to accepted physical processes might be considered as support for the model, just as experimental evidence of much higher fusion cross sections observed in keV deuteron–deuteron collisions [7,8] over the last two decades has supported the hypothesis of nuclear fusion in LENR in general. Nevertheless, these portions are only stepping stones; and they must be properly connected before

[a]The lochon (a “local-charged boson”) is a pair of s electrons tightly coupled by the phonon field to a deuteron (in this case) during the longitudinal optical-phonon collision mode of the hydrogen sub-lattice in a PdD crystal.

the pathway is complete.

Some of the Extended Lochon Model mimics or has similarities with known physical processes, such as proximity-coupling, internal conversion, muon catalysis, electron capture, and cyclical, deep, electron orbitals. This present paper explores the new deep atomic level and then compares this model with some accepted nuclear physics mechanisms to determine the similarities and differences leading to each and the applicability of the known phenomena to the new LENR data and environment.

2. Naudts' Orbits

A deep atomic orbital at a binding energy of about mc^2 is predicted from one solution of the Klein–Gordon (KG) equation [9]. Earlier studies of the relativistic 1-dimensional hydrogen atom [13], of a normally rejected solution to the Schrodinger equation [14], and in an independent development [15], had predicted a similar deep orbit (in some cases infinitely deep [13]). The deep-orbit solution of the KG equation has been rejected by other authors [16,17], as: being from an equation that is not applicable to particles with spin, being non-square integrable, and being singular at the origin. Therefore, by their definition, it cannot be applied to an electron and it could not be real even if it did pertain. Nevertheless, the same KG model predicts two sets of energy levels. One set is 'acceptable' (even without considering spin) because it provides levels consistent with known values for bosons (e.g., pions) and is not singular. The other set is 'unacceptable' because, along with the known levels, it predicts a level that has not been observed. However, in both sets of solutions (neither including spin), the upper atomic-hydrogen levels are predicted to be within parts per 10 thousand of each other and of the normally calculated results.

The values for the deep *accepted* energy levels (e.g., n = 1 and 2), calculated by the 'unacceptable' path, are slightly further from experimental results than those predicted by the basic 'standard' model; but, they converge to those of the 'accepted' Dirac model at the higher energy levels (e.g., $n > 2$). The reason for this deviation at the deeper levels (for both solutions) is that the KG equation does not include the spin of an electron. At higher energies, the electrons are further from the nucleus and each other, so that spin-spin and spin–orbit interactions become less important. A more recent paper [18] has established theoretical criteria for accepting the deep orbit solution in the KG equation, but not in the Dirac equation for which such a solution had been claimed earlier (1993) [19]. This same deep orbit solution for the Dirac equation, in a physical argument, has been rejected based on a low probability ($\sim 2\times10^{-9}$) of the solution in the region of the nucleus [20]. Nevertheless, such an orbit is admitted, even in this earlier critical paper, based on a modified Coulomb potential that permits a non-singular origin (at r = 0).

If the energy-level data are extended from Naudts' paper and rewritten in more convenient notation (Table 1), then some interesting conclusions can be drawn when they are compared with 'standard' [21] calculations. The solutions to the KG equation provide two sets of levels identified by a parameter s (slightly modifying Naudts' notation for the wave function, in Eq. (1)).

$$\Psi(q) = \exp{-iE_{\text{o}}t/\hbar} r^{-s} \exp{-r/r_{\text{o}}}. \tag{1}$$

The KG values for $s \geq 0$ correspond to the standard orbital energy levels. The KG values for $s \ \leq 1$, with a much more centrally concentrated probability distribution, are the 'unacceptable' levels. The n values in the table are chosen to agree with conventional notation and neither the standard nor the KG sets contains a correction for the finite nuclear mass. It can be seen that the KG results 'straddle' the standard values and converge toward it (in parts-per-million, the differences in the last two columns) for the higher n values.

What does this all mean? If the KG equation can predict energy levels within milli-electron volts of the measured and calculated values for the observed results, then it should be reasonable to expect it to predict *all* levels to *some* degree of accuracy. In this case, the deepest ($s \leq 1$) level is predicted to have a binding energy of about 507 keV. Even

Table 1. Hydrogen energy level calculations for Standard and Klein–Gordon solutions

Hydrogen atomic orbit	Standard ('S') calculated E levels (eV)	Klein–Gordon (KG)		'S' minus KG	
		E (eV) for $s \geq 0$	E (eV) for $s \leq 1$	Delta (∼0) × 10^{-6}	Delta (∼1) × 10^{-6}
$n = 0$	–	–	$\sim 507,000$	–	–
$n = 1$	13.605698	13.606600	13.603702	–902	1996
$n = 2$	3.401424	3.401571	3.401208	–147	216
$n = 3$	1.511744	1.511791	1.511683	–47	61
$n = 4$	0.850354	0.850376	0.850331	–22	23

if the corrections from spin, spin coupling, finite nucleus and electron size, relativistic effects, etc., were of the order of 90% (they were less than 100 PPM for the 'normal' calculations and should be within several hundred keV for the more spin-sensitive $n = 0$ level), there is a deep energy level that has been predicted. But, it has not been observed (has it been sought?) nor wanted in the quantum-mechanical description of the atom. With the accuracy of these predictions and modern measurement capabilities, it would appear to be worth looking for and trying to understand what it means to physics today.

The deep level predicted by the KG equation is alone (no other deep levels are predicted in the approximation) and far below the $n = 1$ levels, so we will call it interchangeably the $n = 0$, or 'nought', or 'naught' level. What are some of its properties and problems? Assuming a single electron (without spin), the KG equation (giving Eqs. (2) and (3), with the fine-structure constant $\alpha = \sim 1/137$) predicts a binding-energy level of about 507 keV and a characteristic orbit with $r_o = 390$ fm. The total nought-orbit energy, $\mathrm{TE_o}$, equals the mass energy plus the binding energy (this latter is also the potential energy – a negative value – plus the kinetic energy). Therefore, the binding energy of the orbit (a negative value for an attractive potential) is $E_o – m_o c^2$ and the proposed nought-orbit values from the KG equation are:

$$\mathrm{TE_o} \cong m_o c^2 \alpha \cong 3.7\ \mathrm{keV} \Longrightarrow \text{binding energy} = E_b = \mathrm{TE_o} - m_o c^2 \cong -507.3\ \mathrm{keV}, \tag{2}$$

$$r_o \cong \hbar / m_o c^2 \cong 390\ \mathrm{fm}. \tag{3}$$

Classically, the nought-orbit electron can have angular momentum. However, it will be much lower than Planck's constant divided by 2π (where $h/2\pi = \hbar$). Therefore, as $0 < 1 \ll h$ and the uncertainty in angular momentum is $\hbar/2$, it would be classified as an $l = 0$ orbit. The nought orbit is thus both $n = 0$ and $l = 0$ orbit. (The Dirac nought-orbit gives a nuclear Coulomb repulsive radius as <4 fm [22].)

