Decay modes of excited ^{4}He below the fragmentation levels

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Abstract. Three reasons are given to dispute the claims of numerous experimenters that higher-than-expected heat and radiation are obtained from nuclear fusion of deuterium atoms at room temperature: 1) the inability of two low-energy protons or deuterons to penetrate the mutual Coulomb barrier; 2) the production of heat in excess of that possible for the measured particulate radiation, and 3) the high levels of ^{4}He measured (much beyond that permitted by present nuclear physics models). The first has been addressed earlier. This paper discusses the second and how it leads to an understanding of a critical mechanism behind low-energy nuclear reactions.

Keywords: CMNS, LENR, Fusion, Deuterium, Fragmentation

INTRODUCTION

Adequate evidence has been accumulated[1,2] to confirm a variety of fascinating "near radiationless Low Energy Nuclear Reactions" (LENRs) occurring in deuterated (and hydrided) metallic lattices under certain conditions. The phenomenon has been found to occur primarily on the surface of the deuterated/hydrided samples and that too only in certain highly localized sites, which seem to provide what has been characterized as a "Nuclear Active Environment" (NAE). Reproducibility has significantly improved over the years, approaching almost 100% levels in some configurations. Nevertheless, universal reproducibility and satisfactory theoretical understanding of the phenomenon are lacking even after more than 20 years of research on the topic.

Rather than cover again the evidence for LENR, this paper will address one of the arguments presented against the possibility of nuclear fusion two decades ago. It will show how those objections actually helped to guide the theoretical work needed to explain the results. Answers to this argument, in terms of known nuclear physics data, are presented in the following development.

ACRONYMS

CMNS	- condensed Matter Nuclear Science	^{4}He	- helium atom, (atomic mass 4)
LENR	- low-energy-nuclear fusion	^{4}He*	- excited nuclear state of helium
Lochon	- local charged boson (electron pair)	^{3}He	- Helium atom, (atomic mass 3)
E	- energy (MeV, or keV)	^{3}H	- tritium, T, hydrogen atom, (atomic mass 3)
4d-orbital	- a conduction-band level in palladium (Pd)	H, D	- hydrogen, deuterium atoms
Q	- mass deficit between initial and final state *e.g.*, between D_2 and ^{4}He (MeV)	p, d, t, α	- proton, deuteron, triton, helium-4 nucleus
		γ	- gamma ray

The first of three major arguments against LENR was the *inability of protons or deuterons to overcome the MeV-sized Coulomb barrier between them* without having energies in the many-keV to MeV range. (While the nuclei, protons and deuterons - p and d - or atoms, of hydrogen and deuterium - H and D - are often used generically and interchangeably in this paper to describe the interacting particles, when specificity is required, it will be applied.) There was no evidence in any of the early work to indicate lattice-hydrogen energies above the eV range. Thus, according to the well-known nuclear physics at the time, the interaction cross-section claimed for the LENR results was more than 100 orders of magnitude higher than anything that could be explained by room-temperature D-D fusion reactions. The answer given by Julian Schwinger[3] was that the presence of lattice dynamics in a solid-state environment "capable of storing and exchanging energy." This action, described in the language of phonons, creates a system quite different from that in which the nuclear theories were engendered. Many critical papers were written in the early days (with notable exceptions) showing that this environment could make no difference.

The second argument against LENR has several sub-topics. The general argument involved *the incompatibility of the known radiation of protons, neutrons, tritium,* ^{3}*He, and gammas* [by-products of the D + D => ^{4}He* fusion-decay process known as fragmentation or 'nuclear ash', equations (1) and (2)] *with the measured heat generated from the low-energy process.* The first sub-topic is characterized by the statement, "if there were nuclear reactions generating the heat, then the only ones 'possible' in that situation would have provided *enough penetrating radiation (neutrons) to kill* everyone in the building." Neutrons had subsequently been measured, but at a rate too low to account for the heat generated.

