J. Condensed Matter Nucl. Sci. 13 (2014) 378–391

Research Article

New Visions of Physics through the Microscope of Cold Fusion

A. Meulenberg*

National Advanced IPv6 Centre, Universiti Sains Malaysia, Malaysia

K.P. Sinha

Department of Physics, Indian Institute of Science, Bangalore 560012, India

Abstract

Cold-Fusion (CF) Research is not hindered as much by what we do *not* know as it is by what we *know too well*. This paper identifies several standard physics models, which must be extended beyond present practice, and indicates condensed-matter nuclear science (CMNS) work in this direction.

Keywords: Deep-Dirac levels, Deuterium fusion, Fragmentation, Transmutation

1. Introduction

The authors of this article have been involved in this controversial field from the beginning of the cold fusion (CF) era and one has continually followed its progress over the years very closely. It can be said that, by now, adequate evidence has been accumulated, e.g. [1,2], to confirm a variety of fascinating "near radiationless Low Energy Nuclear Reactions" (LENRs) occurring in deuterated (and even 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 today.

Rather than cover again the evidence for LENR (the nuclear explanation for heat generated in CF), this paper will address the arguments presented against it over two decades ago. It will show how those arguments helped to guide the theoretical work needed to explain the results. Answers to those arguments in terms of experimental results and theoretical models are presented in the following development.

*E-mail: mules333@gmail.com

Soon after the announcement of anomalous heat attributed to nuclear sources and initial attempts to repeat the results failed, scientists collected and presented the physics concepts showing why such a thing could not happen. As a result, Cold Fusion was considered impossible and rejected as science. In the two decades since then, mounting evidence indicates that low-energy nuclear reaction (LENR) *can* happen. Furthermore, there is now evidence that transmutation can occur from this process and could even be taking place in biological systems. Therefore, present physics, chemistry, and perhaps even biology models need to be both reexamined and extended or must be supplemented with new models. This paper identifies some standard models, which can be extended, and indicates results of some condensed-matter nuclear science (CMNS) work in this direction. In particular, three experimental results of this work, which indicate a decay mode not permitted by present nuclear physics models, will be explained in terms of several extended-physics models:

(1) the ability of two low-energy protons or deuterons to penetrate their mutual Coulomb barrier;
(2) the production of heat is far in excess of that permitted based on the measured particulate radiation;
(3) the high levels of ^{4}He measured are much beyond background and at levels consistent with $\sim$20 MeV per ^{4}He atom measured.

The first argument against LENR was the *inability of protons or deuterons to overcome the MeV-sized Coulomb barrier between them* without having energies in the 10s of keV to MeV range. There was no evidence in any of the early cold-fusion 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 cold fusion results was more than 100 orders of magnitude higher than anything that could be explained by room-temperature D–D fusion. The 'known' physics was based on extrapolation from experimental results of high-energy ($E > 1$ MeV range) d–d collisions.

The reason for the high rates, given by the believers at the time, was that the presence of the solid-state environment was different from that in which the nuclear theories were engendered. Nevertheless, many critical papers were written showing (with notable exceptions) that this environment could make no difference. Subsequently, these cross-section predictions, while good for $E > 25$ keV, have been over-turned by lower-energy collision experiments during the last two decades. Extrapolation from the new results is much closer to the measured Cold-Fusion results than to that of the early 'Gospel'.

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 with the measured heat generated from the CF process.* These radiations, by-products known as "nuclear ash" result from the $D + D \Rightarrow {}^4He^*$ fusion-decay process (Eqs. (1)–(3), respectively). While protons and deuterons –p and d – or 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.

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

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

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

The Qs in the equations are the mass deficit between the decay product atoms and the helium atom ground state, ^{4}He. It is seen that the decay to ^{4}He produces the greatest Q (and therefore has the greatest heating potential) of the three paths.

The first sub-topic of the second argument is characterized by the statement, "if there were nuclear reactions generating the claimed 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 many orders-of-magnitude too low to account for the heat generated.

Associated with the dearth of neutrons was the second sub-topic, an *unusual measured 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 decay path). All known D–D fusion reactions provided a 1 to 1 ratio ($P_n = P_p$). The observed CF results gave 10^7– 10^9 tritium atoms for every neutron [3]. According to accepted nuclear physics, since the 1 to 1 ratio is not observed in CF as prescribed by (1) and (2), D–D fusion "cannot" be occurring.

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. Nuclear physicists neglected to consider well-known excited states of helium below the neutron fragmentation level because they 'knew' that d–d collisions could not populate these states.