There are other interesting points about this orbit relative to the normal atomic orbitals. While 'circumferences' of the Bohr orbits are integer multiples of the electrons' *deBroglie* wavelength ($\lambda_{dB} = h/p$, where h is Plancks' constant and p is the magnitude of the electron momentum). The naught orbit in one development [9] has a predicted circumference close to that of the electron's *Compton* wavelength ($\lambda_C = h/mc$). As such, the nought electron still fits within the wave mechanics regime and is consistent with the Heisenberg Uncertainty Relation, $\Delta x\ \Delta p \geq h/4\pi$ (e.g., if $\lambda_{dB} = h/p = \lambda_C = h/mc$, with $\Delta x = \sim 2\ (\lambda_{dB}/2\pi p$, and $\Delta p = 2|\mathbf{p}_{max}|$, see below).

The deep-orbit solution for the Dirac equation has more than a single deep level [22]. It has higher angular-momentum orbitals. These additional orbits have higher binding energy than the $n = 0$ level, ($507.3 < E_b < 511$, as distinct from the conventional orbits that have lower binding energies as n increases). A point not mentioned in the nought-orbit papers is the need for the electron orbit to be in the fermi range, not the picometer range, to attain the 0.5–1 MeV energies required for the solution. This important concept, addressed in [22] and briefly addressed below, must be explored further in a later paper.

The proposed electron naught orbit (radial or circular motion?) is of the same order as that of the muon orbit ($r_{n=0} = \sim 390$ fm vs $r_\mu = \sim 250$ fm) and therefore, a naught-orbit electron should be able to catalyze fusion in a similar manner. If we assume that the predicted naught orbit is approximately valid, then, if it can be attained, it would become a natural bridge to hydrogen fusion, just as is the muon. Moreover, electrons are plentiful (and cheap) and muons are not. But, electrons do not naturally migrate to the nought orbits (as they do to the $n = 1$ orbits) or our universe would not exist in its present form.

Given that this deep orbit exists, then the Quantum Mechanics (QM) argument that the hydrogen ground state is the lowest orbit has only limited validity. However, a hydrogen atom with an electron in a nought orbit, Hˆ, would not last long in the presence of other hydrogen atoms before they fuse; therefore a statement of the hydrogen ground state as the lowest **stable** orbit *may* still be valid. Nevertheless, one should not reject the nought orbit based on this QM claim. Perhaps, there is a reason that the QM claim could be rejected based on the naught orbit, but the accurate QM orbit-energy predictions could still be valid, since they are based on probabilities and the lifetime of this orbit is probably very short. On the other hand, since the QM-orbit equations (Klein–Gordon and Dirac) do not include the nuclear-capture probability and do not address the difficulty in reaching this orbit, the orbit should be real and might even be stable in that limited calculation.

The non-relativistic QM predictions are based on the deBroglie wavelengths and associated resonances of the bound electron. The addition of a (perhaps) single Compton wavelength for the electron could give a new orbit (a solution or resonance) and still not violate the old QM models (they may just not include the most general solution). Since the strict Coulomb potential has no minimum, and nothing except the perceived singularity at $r = 0$ prevents the electron from passing through the nucleus, the normal ground state is a minimum only as a result of 'mechanical' resonance states of the electrons in a potential well. The photon and its requirements for $E = h\nu$ and $l = 1$, which are critical to a proper understanding of the atom, do not directly enter the standard Schrodinger equation picture.

This resonance of an electron in a Coulomb potential is a consequence of the deBroglie relation ($\lambda_{\text{dB}} = h/mv$) that is often used, but seldom explained. Alternatively, it is answered in the form of a mathematical solution of the Schrodinger equation with 'no further discussion required (allowed?).' The relativistic addition of the Compton relation ($\lambda_{\text{C}} = h/mc$) does not alter the former solutions. However, instead of multiple resonances possible because of the variable v (the electron velocity) in the deBroglie wavelength, there may be only a single KG resonance for the single Compton wavelength ($v \leq c$). On the other hand, just as there are beat frequencies when two frequencies are combined, it is possible that there are multiple resonances that can be associated with the relativistic (near-nuclear) regime [22]. This possibility needs exploration.

If we convert the wavelengths to frequencies, we get $\nu_{\text{C}} = mc^2/h$ for the Compton frequency and a *coupled* frequency for the deBroglie wavelength. This new frequency is related to $E = h\nu_{\text{dB}} = \sim (\gamma - 1)mc^2$, where γ is $(1 - v^2/c^2)^{-1/2}$. Thus, as the electron orbit shrinks and the velocity approaches that of the speed of light, its gamma, γ, and effective frequency increases and the effective wavelength of the electron ($\lambda_{\text{dB}} = h/\gamma mv$) decreases further. Is there another resonance at an even deeper level? Approximate solution to the KG equation says no! The neutron could be a candidate for the deep orbit of known stability; however, it takes more energy to get there than the Coulomb potential can provide at even the classical electron radius. On the other hand, the KG equation does not include the nuclear potential, mass, or particle spin; and the approximate solution does not even allow angular momentum. With these inclusions, a more detailed equation could convert mass energy of the proton, assumed to be infinite in the simple case, into electron mass or kinetic energy and produce a two-level 'neutron' or a heavier charged particle. Since there are a number of approximations in the KG equation and its solution(s), particularly as the nucleus is approached, the neutron could provide the deep relativistic orbit that we are addressing and we might not recognize it as such. Some known physics could be violated that was not included as appropriate boundary conditions in the mathematical equations. Therefore, that possibility becomes a different story. The nought-orbit solution of the Dirac equation needs to be explored further.