$$\mathrm{D} + \mathrm{D} \rightarrow {}^{4}\mathrm{He}^{*} \Rightarrow \; t\,(1.01) \; + \; p\,(3.12) + 2\mathrm{e}, \quad Q = 4.13 \quad (\mathrm{P} = {\sim}0.5) \tag{1}$$

$$\Rightarrow \; {}^{3}\mathrm{He}\,(0.82) \; + \; n\,(2.45), \quad Q = 3.27 \quad (\mathrm{P} = {\sim}0.5) \tag{2}$$

$$\Rightarrow \; {}^{4}\mathrm{He}\,(0.08) \; + \; \gamma\,(23.8), \quad Q = 23.88 \quad (\mathrm{P} = 10^{-6}) \tag{3}$$

Associated with the dearth of neutrons was the second sub-topic, an *unusual fragmentation ratio of neutrons to protons or tritium* (P_n/P_p or $P_n/P_t = {\sim}10^{-7}$ where the Ps are the probability of choosing a specific decay path). All known D-D fusion reactions provided a 1-to-1 neutron-to-proton ratio ($P_n = P_p$). The observed LENR results gave 10^7 to 10^9 tritium atoms for every neutron[4]. Since the 1-to-1 ratio is not observed as prescribed by equations (1) and (2), D-D fusion "cannot" be occurring. The Qs in the equations are the mass-deficit energies between the decay-product atoms (right side of the equations) and the incident particles (the deuterium atoms leading to the helium-atom excited state, ^{4}He*). It is seen that the unlikely decay to ^{4}He [equation (3)] produces the highest Q (and therefore has the greatest heating potential) of the 3 paths. There seemed to be a 'disconnect' in the logic of the argument against cold fusion. Instead of seeing the anomalous ratio as an *explanation* for the low number of neutrons produced for the amount of heat observed, the critics added it to the list of arguments against nuclear reactions. This is called the "nuclear ash" problem.

The third sub-topic related to the D-D reaction products was the *high amount of* ^{4}*He measured in many experiments*. Nuclear physics has accurate and repeated measurements indicating the forbidden-transition nature of the gamma-ray decay from the excited state ^{4}He* to the ground state resulting from D-D fusion [equation (3)]. Thus, the probability of forming ^{4}He from D-D fusion is less than one per million fusions. This is almost as low as the percentage of neutrons that were "missing" in the LENR experiments. Nevertheless, the image of "sloppy" experimental work of these researchers was confirmed in the minds of its critics by these "impossible" results.

These arguments, based on a mature field of study (one that produced nuclear weapons and power plants with a high level of reproducibility and predictability) and supported by at least two other fields with equivalent credentials, appeared incontrovertible; therefore, the books were closed on cold fusion. “It is only pseudo-science.”

This paper will address the second of these arguments and show how it actually teaches an important feature of low-energy nuclear fusion (if the data are correct) and how a self-consistent explanation can emerge. No model for LENR has yet been universally accepted, even within their own community. Moreover, new experimental results, just as ’outrageous’ as the earlier ones, have been more-recently confirmed. Nevertheless, it must be clear to all who are willing to examine the issue that something new and different is going on - and - it holds immense promise on many levels.

‘NUCLEAR ASH’ PROBLEM

The nuclear ash problem has to do with known energy levels and decay patterns of the excited helium nucleus. Figure 1 shows these levels and the accepted decay paths.[5,6] The energy level of interest in the standard high-energy D-D fusion reaction starts at the ‘Q’ level and extends upward as the collision energy of the deuterons is increased. The Q value (arrow at ~23.85MeV) is determined from the total energies (kinetic and mass) of the deuterium atoms relative to those of the ^{4}He atom ground state. The fragmentation levels associated with equations (1) and (2) are below the Q level and most of the ^{4}He energy levels. All of these levels are well and accurately known. The decay paths and the ratios of the different paths from these levels are also well known. Therefore, when nuclear physicists claim that the energies of the LENR reaction were incompatible with the energies available and the fragments (particulate residue or ash) of the reaction, they are not talking about theories; they are talking about many years of solid, reproducible, experimental *evidence*. The gamma-decay pathway leading to the ^{4}He ground state (angular momentum, l = 0) from low-energy, l = 0, excited states (accessible from the D-D fusion process) is highly forbidden. Therefore, the lower-energy-release alternative decay paths (to ^{3}He + n and ^{3}H + p) become the paths of choice. And, from years of D-D collision measurements, they have nearly equal probabilities (a 1:1 ratio).