The third argument, somewhat related to the second, 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 the D–D fusion (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 percent of neutrons that were "missing" in the CF experiments. Nevertheless, the image of "sloppy" experimental work of CF researchers was confirmed in the minds of its critics by these "impossible" results.

Assuming that the Coulomb barrier could be tunneled through by minimum-energy, minimum-angular-momentum, deuterons, the available excited-state energy levels ^{4}He* are well-known zero-angular-momentum (l = 0) levels with decay characteristics that led to the second argument (a nearly equal number of neutrons and protons and almost no ^{4}He). There was "no conceivable" means of resonant tunneling below these levels because there are no states between them and the ground state. (This argument is explained further in Section 3.) *Only by tunneling below the fragmentation levels can a deuteron pair attain the* ^{4}*He ground level* by other than the highly-forbidden energetic $l = 0$ to $l = 0$ gamma transition.

The critics have declared that the high levels of ^{4}He observed in the LENR experiments, where it was sought and measured, were only contamination from atmospheric helium or were from 'bad' measurements and techniques. The fact that it correlated with the heat produced, and did not show up in the control experiments, was ignored.

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."

While the three arguments showing that the LENR results could not be fusion were strong and based on experiment and theory, other information was available at the time and subsequently led to even stronger answers. The low-energy experimental work was just beginning at that time. However, some theoretical work [4] goes back 4 decades before the Pons–Fleischman experiment.

Quantum mechanics declares that the ground state of hydrogen is its lowest energy level. However, mathematically, it is a 'minimal', not the minimum, level. The relativistic Schrodinger equations (the Klein–Gordon and Dirac equations) are solved for a charged body in a Coulomb ($1/r$) potential. The solutions that are singular at $r = 0$ have been repeatedly rejected and ignored. Nuclear physics, many decades ago, decided that the Coulomb potential must be different when $r \Rightarrow 0$. There is no singularity! These rejected solutions predict a deep atomic level (binding energy of $\sim$ 500 keV) for relativistic electrons.

This paper will address these arguments against CF and show how they have been repeatedly proven incorrect and how a self-consistent explanation, based on known physics may be emerging. No model for CF, in general, and for LENR, in particular, has yet been universally accepted, even by the LENR community. Moreover, new experimental results that are 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.

2. The Coulomb Barrier

The Coulomb barrier problem dominated much thought for many years. To get fusion, one must get the two nuclei close enough together for the short-range, charge-independent, attractive nuclear force to overcome the weaker, but long-range Coulomb repulsion of the positive nuclear charges. At normal atomic and molecular separations, negatively charged atomic electrons neutralize the nuclear charges and stable configurations (molecules) result from the balance between the attractive dipole-dipole interaction of the atoms (pairs of positive and negative charge) and the repulsive Coulomb field. The latter prevents atoms from getting too close because the electrons have too much kinetic energy to be confined in the space between. Therefore, their ability to neutralize the positive nuclear charges, sufficiently to allow tunneling through the remaining barrier to resonant energy levels inside, is limited at short nuclear distances and the universe does not collapse.

It was recognized, early on, that the palladium lattice must have something to do with the proximity problem. Initial thoughts revolved about the concept that, if protons could exist comfortably in lattice sites within the Pd crystal, then, when those sites were nearly full, two protons could be forced into a single site and therefore become pushed together by the lattice. Careful calculations from the mature field of Solid-State Physics showed that even if a second proton could be forced into an already filled site, rather than into a higher-energy, but empty, adjacent site, the pair would still be forced into a distant configuration within the lower-energy site. Something different must be going on, either in the normal hydrogen sites or within the newly paired site, if low-energy (e.g., room-temperature) nuclear reactions are to occur in the lattice.

Another possible explanation offered for the ability of hydrogen nuclei to get close enough to fuse has been the screening effect of electrons (bound and free) in the palladium lattice. The high number of electrons near the hydrogen atoms in the lattice would reduce the Coulomb barrier between them. This argument has been contested; but, in various forms, it is still going on today (see below).

There are hints from both the natural world and man's industry as to what might be happening to allow the Coulomb barrier to be breached. Catalysts are known to accelerate processes without being greatly affected by the system that they altered. This acceleration can be by many orders of magnitude. However, since nuclear physics states that D–D fusion probability at low energies is more than 100 orders of magnitude below the observed CF results, critics have said that catalytic enhancements are unlikely to be noticed. Nevertheless, at the time of the announcement in 1989 by Pons and Fleischman that started the whole cold fusion adventure, there was already work going on that cast doubt on the standard model's extrapolation to low energies that was the basis of nuclear physics prediction of the extreme difference.