We have given a logical basis for the existence of very-deep energy level for atomic electrons that is predicted by a relativistic correction to the Schrodinger equation. What keeps electrons from filling it and precipitating high rates of fusion in, for example, water? A possible key is in the inability to transfer energy between one or more bound electrons, between a bound electron and a photon/phonon, between a bound electron and a proton, or between the Coulomb field and the relativistic electron without transferring angular momentum. Both photons and phonons are bosons and have angular momentum of 1 (h). Therefore, they are not candidates for energy transfer in this $l = 0$ case. However, to fit the model results, all Coulomb potential energy must be converted into the electron's relativistic kinetic energy.

A potentially more important answer to the question of why the nought orbit is not observed comes from the standard solutions of the Dirac equations in 1-D vs 3-D. While the 1-D equation predicts a nought orbit, the 3-D version does not [13]. I had attributed this difference to the singular Coulomb potential. However, even when using a truncated potential without singularity, this difference remains. There is a piece of information here that pertains directly to the present development. An atom in free, or semi-free, space is essentially in three dimensions. However, when in a very-strong electric field, a single dimension dominates. The lochon model describes that very situation. If the standard model of the Dirac equation is correct, *the very act of bringing two nuclei into close proximity, creates a nought orbit.* The nought orbit would almost never be observed, or recognized if observed, because it has such a transitory existence. Only if the orbit(s) can be populated by one or more electrons, and the nuclei stabilized in a femto molecule, would the nought orbit's existence be demonstrable. We will explore the other options and implications below.

3. Naught Orbits as Applied to the Lochon Model

There are several differences between Naudts' model and the Lochon Model of a nought orbit. First, the lochon model predicts two electrons in the orbit rather than one. This complicates matters and yet, being a boson, the electron pair also counters some arguments against the naught orbit. As a first-order approximation, we ignore the fact that the electron pair is two electrons with a mutually repulsive nature and not a single doubly charged boson. Assuming a boson with charge of $2e$ and mass of $M = 2m_{\mathrm{o}}$, Eqs. (2) and (3) give new values for energy and orbit radius. The energy depends on both mass and potential. The mass and charge are both doubled so that the lochon nought-orbit radius r'_{o} will be twice cut in half (hence, $r'_{\mathrm{o}} = \sim 100$ fm). The potential V for a single electron, given as proportional to the fine structure constant over the radius, will quadruple because of the reduced radius and double again because of the double charge. However, the r dependence cancels out in the calculation for the energy. Therefore, the lochon energy level is $E'_{\mathrm{o}} = 2m_{\mathrm{o}}c^2(2\alpha) = 4E_{\mathrm{o}}$. (Inclusion of the electrons' repulsion may reduce this energy to $1/2$ to $3/3$ of that for a single-bodied doubly charged boson. However, the near-field relativistic magnetic attraction – spin–spin, orbit–orbit, and spin–orbit – may counter this effect.) On the other hand, the binding energy (a negative value) for the pair, being E'_{o} minus the rest mass energy, is still going to be close to twice that for the single electron (in our present approximation).

The actual value of E'_{o} does not change the binding energy much. That is dominated by the mass energy and Compton-wavelength resonance. Therefore, the internal energy of the lochon, which can reduce the Coulomb attraction of the nucleus for the paired electrons by 25– 50%, has little impact on the nought-orbit lochon binding energy that is $\sim$1 MeV. However, it could increase the field radius, r'_{o}, so that it exceeds the Compton radius of a single particle with the same mass.

The binding energy for the nought-orbit lochon is: $\sim$ 1 MeV
The kinetic energy of the nought-orbit lochon is: $\sim$ 1 MeV
The potential energy of the nought-orbit lochon is: $\sim$ -2 MeV
The *suggested* nought-orbit lochon radius, r'_{o}, is: $\sim$ 100–200 fm

To achieve this high magnitude of potential energy, the average electron-charge orbital radius is only on the order of a Fermi, which is near to the classical-electron radius. The electron has shed most of its identify in fusing with the nuclear proton(s) field. The Zitterbewegung is of the order of 390 fm. However, from Eq. (1), the strong 3-D focusing of the electron motion about the nucleus of $r^{-1}\exp(-r/r_{\mathrm{o}})$ allows dimensions of the average field concentration to be this small. Therefore, the Heisenberg Uncertainty Principle is not violated by the small confinement for a low-mass charged particle.

4. Muon Catalysis

Muons catalyze D–D fusion by filling a deep ground-state level in hydrogen atoms that is roughly 200 times smaller in radius than that of the electron [23,24]. This means that they first form pseudo-neutrons (pico-atoms) and then tiny hydrogenic molecular ions (pico-molecules of p–P, p–D, p–T, d–D, d–T, or t–T). These pico-molecules are bound by a muon and would be much smaller than the corresponding molecular ion bound by an atomic-orbit electron. In the d–D case, the proximity is sufficient to allow fusion to occur within 10s of picoseconds [25]. On fusion, the muon generally flies off to restart the cycle.

Before we get into the muon-catalyzed fusion of nuclei, it is useful to mention muon fusion *with* a nucleus and how it would differ from nought-orbit electron fusion with a nucleus. This comparison is important because it provides information, from a well-studied system, on the effects of a tightly bound negative charge for its capture by different nuclei. "We shall also assume that lepton universality holds better than we need, so that the many lessons learned from μ decay can be transferred over to muon capture, which thus can be considered as an extension of electron capture, *though perhaps with many more states available*" [26]. Except for very light nuclei, muon *capture* is more likely than muon atomic *decay* through the many available states to the lowest orbit. We are interested in both the very-light nuclei and a system with no states between the lowest Bohr orbit (n = 1) and the nought orbit (n = 0). Some other differences exist. The muon has sufficient energy to form a neutron from a proton; the nought-orbit electron alone does not. "When muon capture occurs in any nucleus, the energy release of about 100 MeV is mainly donated to the neutrino,…' and "… for muon capture from a μ–p atom, the recoiling neutron takes only 5.2 MeV of kinetic energy, whilst the neutrino takes away 99.1 MeV." This means that any fusion reaction with muons falls into the high-energy nuclear-physics regime. There can be no question about the non-existence of a nought orbit for the muon. The high muon mass means that its nought orbit would be much smaller than that for an electron and therefore capture/fusion would be nearly instantaneous. Can the same point be made for an electron in a nought orbit about a high-Z nucleus? Another point, which may become important for electron decay to the nought orbit about a proton, is that the muon capture rate from a singlet state is more than 50 times that from the triplet state.