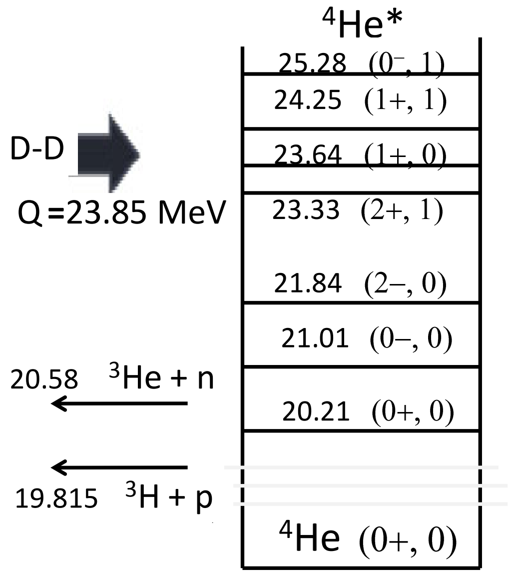

Figure 1. *^{4}He nuclear energy levels.*

When it was claimed that large energy releases were observed and yet nobody in the lab was killed or sickened by radiation damage, the inconsistencies between known and proposed nuclear fusion reactions became clear. As particulate radiation from the LENR experiments became more accurately measured, the ratio observed was “wrong.” There were almost no neutrons relative to the number of measured protons (or tritium). On the other hand, this phenomenon (if real) would account for the low level of neutron radiation in CF experiments. It also would be a very valuable asset for any nuclear power source. Furthermore, measurements of ^{4}He indicated anomalously high levels of this isotope in LENR experiments. This observation could have helped to explain the low neutron radiation levels (and perhaps low proton, tritium, and ^{3}He levels as well). However, by this time, CF had been "declared" pseudo science and nobody seems to have noticed the strong signature of a different situation from the normal D-D fusion.

Table 1 shows the fragmentation ratio for different excited ^{4}He energy levels[7] with E < Q. It tells a clear story of what is happening. The table identifies neutron- and proton-decay percentages for levels below the Q value that is the lower limit of hot-fusion theory. Notice that, as the energy level approaches Q (at 23.85MeV) *from below*, the decay path approaches the high-energy-physics predicted values of 50/50% for neutron/protons. When the energy level (*e.g.*, at 20.21MeV) is below the neutron fragmentation level (at 20.58MeV, from Figure 1), the decay path is 100% via protons.

Table 1. *^{4}He energy levels and decays*

E level (MeV)	J (parity)	Decay
23.64	**1 (-)**	% n = 45 % p = 55
23.33	2 (-)	% n = 47 % p = 53
21.84	2 (-)	% n = 37 % p = 63
21.01	0 (-)	% n = 24 % p = 76
20.21	0 (+)	% p = 100
0.0	0 (+)	Stable

The expected monotonic-increasing n/p transition ratio exists between these lower levels and the Q levels. Above the Q level, the near 50/50 ratio is universal. However, it is obvious that, if there existed an energy level below 19.3 MeV (or > ½ MeV below the proton fragmentation level at 19.82MeV, from Figure 1), the decay path could no longer be via protons either. Without this fragmentation, another path to ^{4}He ground would dominate (perhaps via energetic-gamma emission). Such lower-energy levels (or even resonances) had been proposed, and sought, to explain the observed results. These results have not been found in experiments that would have measured them; therefore, such levels probably do not exist. Recent work[8] has suggested that, even in keV-energy d-D collisions, these n/p ratios may depend on the target material. Thus sub-fragmentation-level injection, or some similar, explanation must be proposed to account for the observed LENR and low-keV d-D collision results.