The nuclear physics model was/is based on accelerator data for particles with energy greater than 1 MeV. The cold fusion particle energies were assumed to be close to that associated with room temperature thermal motion (i.e., in the range of 25 meV). Actual data at lower beam energies (down to 25 keV) had confirmed the model; so the critics assumed that they were on firm ground with their arguments. Nevertheless, early astro- and nuclear-physics papers, e.g., [5–7], showed a major deviation from the model beginning below 25 keV for D–D fusion experiments in the presence of matter. Thus, multiple works (at <10 keV) had been ignored by nuclear physics because that energy range was of interest only to the astrophysics community. The new low-energy D + D collision result has now been fully confirmed in the low-keV range for a large range of elements [8, 9].

The model preferred by the nuclear physicists to explain these new low-energy results is one of electron screening by the material in which the deuterons are being implanted. Note that the observed fusion interaction is now taking place at low energies (keV range) and in dense matter, rather than at high energies (> 1 MeV) and generally in low-pressure gases. Originally, the deviation below 10 keV was small, almost within experimental error of an individual measurement. However, as data accumulated over many successively refined experiments [9,10], the trend has become clear. The expected exponential fall of fusion cross section *does not continue to lower energies.* The mechanism of electron screening that had been rejected as "not possible to have any major impact on fusion reactions" suddenly is observed and modeled to make nearly 100 orders of magnitude difference in the data conventionally extrapolated down below the 100 meV range. The critics would say, that does not matter, the cross-sections are still 30–50 orders of magnitude too low to account for the claimed CF results to be nuclear in origin. They would like to ignore the fact that they had been 100 orders of magnitude off in the basis of their criticism and that all CF results are closer to the present extrapolated fusion cross-section prediction than 20th Century nuclear physics was. It is likely that few nuclear physicists are aware of this discrepancy even today.

Many of the arguments against the proximity of hydrogen in the lattice have been based on quantum mechanical (QM) calculations. However, any such calculation depends strongly on what is put into the model. Early models typically looked at equilibrium conditions that did not include the dynamic or non-linear contributions to the system. Phonon interaction (resonant mechanical-motion modes) of the collective atoms, ions, and electrons of the lattice is such a contributor [11]. Individual phonon energies are in the 10s-of-meV energy range and therefore would not be expected to make any difference in the fusion mechanism that requires keV-range incident-particle energies. Nevertheless, phonons (as bosons) have collective action and the net energy could get much higher (multi-eV range). Furthermore, the induced motions are coherent and therefore additive over time (within limits imposed by non-linearities and damping). The collective coherent modes can be incorporated into the QM calculations and, suddenly, deuterons have a much higher probability of getting closer together than had ever been calculated before [12,13]. Here is another mature field of physics that, when updated to a realistic model, should suddenly change its predictions about Cold Fusion.

Two additional aspects of phonons can contribute to LENR. The first is that the phonon field intensity can be enhanced by application of a resonant "driver." The increased heat output of an experiment, when subjected to this enhancement has been observed with the application of laser pairs with frequencies set so that the beat frequencies are at the lattice-phonon frequencies [14]. Individual lasers also can increase the measured heat output by increasing the electron energies and electric fields of the lattice. Thus, even though the deuterons cannot respond directly to the higher frequencies of the single laser, the atom can move as a whole into the stronger electric-field regions that the laser induces locally in the lattice. This second effect is related to the field enhancement associated with structural defects in a lattice. Electric fields, at surface or lattice defects, may be concentrated by orders of magnitude. The increased fields align charge pairs, or simply orient motion of the deuterium atoms, and thereby increase the interaction cross section [15]. The pair alignment (forming a 1-D structure) and increased local electric fields also deepen the bound-electron energy levels (particularly the ground-state levels) by the Stark effect. Experimental evidence for this effect comes from post CF-experiment surface studies and other results that indicate the prior existence of both "hot spots" and localized radiation sources on an apparently otherwise uniform surface.

A final point on penetrating the Coulomb barrier is also related to the phonon effects. Phonon fields can polarize the electron populations in a crystal lattice. It is known that some phonon modes (longitudinal-optical modes) cause the lattice atoms to oscillate in opposition to their immediate neighbors (resulting in a "collision" mode). The two effects are generally synchronous and phased so that the polarizing fields are maximal at the same time that two colliding deuterons are closest together. It is then possible for the previously covalently bonded s-electrons of the deuterons (shared with 4d-electrons in adjacent palladium atoms) to be confined to one of the deuterons, while the electrons of the other deuteron are more closely confined to an adjacent Pd atom. The net result is that, at a time when the deuterons are closest, they become charge polarized [16,17] so that they are effectively attracted to one another rather than being repelled by the Coulomb barrier [18]. This phonon-catalyzed attraction draws the deuterons closer together than otherwise possible. Work done by the electrons in pulling the deuterons together allows the paired-electron paths to