How does this picture compare with that of the Lochon Model? The muon starts out being massive and independent. The Lochon starts out as a bound electron pair in an s orbital about a nucleus (generally hydrogenic in our usage). The muon, on 'atomically' binding to a 'proton' subsequently finds another hydrogen atom or molecule and forms a very small (pm-size) molecule. The lochon in a special lattice matrix does work on a colliding hydrogen pair and in the process gains kinetic energy as it slides deeper into the Coulomb potential well. The muon resides in a deep 'Bohr' orbit ($\sim$ 250 fm) and the separation of the muonic molecule nuclei is about twice that radius. If attained, the nought-orbit-bound lochon will have become relativistic and, being doubly charged in the n = 0 orbit (at 100–200 fm, by one interpretation of the KG equation), will bind another proton or deuteron at about that distance, forming a 'pico-molecule'.

The muonic molecular ion (e.g., $H\mu H^+$) and the nought-orbit molecular ion (e.g., $H\hat{}H^+$) are of nearly the same size (both less than a pm in diameter). The major differences are in the location of the energies and the energy levels. The excess energy of the muonic molecule (relative to standard molecular hydrogen) is in the muon mass. In the nought-orbit molecule, much energy is tied up in electron and nucleon kinetic energy and in the concentrated, fluctuating, EM fields about the relativistic electron pair. This 'AC' EM-field energy, resulting from the extreme electron acceleration, has been subtracted almost entirely from the proton field-energy (mass) in the nought-orbit molecule (not so in the muonic molecule). From the fusion perspective, this reduced nuclear mass means that there might not be fragmentation in the former case and there is confirmed fragmentation in the latter case. This is a major difference in the conventional muon-catalyzed D–D fusion story and in the lochon-catalyzed cold-fusion story.

If the nought-orbits were accepted, there is little doubt that fusion, with different or reduced fragmentation ratios, would be expected. It would be understood as a natural consequence of the reduced energy of the combined nuclei. There is still the problem of how to populate these orbits. It is not a given that this orbit must be filled with the assistance of paired hydrogenic atoms under just the right circumstances. It is possible that the nought-orbit atom, and therefore the nought-orbit molecule or molecular ion, could be created in another manner.

Another difference in the fusion processes of the two molecules is a consequence of the relative muon or lochon ability to radiate or otherwise couple the fusion energy away from the excited helium nucleus. The muon is fat and slow relative to the relativistic electrons or lochon. Therefore, it has little ability to radiate much acquired nuclear energy in the fusion process. Because it cannot readily dissipate nuclear energy, the fragmentation process is still dominant. In the case of the 0.5–1 MeV tightly-bound electrons, they have the ability to couple closely to both the accelerating nucleons and to the adjacent Pd electrons. With this proximity to, and energy flow from, the fusing deuterons, they may drop below the fragmentation levels before that becomes a real event.

Fragmentation is a feature of energetic nucleons in an excited nucleus when that energy exceeds the binding of the potential well. Both the muon and the lochon, as tightly bound negative charges, will be able to reduce the proton Coulomb forces that will try to force the nucleons out of the nucleus. However, the lochon has twice the charge and, particularly in a fermi-sized nought orbit, will therefore raise the fragmentation levels much more than can a muon.

5. Electron Capture

We can talk of muon capture from a deep orbit by the nucleus, but we also have information about orbital-electron capture by the nucleus [27]. This process, equivalent to positron (β^+) emission in terms of change in nuclear charge, is a major contributor in nuclear decay. By 1977, it was found to contribute to the decay of nearly 500 different nuclides. Electron capture from a nought orbit may become as important to transmutation processes [28] in LENR as is the actual fusion of nuclei.

Two principle observations are made that will pertain to the comparison of electron capture from an atomic orbit to that from a nought orbit. First, the nuclear weak interaction converts nuclear energy, an orbital electron, and a nuclear proton into a neutron and neutrino. Second, EM radiation *may* be involved in the collapse of the electron from an atomic orbit into the nuclear region during the capture. The weak interaction has a very small range defined by the overlap of the atomic electron and nuclear wave functions. This latter is of the same order as the classical electron radius. The range for generation of EM radiation (called internal Bremsstrahlung in this case), is much larger. It is defined by the range of the Green's function and is of the order of the Compton wavelength (except for energies near the electron binding energy, where the Green's function range expands greatly).

While the interaction cross section of an EM interaction is much greater at the binding energy, the total interaction is still reduced by about four orders-of-magnitude because the weak interaction must still take place. In this case, the nuclear decay energy is shared between the electron, the neutrino, and the photon. While we may normally consider Bremsstrahlung to be a continuous process with many photons coming out from an accelerating electron with an energy continuum, the probability of even a second photon being emitted in this single-event process of electron capture is much less than that for a single photon. Here is a case, of an electron changing energy levels (greatly) and not generally radiating photons. This apparent violation of both Maxwell's equations and QM explanations must be addressed elsewhere. (While quantum electrodynamics mathematically treats it accurately, the physical mechanism of radiation, or its inhibition, is not developed therein.)

When electron capture from an atomic orbit is discussed, that from a molecule is often referred to in a side note indicating that capture from 'outer' electron shells can be influenced by the chemical environment. In a nought-orbit molecule (a femto-molecule?), the nought orbit can be considered the outer orbit and it is very much affected by the neighboring nucleus (and vice versa). This effect could greatly enhance or retard electron capture. One means of explaining this has to do with an altering of the nature of the transitions. Electron capture has ‘allowed’ transitions ($\Delta J = 0, \pi_i\pi_f = +1$, if $L = 1$ and $\Delta J = 1, \pi_i\pi_f = +1$) and various levels of ‘forbidden’ transitions $\Delta J = 0,1\ \pi_i\pi_f = -1$; and $\Delta J = n > 1\ \pi_i\pi_f = (-1)^n$; or $\Delta J = n > 1\ \pi_i\pi_f = (-1)^{n-1}$, where L, J, and π gre the radiation multipolarity and the spin and parity of the various states Forbidden transitions could be many orders of magnitude less likely than allowed ones. The probability of electron capture relative to fusion of the nuclei in a femto-molecule could depend as much on parity as on the energy levels of the product nuclei.