BELOW THE FRAGMENTATION LEVEL

If the Q value for D+D fusion is above the fragmentation levels, and if fragments and energetic gammas are not observed in the quantities and ratios expected, then, according to the critics, the deuterons must not have tunneled through the Coulomb barrier and D-D fusion has not occurred.

Therefore, the information available from known nuclear physics, and now from LENR results, leads to a single conclusion "the deuteron pair must penetrate the Coulomb barrier and enter the common nuclear-potential well with energies below the neutron fragmentation level and perhaps even below the proton fragmentation level." This is not possible, according to 'known' physics, so something else must be happening. Tunneling through the Coulomb barrier to resonant states at or above the Q value is presently accepted physics. Before quantum mechanics was available, tunneling was not considered possible. Now the concept has been extended to include virtual particles and 'off-shell' mechanisms. It does not take too much imagination to extend the concept to that of tunneling to non-resonant states and to energies below the Q value. However, there may be other fundamental processes that need to be considered.

Several models, including the Lochon Model described previously[9,10,11,12] have addressed the means of getting the deuterons through their Coulomb barrier. However, if they cannot address the fragmentation issue, they cannot be complete. Purely quantum-mechanical models, with wave-function overlap of the deuterons, indicate the probabilities of fusion through the barrier; but, without proper interpretation, they say nothing about the fragmentation-ratio dilemma. A model of direct D-D fusion that seems to have promise in being able to do both is the Extended-Lochon Model.[13 ,14]

The Lochon Model provides a means of, and calculation for, D-D fusion from the Pd-lattice-defect sites. Deuterons are embedded in the Pd lattice and are highly confined and electrically screened from one another by the bound Pd electrons. Older models of hydrogen mobility in a lattice assumed that the ionized hydrogen (a bare proton) was the high mobility component. Modern models for PdD show that the ground state of the hydrogen atom is nearly 8 eV below the Fermi level of the Pd lattice[15] and is therefore unlikely to directly contribute its electron to the conduction band. However, it can share electrons with the broad Pd d-orbital. Thus, it allows the Pd atoms to contribute more of their electrons for conduction. The point is, the proton in a Pd lattice is never 'bare'. It must migrate because of the Pd-lattice phonon field and must be 'handed' over from one Pd atom to the next in the lattice. With increased filling of hydrogen into the lattice, fewer Pd atoms are able to receive these D atoms and thus hydrogen transport nearly ceases even though its mobility has increased because of the expanded lattice and enhanced 'sub-lattice' phonon fields.

As the local Pd lattice becomes fully 'loaded' with hydrogen (deuterium), a uniformly spaced D sub-lattice forms within and the Pd lattice stretches to its greatest extent. When the hydrogen concentration matches the Pd concentration, all of the readily accessible interstitial sites are filled and each D has eight other deuterons in adjacent 'octahedral' sites. This forms a complete sub-lattice. A full lattice will generally have greater average collective sub-lattice motion, even though a break in the lattice can often produce larger local motion. Such breaks, which are common in fully loaded PdD lattices,[16] could provide just the conditions required for LENR. One form of resonant motion in both crystalline and amorphous material (with short-range order) has adjacent lattice elements moving against each other rather than with each other. This 'longitudinal optical-phonon' mode is the one used by the model to produce the conditions needed for LENR.

The lattice and sub-lattice can interact with each other to enhance or interfere with the collective motion.[17] This may produce the final piece of the puzzle. Since the lattices are composed of charged atoms, their relative motion can create polarization of the atoms and electric fields between different elements of the lattice and the sub-lattice. If the local electric field caused by motion of the lattice is in one direction over a lattice spacing, and two deuterium atoms are coming together from adjacent sites in the D sub-lattice region, one D may be in phase with the field and the other D in opposite phase. The result is charge polarization with the result being a D^+ D^- pair. Because of screening and electron sharing, these are not unit charges. Nevertheless, the Coulomb barrier between the deuterons is thereby reduced in both length and height.