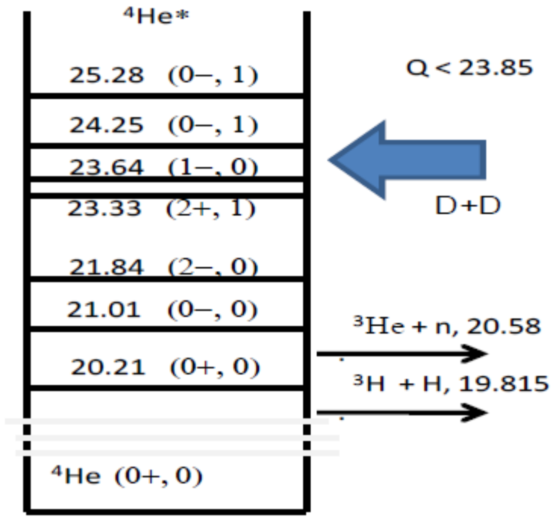

Figure 1. ^{4}He Nuclear energy levels.

shrink (electrons going deeper into the deuteron's Coulomb potential well) and thereby increase the electron screening of the Coulomb barrier [19]. The "bare" deuteron easily penetrates the Pd-lattice barrier and is drawn closer to the now shrinking negative part of the deuteron pair. Once through the lattice barrier, the bare deuteron now is part of a shrunken polarized pair that can easily fit into the lattice site that would not normally hold two deuterons. From here, the process to $D^- D^+$ fusion continues [20,21].

It seems that the three mature fields of physics that rejected cold fusion (Nuclear, Solid-State, and Quantum Physics) are presently in the embarrassing situation of having provided a basis for its operation – and not having recognized it. Furthermore, there are still other arguments made against CF and LENR that are now turned around. In examining two of them, we find the difference between hot fusion and cold fusion that simply overcoming the Coulomb barrier, by whatever means, does not address.

3. '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 [22,23]. 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 $\sim$23.85 MeV) is determined from the total (center-of-mass kinetic and mass) energies of the deuterium atoms relative to those of the ^{4}He atom ground state. Note that the usage today in nuclear physics is to include the electron(s) in the total energy of the atom. When used consistently, this makes no difference in the predicted and measured 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 claimed that the energies of the CF reaction were incompatible with the energies available and the fragments (particulate residue or ash) of the reaction, they were not talking about theories; they were talking about years of solid, reproducible, experimental *evidence*. The pathway leading to the $l = 0$ ^{4}He ground state from low-energy, $l = 0$, D–D fusion is highly forbidden. Therefore, the lower-energy-release alternative decay paths (to ^{3}He + n and ^{3}H + H) become the paths of choice. And, from years of D-D collision measurements, these paths have nearly equal probabilities (a 1:1 ratio).

When CF claimed that large energy releases were observed and nobody in the lab was killed or sickened by radiation damage, the inconsistencies became clear. As particulate radiation from the LENR experiments became more accurately measured, the n/p ratio observed was "wrong." There were almost no neutrons relative to the number of measured protons (or of 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 a 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 with $E < Q$ [24]. 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 23.85 MeV), 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 20.21 MeV) is below the neutron fragmentation level (at 20.58 MeV, from Fig. 1), the decay path is 100% via protons.

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 > 0.5 MeV below the proton fragmentation level at 19.82 MeV, from Fig. 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 CF results. They have not been found and such measurements have been made in CF and other experiments; therefore, such levels probably do not exist. (No LENR advocate has suggested that nuclear physicists have done sloppy work or hidden data to block a viable LENR model.) However, recent work [25] has suggested that, even in keV-energy D–D collisions, these n/p ratios may depend on the target material. This sub-fragmentation-level injection, or some similar, explanation must be proposed to account for the observed CF results.

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

4. Below Fragmentation Levels

If the Q value for $D + D \Rightarrow {}^4He$ forces fusion into excited states 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.

Several models, including the Lochon Model described below, have addressed the means of getting the deuterons through their Coulomb barrier. However, if they cannot address the fragmentation issue, they cannot be complete explanations for the observed CF effect. 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. One model of direct D–D fusion that seems to have promise in being able to do both is the Extended-Lochon Model [20,21].

The Lochon Model provides a means of, and calculated results for, D–D fusion from the Pd-lattice-defect sites [19]. 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) had the high observed mobility. 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 [26] and is therefore unlikely to contribute its electron to the conduction band. However, it can share electrons with the broad Pd 4d 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 almost 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 cites 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 large sections of a complete sub-lattice. A full lattice will generally have greater average collective sub-lattice motion. A 'break' in the sub-lattice can often produce even larger local motion. One form of resonant motion has adjacent lattice elements moving against each other rather than with each other. This 'longitudinal optical-phonon' mode is the one used by the lochon model to produce the conditions needed for LENR.