As a competition to nought-orbit catalyzed fusion, the well-known electron capture from an atomic orbit should be compared with that proposed from a nought orbit. Some similarities include:

(1) Both atomic- and nought-orbit electron capture probabilities are proportional to their wave function overlap probability with that of the nucleus (e.g. the electron density at the nucleus).
(2) Both may emit EM radiation in the process.
(3) The assumed nuclear-charge distribution affects the capture probability calculation. However, for light elements, the electron, during a transit, may have a greater effect on nuclear charge distribution than the model used.
(4) Relativistic effects are important (s orbitals transit the nuclear region).
(5) Capture probability depends on parity and change in angular momentum (spin and orbital) during the transition. Forbidden transitions are many orders-of-magnitude less probable.

Some differences are as follows.

(1) The electron density for a nought-orbit electron is orders of magnitude larger than that for an atomic-orbital electron. Thus, nought-electron-capture probability can become orders of magnitude higher than the probability of positron decay (or some other decay paths) from many radioactive nuclei. This mechanism alone provides a basis for the observed LENR reduction of radioactive waste materials as seen in the transmutation studies that show strong trends toward stable nuclear isotopes.
(2) Effects of orbital-electron screening is large for orbital-electron capture, but negligible for nought-orbit electron capture - where the orbit is far inside that of the atomic electrons and the nought-electron capture probability is so much higher.
(3) For the nought-orbit electron, distortion of the nuclear charge density is significant most of the time, not just during a transit.
(4) Relativistic effects are important mainly for high-Z ($Z > 70$) atoms (where low-n orbital electrons are relativisitic and transit the nucleus).
(5) Introduction of another ‘coupled’ nucleus can alter the transition probability of the nought orbit by changing the parity, spin, or angular momentum of the final nuclear state. Thus, a forbidden transition can become allowed, and vice versa. This cannot happen with an atomic electron capture.
(6) The lack of energetically nearby atomic levels, makes more difficult any transfer of energy from a nought-orbit electron in its descent into the nucleus.
(7) The possibility of a lochon in a nought orbit, rather than a single electron, can change the spin and parity of both the initial and final states to increase the probability of either nuclear fusion or of electron(s) capture.
(8) A lochon in a nought orbit does have high proximity and enough energy to create a neutron from a proton (but not the one it is orbiting until the nuclear potential is available). Therefore, the fusion of a hydrogenic femto-molecule (p–2eˆ—p $\geq$ d^+ + e) is very rapid.

6. Internal Conversion

The details of nuclear de-excitation, once a nought-orbit electron, lochon, atom, or even a nought-orbit molecule have been captured by a nucleus, must be explored. There are similarities and differences between these systems and that of normal nuclear decay. In electron capture, the formation of a neutron allows decay to a lower, or ground, state with the excess nuclear energy leaving via the neutrino, and perhaps a gamma ray. Electron capture from the nought-orbit is not greatly different. However, the electron binding energy and kinetic energy are much greater. Therefore, the energy requirements for the process are much less. Nevertheless, neutron formation is a weak interaction and there are competing processes for converting the nought-orbit or nuclear fusion energy to lower levels. Internal conversion, IC, is one of them.

IC is a radioactive decay process whereby an excited nucleus interacts with an electron in one of the deepest atomic orbitals, causing the electron to be emitted from the atom. However, the high-speed selectrons from internal conversion are not beta particles (β particles) since they have a well-specified discrete energy and have no associated neutrinos. The kinetic energy of the emitted electron is given as $E = h$gωg= $(E_{\rm i} - E_{\rm f}) - E_{\rm B}$, where $E_{\rm i}$ and $E_{\rm f}$ are the energies of the atom in its initial and final states (including excited nucleus), respectively, while $E_{\rm B}$ is the binding energy of the electron [29] and ω is the frequency of the electric dipole moment of the nucleus [32]. Since the probability of IC is proportional to ($2mc^2/h\omega$p$^{7{\rm vy}}$, energetic conversion electrons are much less common than low-energy ones (keV range). The high binding energy of a nought-orbit electron ($E_{\rm B} = \sim 0.5$ MeV) prevents ejection of such electrons for too small energy transfers ($\Delta E = (E_i - E_f) < E_{\rm B}$). On the other hand, in the case of d–Dˆ fusion, the energy of fusion is so high ($E = \sim$20 MeV) that, as the fusion energy is converted into nucleon kinetic energy, internal conversion could be a major pathway for ejecting the nought-orbit electron as the nucleons approach within keVs of ground state. This event occurs by reducing the nuclear energy in a single energy step close to the electron binding energy. Another difference between d–Dˆ fusion and normal IC has to do with the stability of the nuclear states. If E_i is not fixed (not a stationary orbit), then the conversion electron will not have a fixed energy. What values of the energies (E_i and E_f) should be used for an actively decaying nucleus in the equation above? The final energy of such IC is not necessarily the ground state. How do the dynamics of this process affect the IC-like decay probability relative to the other decay mechanisms?

In the internal-conversion process, the wavefunction of an inner-shell electron penetrates the nucleus and may couple to the excited state and take the energy of the nuclear transition directly, without an intermediate gamma ray being produced first. The process of imparting energy to the electron may be seen as taking place by means of a *virtual photon*, which never appears - except as a feature of an equation rather than as a directly measurable particle.