Key to the model is the stability of electron pairs in the 1s ground state. This coupled electron pair is a boson (integer-spin system => local charged boson = Lochon). Its stability permits momentary charge polarization of interstitial D-D pairs by the phonon-induced electric fields into an attracting D^+ D^- pair. Being at adjacent sites in the D sub-lattice, these deuterons are initially embedded in the Pd lattice among the bound Pd electrons. Because they are well screened, the deuterium atoms may not even be aware of the other's charge state most of the time. However, when they do get close enough for charge separation of the polarized atoms to shift from a dipole-dipole lattice interaction to a monopole-monopole interaction, they appear to be oppositely charged ions. The ionized-deuterium energies at simultaneous contact with the lattice barrier at this point of their phonon collision mode are much higher than for neutral deuterium-atom collisions. Thus, for multiple reasons, fusion probability is greatly enhanced by the lattice phonons and the resulting local electric fields.

While it provides a mechanism for fusion, the basic Lochon Model does not address the nuclear interaction after fusion. However, when it is extended into this regime, it fits very naturally and helps to explain the mechanism involved in tunneling below the fragmentation levels. This extension uses a concept introduced by Tom Barnard (http://www.ichaphysics.com/the-science-of-cold-fusion) that enhances aspects of the lochon model to deepen the atomic-electron energy levels during a portion of the phonon-induced oscillations of the deuterons within their individual lattice sites. Part of this energy goes into the electron kinetic energy and part into the work of accelerating and drawing two deuterons together (work = F x Distance). The deepened energy levels also mean that the electron orbitals are greatly reduced in size. Therefore, the D^- electrons are no longer shared with the Pd d electrons, are much better at screening the deuterons' Coulomb field, and aid the positive ion in passing into or through the minimum in the lattice barrier between hydrogen sites. It is at this point that the deuterons reflect from the barriers (lattice or nuclear Coulomb) and return to their individual sites; or, the two deuterium ions can fall back (now together) into a single site under conditions much more conducive to fusion; or, fusion can take place directly as the deuterons come close enough together.

The extended-lochon model recognized that this net energy transfer (from deuterons to electrons) came from the total energy (**E** field and mass as potential energy) of the deuterons and the electrons. However, the electrons gained kinetic energy (~1/2 MeV each) and binding energy (~1/2 MeV each) at the same time. This energy comes from the potential energy of the proton binding them. Therefore, when the mass-energy value of the fusion reaction is calculated, the result must be lower for the nuclei (~ 1/2 MeV from the D^+ and ~ 3/2 MeV from the D^- nucleus), but not for the atoms. This separation, to account for the individual electrons and nucleons, is not normally done in nuclear physics, since the atomic electrons seldom change energy very much relative to the fusion-process energies. The total nucleon Q value in the extended-lochon model can decrease by about 2 MeV before fusion ever occurs.

A two MeV reduction in Q is not sufficient to get the deuterons beneath the fragmentation level. However, the much greater electron density within the nuclear region (from the deep-electron orbitals) reduces the proton-proton repulsion and thereby increases the effective attractive nuclear potential by 1-2 MeV. The $^4He^\#$ ground state (# indicates one or both of the deep-orbital electrons are present in the nuclear region), dominated by the nucleon momenta, is not lowered nearly as much. Nevertheless, this reduced repulsion does raise the fragmentation levels relative to the $^4He^*$ (excited-state) levels, relative to the $^4He^{\#*}$ levels, and relative to the total initial energy of the deuteron pair.

Figure 2 indicates the adjusted energy levels and $Q^\#$ value for the nucleus (with lochon present), not for the atom. However, the ground state used is that of the final bare nucleus, hence, an alpha particle, $^4\alpha$, since the deep-orbit electron(s) would have been ejected by the time ground-state energy is achieved. The excited nuclear levels are taken to be relative to the final nucleus, but with the 'less-than' sign added to indicate that the deep-orbit electrons are allowing the protons, and thus the neutrons, to be closer together and thereby spend more time in the nuclear potential well (with greater nuclear-wavefunction overlap).