The lattice and sub-lattice atoms can interact with each other to enhance or interfere with the collective motion. 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 dynamic charge polarization with the momentary 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 greatly reduced in length and somewhat in height.

Key to the model is the stability of electron pairs in the 1s ground state. This spin-coupled electron pair is a boson (integer-spin system $\Rightarrow$ local charged boson = Lochon). It is similar in concept to the Cooper-pairs, electrons coupled in momentum space that produce superconductivity. However, these electrons are coupled in physical space and, because of the much stronger spin-coupling and shared Coulomb potential well, this pairing exists even at high temperatures. 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 the interaction from a dipole–dipole to a monopole–monopole interaction, they appear to be oppositely charged ions. The ionic-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[a] 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 = $F \times$ 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 4d electrons; are much better at screening the deuterons' Coulomb field; and are a lesser impediment to the negative ion in passing into or through the minimum in the lattice barrier between hydrogen sites. It is at this point that either: 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.

The extended-lochon model recognizes that this net energy transfer (from deuterons to now-energetic electrons) comes from the total energy (**E**-field and mass as potential energy) of the deuterons and the electrons. However, the electrons gained kinetic energy ($\sim$1 MeV each) and binding energy ($\sim$1/2 MeV each) at the same time [27]. This energy comes from the potential energy of the proton binding them to itself. Therefore, when the mass–energy values of the fusion reaction is calculated, the result must be lower for the *nuclei* ($<$ 1 MeV from the D^+ and $>$ 2 MeV from the D-nucleus), but not for the atoms. This separation of mass and energies, and its attribution to the individual electrons and nucleons, is not normally considered in nuclear physics, since the atomic electrons seldom change orbit or energy very much relative to the fusion-process energies. The total *nucleon Q* value in the extended-lochon model can decrease by $\geq$3 MeV before fusion ever occurs.

A 3-MeV reduction in Q is not sufficient to get the deuterons beneath the proton-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 $\sim$0.7 MeV for the first electron [28] and $\sim$ 0.3 MeV for the second. The $^4He^{\#\#}$ ground state energy (the double # indicates both of the deep-orbital electrons are present in the nuclear region), dominated by the nucleon momenta, is also lowered until the deep-orbit electrons are ejected. Furthermore, the reduced repulsion from this neutralizing charge, which allows the protons to move deeper into their nuclear potential well, 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 incident deuterons and the resultant nucleus (all excited states are with the deep lochon present), not for the atoms. However, the ground state used is that of the final nucleus (without lochon or electrons), hence the use of $^4\alpha$, 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).

Fragmentation is also identified with the nucleons, $^3\alpha$ + n and ^{3}t + p, not with the atoms. These fragmentation levels have been raised ($\sim$ 1 MeV) relative to the nuclear energy levels because of the reduced proton–Coulomb repulsion [28–30] and greater nuclear-potential attraction with the deep-orbit electrons present.

Because of its importance and difference from normal practice, we re-emphasize - the value of $Q^\#$, for deuterons, $d^\#$, but with the deep-orbit electron(s) present, is relative to the normal ^{4}He nucleus with atomic electrons present.

[a]http://www.ichaphysics.com/the-science-of-cold-fusion

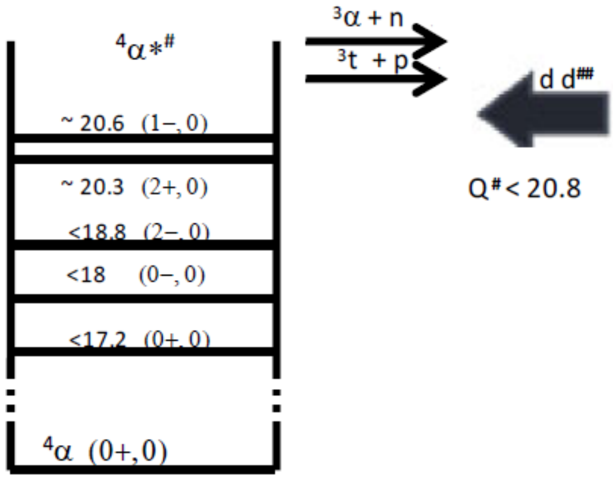

Figure 2. ^{4}He nucleus (see text for notation): incident d-d$^{\#\#}$, excited-state ^{4}He$^{\#\#}$*, and fragmentation levels.