The importance of IC to our discussion of the nought-orbit electrons and the lochon is the known direct transfer of excess nuclear energy to transiting electrons. Whether an electron or lochon is in a nought orbit of an atom, a femto-molecule, or in a fusing pair, because of the proximity to an adjacent accelerating charge [30,31], it is able to draw energy from any excited-state protons (and perhaps the neutrons?). In the same 'manner' as a photon can form from the EM field about an excited atomic electron, energy can concentrate in a resonant state or flow into or through an 'absorber', e.g., the bound electron (this 'manner' is the topic of another paper) from Ref. [32]:

"In a semiclassical picture of internal conversion, the atomic electron is perturbed by an electromagnetic field that contains near- as well as far-zone components. The former corresponds to the instantaneous electromagnetic field, the latter contains components due to retardation which transport energy off to, in principle, infinity, that is, radiation components."

A deep-orbit electron, being relativistic most of the time, provides (and can receive) a much higher level of both near- and far-field EM energy from the nucleus than does an atomic electron. Thus, both IC and the nuclear-induced photo-effect are greatly enhanced. Sorenson continues,

"… contributions to internal conversion primarily come from distances from the nucleus of the order of the Compton

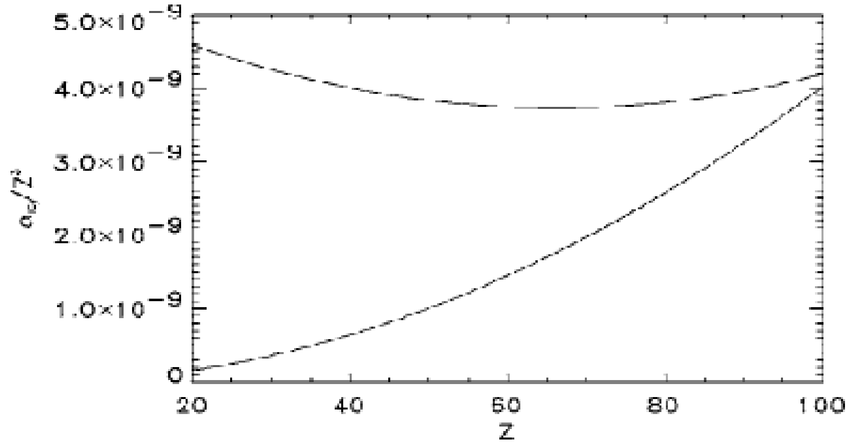

Figure 1. K-shell internal conversion. The $E1$ conversion coefficient divided by Z^3 is shown as a function of atomic number Z at a transition energy of 1 MeV. The upper curve is the full coefficient; the lower curve is the photoeffect contribution only. ([32]Sorenson, by permission ...)

wavelength of the electron or shorter."

This statement of proximity coupling indicates why an IC-like process may be important for the deexcitation process in the fusing of deuterons into a sub-fragmentation level ^{4}He* [11].

Normal internal conversion is favored when the energy gap between nuclear levels is small and there is insufficient energy to decay by pair production. It is slower when the nuclear-energy gap is large and therefore other processes may dominate. *It is the primary mode of de-excitation for the forbidden* $0^+ \rightarrow 0^+$ *(i.e. E0, or photonless) transitions.*

"The *total angular momentum carried by virtual photons can be zero*, and therefore the process is not restricted. The process of the exchange by virtual photons without changing the total angular momentum, *called* E_0, is known in

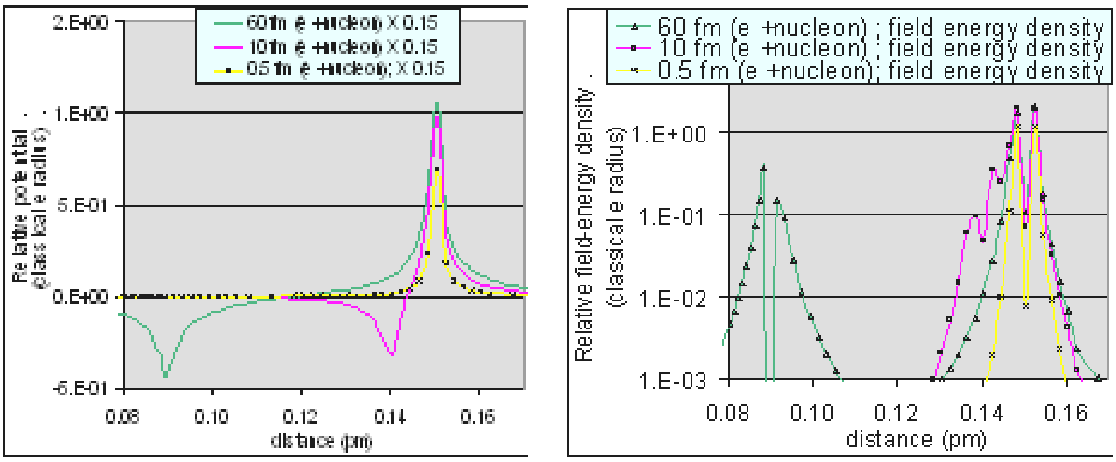

Figure 2. (a) Electric potential between, and (b) EM mass-energy distribution of, an electron (assuming a classical radius) and proton separated by 60, 10, and 0.5 fm. Note change in "size" of both particles, as they approach each other, and the change in vertical scale between (a) and (b).

nuclear spectroscopy and is sometimes called *photonless exchange"* [33]¸ my emphasis**.**

In this process, the excited nuclei are able to rid themselves of energy (donating it to relativistic electrons) without changing electric and magnetic moments.

Compared to many competitive processes such as radiation or the photoelectric effect, IC is a dominant decay mode for low-Z nuclei, even when angular momentum is available (for allowed photo-transitions). The upper curve in Fig. 1 (*Sorenson fig get permission*), for the total dipole-conversion coefficient (α_{IC} = IC + photo effect) divided by Z^3 as a function of Z, shows this increasing internal conversion coefficient relative to the photoeffect with decreasing atomic number. Since both effects are related to the number density of electrons in the vicinity of the excited nucleus, can the photoeffect be enhanced by the near presence of adjacent lattice-atom electrons? (For example, as the s–d hybrid electrons are shared by the Pd and D atoms.) If so, it would be a major means of dissipating excess nuclear energy resulting from fusion of deuterons in condensed matter. In the case of femto-hydrides with a high-Z partner, the photoeffect would likely be the dominant de-excitation mode.