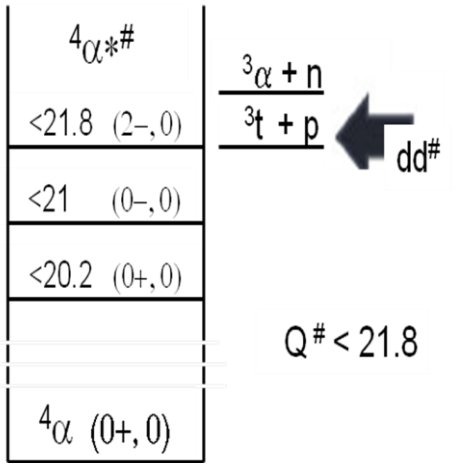

Figure 2. *^{4}He nucleus (see text for notation): incident d-d$^\#$, excited-state ^{4}He$^{\#}$* and fragmentation levels.*

Fragmentation is also identified with the nucleons, $^3\alpha$ + n and ^{3}t + p, not with the atoms. These fragmentation levels have been raised (~ 2 MeV) relative to the nuclear energy levels because of the reduced proton-Coulomb repulsion and greater nuclear-potential attraction with the deep-orbit electrons present.

The value of $Q^\#$, for deuterons, $d^\#$, with the deep-orbit electrons, is relative to the normal ^{4}He nucleus. This $Q^\#$ value has been lowered (~ 4MeV) relative to the fragmentation level by the two processes: reduction of input nucleon mass and reduction of proton-proton repulsion in the nucleus. Since the dd$^\#$ insertion level is now below the neutron fragmentation level and perhaps the proton fragmentation level as well, we can see how the pattern of low neutron flux is possible in specific low-energy-fusion experiments. This reduced value of $Q^\#$ provides the answer to the question of nearly eliminated neutrons and reduced levels of protons and tritium relative to the observed levels of heat and ^{4}He from LENR.

The actual values for $Q^\#$ and the fragmentation levels depend on details of the lochon model, at what point one or both of the electrons are ejected, and an additional factor mentioned in the next section. The nuclear resonance states at and above the proposed dd$^\#$ entry level are high angular-momentum states that cannot be accessed by the low-energy process. Therefore, the forming ^{4}He$^\#$ nucleus immediately transfers energy to the nucleons, and from the accelerating protons to the lattice via near-field radiation from the extremely tight EM coupling of the deep-orbit electrons. The first accessible metastable states that would allow momentary pause in the rush to the ground state are the (0, 0) states now well below the fragmentation level. These are the states most likely tunneled to. This is another major difference between LENR and hot fusion processes. If energetic deuterons are collided at Q > 23.85MeV, the expected incident and available excited resonant states have angular momentum (Fig. 1). For tunneling at Q = 23.85MeV (i.e., without the lochon model), there is no $\ell = 0$ nuclear state into which the deuterons can resonantly tunnel.

The extended-lochon model permits resonant tunneling into the ~21MeV (0, 0) level. However, neither the nuclear nor the collision parts of the model have developed far enough to determine either the actual nuclear levels or the $Q^\#$ values yet. Furthermore, the variability and poor reproducibility of the LENR data indicate that these values might not be fixed. If only one electron is deeply bound, or if the electrons don't penetrate deeply enough into their Coulomb wells before D-D tunneling occurs, or if one or both electrons are ejected early in the fusion process, then the deuterons would fuse above the proton fragmentation level. Under these conditions, neutrons might not be observed, but protons and tritium would be. This would account for observations. If in Figure 2, the nuclear levels were raised relative to $Q^\#$, then the tunneling probability would go up; but, perhaps the proton fragmentation energy levels would also. Thus, while the extended-lochon model provides an explanation for observed effects, it does not yet have sufficient information to suggest a 'best' path to the goal of radiationless heat from LENR. However, it also provides more possibilities to explain the 'inexplicable'. How does the excited ^{4}He$^\#$ nucleus decay to ground state and how can LENR produce transmutations? This is the basis for another paper.