The electrons are present but *not* included in the $Q^\#$ value. This $Q^\#$value has been lowered ($\sim$ 4 MeV) 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 cold-fusion experiments. This reduced value of $Q^\#$provides the answer to the question of nearly eliminated neutrons and reduced protons and tritium relative to the observed levels of heat and ^{4}He from cold fusion.

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 Section 5. 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 of CF. Therefore, the forming ^{4}He$^\#$ nucleus immediately begins transferring energy to the nucleons, and from the accelerating protons to the lattice via near-field radiation from their extremely tight EM coupling with 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 CF and normal hot fusion processes. If energetic deuterons are collided at $Q > 23.85$ MeV (KE > 0), both the expected incident particles and available excited resonant states have angular momentum (Fig. 1). For tunneling at $Q = 23.85$ MeV (i.e., CF without the lochon model), there is no $l = 0$ nuclear state into which the deuterons can resonantly tunnel and no levels below fragmentation.

The extended-lochon model permits weak resonant tunneling into the $\sim$18 MeV (0, 0) level. There is insufficient angular momentum to tunnel to the levels between 18 MeV and $Q^\#$ and not enough energy to reach the higher (0, 0) levels ($E > Q^\#$). 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 CF data indicate that these values might not be fixed. For example, 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. Neutrons would not then be observed in CF, but protons and tritium would be. This would account for observations.

If in Fig. 2, the nuclear levels were raised relative to $Q^{\#}$, then the tunneling probability would go up; but perhaps the proton fragmentation 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. Nevertheless, it also provides more possibilities to explain the 'inexplicable'. But, how does the excited $^4He^{\#}$ nucleus decay to ground state and how can CF produce transmutations?

5. $^4He^{\#*}$ to ^4He

The lochon, being tightly coupled to the fusing nucleons, provides a new path for their decay to the ^4He ground state that is not much different from internal conversion [31]. However, there *are* differences. The primary one being that, after D–D tunneling, the nucleons and electrons are not in a stable configuration. Therefore, instead of a resonant transfer of energies in internal conversion, the transfer of nuclear energy from the protons to the electrons, via the electric and magnetic field coupling, is chaotic. If this were the only consideration, it could take longer. On the other hand, the average electron–proton separation is orders-of-magnitude less, if the lochon model is correct; thus, the amount of energy transferred during each pass can be many orders higher and the number of passes per second is also orders of magnitude higher. The second difference is that the electrons (lochon) are very energetic (near the MeV range) and tightly bound, instead of in the many-eV range of the normal, loosely bound, k-conversion electron. Thus, their acceleration-induced EM field is perhaps tens of orders of magnitude higher. Furthermore, when they interact with the protons and the adjacent lattice phonons and electrons (as a multi-body system), they may acquire sufficient angular momentum to radiate photons and to (more efficiently) proximity-couple this energy to the neighboring Pd electrons [32]. The expected energetic gamma ray needed to de-excite a nuclear level requires a more stable state as a starting point. Furthermore, since the only states accessible to the low D^+D^- entry energy and angular momentum in the lochon model are (0, 0), these highly forbidden (i.e. very slow to form) $0 \Rightarrow 0$ transition gamma rays are not observed. This process explains the high concentration of ^4He atoms that violates the nuclear physics data based on electron-free energetic-particle collisions. It also explains the dearth of fragmentation products *and* energetic gammas.

A consequence of the only available path to ground is the continued presence of the tightly bound electrons during the extended decay process. This gives the $^4He^{\#}$ nucleus a net zero charge and a multi-Fermi sized charge distribution. In the case of hydrogen, rather than deuterium fusion, a 2p+2e$^{\#}$ nucleus, a femto-sized $H_2^{\#}$ molecule, will be present. Thus, a neutral, but active, nucleus can drift at will through the lattice-atom's electron clouds and it can drift into range of the nearby nuclear potentials. Entering another nucleus means transmutation. Since the now-compound nucleus has excess energy available and several combinations of loosely bound protons, neutrons, and electrons, the paths to a minimum energy level nucleus are multiple and varied [33]. The ability to shed excess energy by forming bound neutron(s), by proximity coupling to lattice electrons, and/or by emission of tightly bound electrons and heavy particles, means that long-range energetic radiation is not a common by-product.

The Extended-Lochon Model is based on starting assumptions that must be validated. The Lochon Model 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 CF priorities today.

6. 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 [34]. This is a natural consequence of tightly bound electrons easing protons or energetic deuterium and helium nuclei into adjacent atoms and their nuclei.