Internal conversion for forbidden optical transitions is greater for small nuclear-energy gaps. Therefore, MeV naught-orbit electrons are not likely to be ejected from the nuclear region, via IC, until the nuclear energy has dropped to much lower levels or, via photoemission, until the electrons or protons have acquired angular momentum during the decay process to the ^{4}He ground state.

What are the similarities between internal conversion in the solid state [34]and the proposed nought-orbit electron or lochon-induced de-excitation of the excited ^{4}He* nucleus?

(1) Both are an exchange of energy between nucleons and electrons transiting the nucleus.
(2) Energy is directly transferred from protons to electrons within an electron Compton radius of the nucleus
(3) Angular momentum is not necessarily transferred between nucleons and nought-orbit or internal-conversion electrons
(4) Both are competing with other nuclear decay modes.
(5) Both take place when other, faster, decay processes are not possible or are suppressed, e.g., the forbidden $0^+ \rightarrow 0^+$ transitions.
(6) Both may result in the exit from the atom of an energetic electron.

How does internal conversion differ from the proposed lochon-induced deexcitation of the excited ^{4}He* nucleus?

(1) IC is important in unstable or metastable nuclear states. Nought-orbit electrons, and a lack of any stable states beneath the energy level of an excited nucleus (e.g., in lochon-mediated deuterium fusion) prevents the relative nuclear stability required for consistent energy transfer to photons and atomic-orbit electrons.
(2) Internal conversion for forbidden transitions dominates in small-energy-gap transitions; the ^{4}He* to ^{4}He ground-state energy difference is very large (at least initially).
(3) Energies in the excited ^{4}He* nucleus are sufficient to make real electron-positron pair production a competitive process. IC for high-energy forbidden optical transitions is generally low and generally cannot compete with pair production. However, this characteristic radiation has not been observed in LENR – why not? See 1 above.
(4) Internal-conversion electrons exit the nucleus with fixed energy; in LENR, energetic electrons have not been observed to exit the nucleus; and, in the present model, they will not do so until they have already transferred most of the excess nuclear energy to the surrounding electrons.
(5) Internal-conversion electrons have binding and average kinetic energies in the atomic-orbital range. Lochons have binding and average kinetic energies in the MeV range. This difference in energies means that:
    (a) The much greater binding energy of the lochon, makes it more difficult to be ejected from the nucleus Coulomb potential. Therefore*, it can accumulate and reradiate large amounts of energy without being ejected itself.*

(b) The deBroglie frequencies of the Mev lochon is greater than that of the multi-Mev nucleons and therefore can accumulate (and reradiate) energy from the ^{4}He* protons. This competitive decay path (and the forbidden photo transition) accounts for the low observed electron–positron pair production.
(c) The deBroglie frequency of a low-Z atomic electron (multi-eV) is less than that of the nucleons and therefore cannot gain resonant energy from such a source.
(d) The energy transfer from energetic nuclear protons to lattice electrons via proximity coupling is orders-of-magnitude less for the lower energy internal-conversion electrons.

(6) The possibility of an electron pair (lochon) rather than a single electron interacting with the nucleons permits some additional decay processes. For instance, actual photon exchange might occur for paired electrons so that no net change in nucleon angular momentum results.

The net result of these two lists is to show that there exists a process that allows transiting energetic electrons to de-excite a nucleus, via direct energy coupling and an internal-conversion-like process, without violating known physics. Also, the differences between internal conversion and the proposed lochon-induced deexcitation processes all point to a much greater efficiency in the energetic LENR process. This direct energy-coupling process improves the LENR competition with other decay modes. Therefore, even with fragmentation energetically possible, the 'internal-conversion' energy-transfer process involving tightly bound (and paired?) electrons could be important pathways to the ^{4}He ground state.

7. Summary

The Extended Lochon Model, in seeking to explain the observed phenomena of LENR, has begun to provide an understanding of bound electrons in relativistic quantum mechanics that has been available from the mathematics (KG and Dirac equations) for many decades. This important application of the 'naught' orbit may lend credence to a here-to-for rejected solution in the Quantum Mechanics formalism. The mathematical wave-mechanics model may not be the reality. However, if not, it still reflects reality very well in most cases and is a very useful tool. We may not know exactly how it works; and as a consequence we may not interpret it correctly. Nevertheless, with a new set of data from LENR, we may now be able to provide new insights into the physical nature of elementary particles and their interactions and benefit from some work that has gone before, but has not necessarily been accepted.

The naught orbit, defined by both the nature of an electron and its relativisitic interaction with charged nucleons, now becomes a powerful tool for physically explaining some accepted mathematical physics as well as a here-to-fore available, but unaccepted, physics model. It provides a mechanism for understanding how nature has avoided the contradiction of an apparent singularity at the center of a Coulomb potential about a charge. More details of this new understanding, as it rapidly evolves, will be provided elsewhere. LENR may be providing the data needed to open up the mystery of the nuclear interaction and to combine both nuclear and atomic physics in a smooth manner.

Acknowledgements

This work is supported in part by HiPi Consulting, New Market, MD, USA; by a Universiti Sains Malaysia Research Grant (1001-PNAV-817058), by the Science for Humanity Trust, Bangalore 560094, India; and by the Science for Humanity Trust Inc, Tucker, GA, USA. Various members of the CMNS googlegroup have been most helpful in contributing concepts and comments to the development of this model. In particular, Tom Barnard (ideas developing at http://www.ichaphysics.com/blog-commentary/), Robert Godes (brillouinenergy.com, ideas now expressed in *Infinite Energy* http://www.brillouinenergy.com/GodesIE82.pdf), and Horace Heffner (ideas now organized at *http://www.mtaonline.net/∼hheffner/dfRpt* and http://www.journal-of-nuclear-physics.com/?p=179_) provided new ideas and novel concepts that supported, or developed into, important parts of the extended lochon model. Scott Chubb corrected a misconception of the nature of the hydrogen electron structure in the Pd lattice. Ed Storm, from his great knowledge of the LENR field and desire to understand the actual mechanisms, contributed continuing feedback in the form of useful questions and challenges.