The extended-Lochon model is based on starting assumptions that must be validated. It assumes that, in a lattice-phonon field, electron pairing in deepened ground states is of sufficient strength to provide a continuing attractive potential (for protons, as well as deuterons) rather than just a screening potential between hydrogen nuclei. Since a consequence of this effect is not normally observed (often even when sought), it is likely that a special condition or structure must exist to make this possible. Identifying such a structure is one of the priorities today.

STEPS BEYOND

The steps to low-energy nuclear reactions are well delineated; the mechanisms to carry them out are less well identified. Nevertheless, there is evidence from other fields that supports the proposed mechanisms. Evidence of transmutation resulting from these reactions is now nearly ubiquitous and incontrovertible.[18] This is a natural consequence of tightly bound electrons easing protons or energetic deuterium and helium nuclei into adjacent atoms and their nuclei. Furthermore, there is mounting evidence that the immense laboratory of nature has actually provided a catalytic (enzymatic?) path to biologically-induced transmutation.[19],[20]

Another line of support for this effect, from quantum physics, is a here-to-for-rejected deep (relativistic) atomic level[21]. Figure 2, uses values based on this model.[22] This level has been rejected for several reasons, lack of experimental evidence for the predicted 500keV binding energy being one of them. However, in addition to the many years of LENR results that could support the deep-orbit model, there are nuclear physics data[23] from the last two decades for ‘halo’ nuclei. These nuclei that exist far outside (e.g., 7 fm) of the nuclear potential are still difficult to explain in terms of contemporary nuclear physics; but, they fit very nicely with the LENR model presented above and extended more recently in terms of ‘femto-molecules’.[21]

CONCLUSION

Three major objections were made over two decades ago against the claims of a nuclear source for the observed excess heat in the LENR experiments. These objections have been carried over against the last 20 years of low-energy nuclear reaction research conducted to provide evidence to support the nuclear hypothesis. It has been subsequently shown (but not yet proven) that these objections might be overcome with more detailed analysis, by experimental evidence, and by extension of known physical processes. The Coulomb-barrier problem has been addressed in terms of dynamic processes in a solid-state environment. Experimental work over the last 25 years within the field of low-energy nuclear- and astro-physics has demonstrated that this objection, which was based on extrapolation from a well-known and accepted high-energy model into a region far from its base, was further from the present nuclear data (at $E < 10$ keV) than is data at $E = \sim 1$eV. The nuclear-ash problem actually identifies the LENR process (as briefly described above), rather than proving it wrong. The production of ^{4}He and the dearth of neutrons relative to the heat produced is a natural consequence of one LENR model that extends the solution of these problems into the nucleus.

Other objections and solutions not detailed here, particularly those involving p-p fusion, can be treated similarly. Observed transmutations in LENR, and even in biological systems have immense implications. The differences between ‘hot’ fusion, with its known physics, but very difficult technology, and low-energy nuclear fusion, with its ‘unknown’ physics and simple technology, are worth noting.[24] There are even some surprises coming from quantum mechanics that now support LENR by providing a theoretical basis for a relativistic deep-electron orbit. It is to be hoped that, with the new knowledge obtained over the last two decades, more physicists and chemists (and biologists) will recognize something real here and will look for ways of applying their specialties to the expanding field.

SUMMARY

This paper demonstrates, within the framework of known nuclear physics, a mechanism whereby heat generation can occur in the fusion of two deuterons without producing particulate radiation. The fact that this cannot occur in a free-space interaction leads to an understanding of a critical process behind low-energy nuclear reactions. This process requires that one or more deuterium-bound electrons be ‘briefly’ confined in the near-nuclear environment. Theory and experimental data from LENR and other research over the last 2 decades supports the existence of such confinement and thereby extends the present understanding of both atomic and nuclear physics.

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