Another line of support for this effect, from quantum physics, is a here-to-for-rejected deep (relativistic) atomic level [35]. Figure 2 uses values predicted by this model. This level has been rejected for several reasons, lack of experimental evidence for the predicted 500 keV binding energy being one of them. The recognition of halo nuclei [36] as femto-molecules would be clear evidence of the deep-Dirac levels that would explain so much in CF.

7. Conclusion

Three major objections were made over two decades ago against the cold fusion claims of a nuclear source for the observed excess heat in the CF experiments. These objections have been carried over against the last 20 years of low-energy nuclear reaction (LENR) research conducted to provide evidence to support the nuclear hypothesis. It has been subsequently shown; but as yet unproven, that these objections might be overcome with more detailed analysis, by experimental evidence, and by extension of known physical processes.

The Coulomb-barrier problem is addressed in terms of dynamic processes in a solid-state environment. One main 'new vision' is the ability of atomic electrons to change energy levels without emitting photons. Experimental work over the last 25 years within the field of low-energy nuclear- and astro-physics has led to a new extrapolation from the well-known and accepted high-energy model into a region far from its base. The 'standard' prediction of the Coulomb barrier effects (for $E < 1$ eV) is much further from the new predictions based on the recent nuclear data (at $E < 10$ keV) than is the prediction based on Cold Fusion data.

The nuclear-ash problem actually identifies the CF process, 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 a particular LENR model that extends the solution of these problems into the nucleus. The 'new vision' identifies proton mass as a source of electrostatic potential energy and sees it lowered as the atomic electron(s) comes close.

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 cold fusion, with its 'unknown' physics and simple technology, are worth noting [37]. There are even some surprises coming from quantum mechanics that now support LENR by providing the 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.

Acknowledgement

This work is supported in part by HiPi Consulting, New Market, MD, USA; by a Universiti Sains Malaysia Research Grant [1001/PNAV/817058 (RU)]; by a USM International Grant from the Science for Humanity Trust, Bangalore, India; by the Science for Humanity Trust Inc., Tucker, GA, USA, and by the Indian National Science Academy.

References

[1] E. Storms, *The Science Of Low Energy Nuclear Reaction*, World Scientific, Singapore, 2007.

[2] M. McKubre, Cold Fusion (LENR) One Perspective on the State of the Science. This is the Forward to V. Violante and F. Sarto (Eds.), *Proc. 15th Int. Conf. on Cond. Matter Nuclear Sci* (Part 1), 2009, ENEA: Rome, Italy, p. 385. http://lenr-canr.org/acrobat/ViolanteVproceeding.pdf

[3] M. Srinivasan, Wide-ranging studies on the emission of neutrons and tritium by lenr configurations: An historical review of the early BARC results, *Low-Energy Nuclear Reactions and New Energy Technologies Sourcebook, Volume 2*, ACS Symposium Series 1029, pp. 35–57, American Chemical Society, 2009.

[4] R. Loudon, One-dimensional hydrogen atom, *Amer. J. Phys.* **27** (9) (1959) 649–655.

[5] A. Krauss, H. Becker, H. Trautvetter et al., Low-energy fusion cross sections of D+ D and D+< sup> 3</sup> He reactions, *Nucl. Phys. A* **465** (1) (1987) 150–172.

[6] H.J. Assenbaum, K. Langanke and C. Rolfs, Effects of electron screening on low-energy fusion cross sections, *Zeitschrift für Physik A Hadrons and Nuclei* **327** (4) (1987) 461–468.

[7] S. Ichimaru, Nuclear fusion in dense plasmas, *Rev. Modern Phys.* **65** (2)(1993) 255.

[8] K. Czerski, A. Huke, P. Heide et al., The 2H (d, p) 3H reaction in metallic media at very low energies, *(Europhys. Lett.)* **68** (2004) 363.

[9] F. Raiola, L. Gang, C. Bonomo et al., Enhanced electron screening in d(d,p)t for deuterated metals, *Euro. Physical J. A* **19** (2) (2004) 283–287.

[10] A. Huke, K. Czerski and P. Heide, Measurement of the enhanced screening effect of the d+ d reactions in metals, *Nucl. Instr. Methods Phys. Res. Section B* **256** (2) (2007) 599–618.

[11] K. Sinha, A theoretical model for low-energy nuclear reactions in a solid matrix, *Infinite Energy* **5** (2000) 29–54.

[12] V. Vysotskii and S. Adamenko, Correlated states of interacting particles and problems of the Coulomb barrier transparency at low energies in nonstationary systems, *Tech. Phys.* **55** (5) (2010) 613–621.

[13] K. Sinha and A. Meulenberg, Quantum-correlated fluctuations, enhanced tunneling, and low-energy nuclear reactions in condensed matter (alloys), in *16th Int. Conf. on Cond. Matter Nucl. Sci.* (ICCF-16), Chennai, 2011, pp. 132–141; and *JCMNS-8*, 2012, pp. 105–114.