References

[1] V.A. Chechin, V.A. Tsarev, M. Rabinowitz and Y.E. Kim, Critical review of theoretical models for anomalous effects in deuterated metals, *Int. J. Theoret. Phys.* **33** (1994) 3.
[2] K.P. Sinha, Theoretical model for low-energy nuclear reactions in a solid matrix, *Inf Energy* **29** (2000) 54.
[3] K.P. Sinha and A. Meulenberg, Laser stimulation of low-energy nuclear reactions in deuterated palladium, *Current Science* **91** (2006) 907 (*arXiv:cond-mat/0603213*).
[4] K.P. Sinha and A. Meulenberg, Lochon catalyzed D–D fusion in deuterated Pd in the solid state, *Nat. Acad. of Sc. (India) Letters* **30**(7,8) (2007) (*arXiv:0705.0595v1*).
[5] K.P. Sinha and A. Meulenberg, A model for enhanced fusion reaction in a solid matrix of metal deuterides, in Proc. of *ICCF-14 Int. Conf. on Condensed Matter Nuclear Science,* Washington, DC, (2008), ISBN: 978-0-578-06694-3, D.J. Nagel, M.E. Melich, R. W. Johnson, S.R. Chubb and J. Rothwell (Eds.), http://www.iscmns.org/iccf14/ProcICCF14b.pdf.
[6] K.P. Sinha and A. Meulenberg, Quantum-correlated fluctuations, enhanced tunneling, and low-energy nuclear reactions in condensed matter (alloys), *16th Int. Conf. On Condensed Matter Nuclear Science (ICCF-16)*, Chennai, 6 Feb. (2011), to be pub. *J. Condensed Matter Nucl. Sci.* (JCMNS) (**6**).
[7] F. Raiola, *et al.*. of the LUNA Collaboration, Enhanced electron screening in d(d,p)t for deuterated metals, *Eur. Phys. J.* **A 19** (2004) 283–287, DOI 10.1140/epja/i2003-10125-0.
[8] K. Czerski, A. Huke, P. Heide and G. Ruprecht, Evidence for a host-material dependence of the n/p branching ratio of low-energy d+d reactions within metallic environments, *Eur. Phys. J.* A **27** (2006) 187.
[9] J. Naudts, On the hydrino state of the relativistic hydrogen atom, http://arxiv.org/abs/physics/0507193.
[10] A. Meulenberg and K.P. Sinha, Tunneling beneath the fragmentation level, 15^{th} *Int. Conf. on Cond. Matter Nuclear Science*, Rome, Italy, Oct. (2009).
[11] A. Meulenberg and K.P. Sinha, Tunneling beneath the $^4He^*$ fragmentation energy, *J. Condensed Matter Nucl. Sci.*, JCMNS **4** (2011) 241–255.
[12] http://en.wikipedia.org/wiki/Halo_nucleus.
[13] H.N. Spector and J. Lee, Relativistic one-dimensional hydrogen atom, *Am. J. Phys.* **53** (1985) 248.
[14] Zhong-Liang Zhang, Wu-Shou Zhang and Zhao-Qun Zhang, Further study on the solution of Schrödinger equation of hydrogen-like atom, *Pro. 9th Int. Conf. on Cold Fusion.* May 21–25, 2002, Beijing, China, pp. 435–438.
[15] J.V. Kadeisvili, The Rutherford–Santilli neutron, *Hadronic Journa*l **31** (2008) 1–114.
[16] N. Dombey, *Phys. Lett. A* **360** (2006) 62.
[17] A. S. de Castro, *Phys. Lett. A* **369** (2007) 380.
[18] T. Nadareishvili, A. Khelashvili, Some problems of self-adjoint extension in the Schrodinger equation, http://arxiv.org/abs/0903.0234 accessed 28 June 2010.
[19] J.A. Maly and J. Vavra, Electron transitions on deep Dirac levels I, *Fusion Technol.* **24** (Nov) (1993) http://people.web.psi.ch/pruchova/Vavra_d_dirac_l.pdf.
[20] R.A. Rice, Y.E. Kim and M. Rabinowitz, Comments on electron transitions on deep Dirac levels I, *Fusion Technol.* **26** (1994) 110.
[21] http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html.
[22] J.A. Maly and J. Vavra, Electron transitions on deep Dirac levels II, *Fusion Techol.* **27** (Jan) (1995) 59.
[23] J.D. Jackson, Muonic-hydrogen molecular bound states, quasibound states, and resonances in the Born-Oppenheimer approximation, *Phys. Rev. A* **49**(1) (1994).
[24] J.D. Jackson, A Personal adventure in muon-catalyzed fusion, *Phys. Perspect.* **12** (2010) 74–88 _2009, Published open access at Springerlink.com, 1422-6944/10/010074-15, DOI 10.1007/s00016-009-0006-9.

[25] J.C. Séamus Davis, Quoted from “Old question answered: ’Heavy fermions’ aren’t really heavy – they just dawdle,” *Cornell Chronicle*, June 3, 2010, http://www.news.cornell.edu/stories/June10/HeavyFermions.html.
[26] D.F. Measday, The nuclear physics of muon capture, *Physics Reports* **354** (2001) 243–409.
[27] W. Bambynek et. al., Orbital electron capture by the nucleus, *Rev. Mod. Phys*. **49**(1) (1977).
[28] M. Srinivasan, G. Miley and E. Storms, *Nuclear Energy Encyclopedia*, Chapter 43, Steven B. Krivit and Jay H. Lehr (Eds.), John Wiley, ISBN 978-0-470-89439-2 (Aug) (2011).
[29] http://en.wikipedia.org/wiki/Internal_conversion .
[30] K.P. Sinha, A. Meulenberg and P.L. Hagelstein, Quantum-coupling between closely-spaced surfaces via transverse photons, arXiv:cond-mat/0606184v2.
[31] K.P. Sinha and A. Meulenberg, Radiative-field quantum-coupling between closely-spaced surfaces, arXiv:0902.0682.
[32] A.H. Sørensen, Internal conversion and the photoelectric effect, *Phys. Rev. A* **73** 032719 _2006.
[33] H.C. Pauli, K. Adler and R.M. Steffen, *The Electromagnetic Interaction in Nuclear Spectroscopy*, W.D. Hamilton (Ed.), (North-Holland, Amsterdam, Oxford, 1975), p. 341.
[34] P. Kalman and T. Keszthelyi, *Phys. Rev.* **C69** (2004) 031606(R).