[14] D. Letts, D. Cravens and P.L. Hagelstein, Dual laser stimulation of optical phonons in palladium deuteride, *J. Sci. Exploration* **23** (4) (2009) 459–461.

[15] K. Sinha and A. Meulenberg, Laser stimulation of low-energy nuclear reactions in deuterated palladium, *Current Sci.* **91** (7) (2006) 907–912.

[16] P.W. Anderson, Model for the electronic structure of amorphous semiconductors, *Phy. Rev. Lett.* **34** (15) (1975) 953–955.

[17] A.S. Alexandrov and N.F. Mott, *Polarons and bipolarons*, Singapore; River Edge, NJ: World Scientific, 1995.

[18] K. Sinha and A. Meulenberg, Lochon catalyzed DD fusion in deuterated Pd in the solid state, *Nat. Acad. Sci.(India) Lett.* **30** (7,8) (2007) 243–246.

[19] K. Sinha and A. Meulenberg, A model for enhanced fusion reaction in a solid matrix of metal deuterides, *arXiv e-print* (2009) 1–5.

[20] A. Meulenberg and K. Sinha, Tunneling Beneath the Fragmentation Level, V. Violante and F. Sarto (Eds.), *Proc. 15th Int. Conf. on Cond. Matter Nuclear Sci.* (Part 2), pp.337-341,2009, ENEA: Rome, Italy. p. 385.
http://lenr-canr.org/acrobat/ViolanteVproceedinga.pdf

[21] A. Meulenberg and K. Sinha, Tunneling beneath the 4He* fragmentation energy, *J. Cond. Matt. Nucl. Sci.* **4** (2016) 241—255.

[22] D.R. Tilley, H.R. Weller and G.M. Hale, Energy levels of light nuclei A = 4, *Nucl. Phys. Section A* **541** (1) (1992) 1–104.

[23] A. Csótó and G. Hale, Nature of the first excited state ofˆ{4} He, *Phy. Rev. C* 55 (5) (1997) 2366.

[24] J. Kelley, D. Tilley, H. Weller et al., Adopted levels of ^{4}He, National Nuclear Data Center, 2011.
http://www.nndc.bnl.gov/nudat2/getdataset.jsp?nucleus=4HE&unc=nds (Accessed 17/05/2014).

[25] K. Czerski, A. Huke, P. Heide et al., Experimental and theoretical screening energies for the 2 H (d, p) 3 H reaction in metallic environments, *Euro. Phy. J.* **27** (1) Supplement (2006) 83–88.

[26] I. Chernov, Y. Koroteev, V. Silkin et al., Evolution of the electron structure and excitation spectrum in palladium as a result of hydrogen absorption, *Doklady Phys.* **53** (6) (2008) 318–322.

[27] J. Maly and J. Vavra, Electron transitions on deep Dirac levels I, *Fusion Technol.* **24**(3) (1993) 307.

[28] F. Oner and B.A. Mamedov, Evaluation of Coulomb energy difference for light mirror nuclei using Slater-type orbitals, *Commun. Theoret. Phys.* **37** (3) (2002) 327–330.

[29] S. DeBenedetti, *Nuclear Interactions*, Wiley, New York, 1964.

[30] V.R. Shaginyan, Coulomb energy of nuclei, *Phys. Atomic Nuclei* **64** (3) (2001) 471–476.

[31] P. Kálmán and T. Keszthelyi, Solid state internal conversion, *Phy. Rev. C* **69** (3) (2004) 031606.

[32] A. Meulenberg and K. Sinha, Deep-orbit-electron radiation emission in decay from 4H*ˆ to 4He, in *17th Int. Conf. on Cond. Matter Nucl. Sci*. (ICCF-17), Vol. 13, Daejeon, 2012, pp.378–391.

[33] A. Meulenberg, Femto-atoms and transmutation, in *17th Int. Conf. on Cond. Matter Nucl. Sci*. (ICCF-17), Vol. 13, Daejeon, 2012, pp. 378–391.

[34] M. Srinivasan, G. Miley and E. Storms, *Nuclear energy encyclopedia*, Wiley Online Library, 2011.
[35] J. Maly and J. Vavra, Electron transitions on deep Dirac levels II, *Fusion technol.* **27** (1) (1995) 59.
[36] Halo Nucleus, http://en.wikipedia.org/wiki/Halo_nucleus.
[37] D.J. Nagel, Hot and cold fusion for energy generation, *J. Cond. Matter Nucl. Sci.* (Review Article) **4** (2011) 1–16.