Extensions to Physics: Low-Energy Nuclear Reactions

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Abstract. Soon after the announcement of anomalous heat attributed to nuclear sources and initial attempts to repeat the results failed, people 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 20 years since then, mounting evidence indicates that low-energy nuclear reaction (LENR) *can* happen. Therefore, present physics models need to be either reexamined and extended or supplemented with new models. This paper identifies some standard models that must be extended and indicate results of some condensed-matter nuclear science (CMNS) work in this direction. In particular, the ability of two low-energy protons or deuterons to penetrate the mutual Coulomb barrier, the production of heat far in excess of that permitted based on the measured particulate radiation, the high levels of ^{4}He measured (much beyond background) that indicate a decay mode not permitted by nuclear physics will all be explained in terms of several extended-physics models.

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INTRODUCTION

The authors of this article have been involved in this controversial field from day one of the cold fusion (CF) era and one has followed its progress over the years very closely. It can be said that, by now, adequate evidence has been accumulated (e.g., Storms, 2007) to confirm a variety of fascinating "near radiationless Low Energy Nuclear Reactions" (LENRs) occurring in deuterated (and sometimes 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. But, universal reproducibility and a satisfactory theoretical understanding of the phenomenon is 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 two decades ago. It will emphasize the answers to those arguments in terms of experimental results and models presented to account for them. The first argument against LENR was the *inability of protons or deuterons to overcome the Coulomb barrier between them* without energies in the 25 keV to MeV range. (While p and n, or hydrogen and deuterium, or H and D, are often used generically and interchangeably in this paper to describe interactions, 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 of 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 D-D fusion. The answer given by the believers was that the presence of the solid state environment was different from that in which the nuclear theories were engendered. Many critical papers were written (with notable exceptions) showing that this 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, and gammas – by-products of the D + D => ^{4}He* fusion-decay process known as the "nuclear ash" (equations (1), (2), and (3) respectively) - with the measured heat generated from the CF process. If there was a nuclear reaction 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.

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

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

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

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 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 to 10^9 tritium atoms for every neutron (Srinivasan, 2009). Since the 1 to 1 ratio is not observed as prescribed by equations (1) and (2), D-D fusion "cannot" be occurring. The Qs are the mass deficit between the decay product atoms and the helium atom ground state, ^{4}He. It is seen that this decay to ^{4}He produces the greatest Q (and therefore has the greatest heating potential). 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.

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 the D-D fusion [equation (3)]. Thus, the probability of forming ^{4}He from D-D fusion is less than 1 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.

The third argument is somewhat related to the second. Assuming that the Coulomb barrier can be tunneled through by minimum-energy, minimum-angular-momentum, deuterons, the available excited-state energy levels ^{4}He* are well-known zero-angular-momentum ($\ell = 0$) 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 the "nuclear ash" section. *Only by tunneling below the fragmentation levels can a deuteron pair attain the ^{4}He ground level* by other than the highly-forbidden energetic $\ell = 0$ to 0 gamma transition.

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 was only pseudo-science." This paper will address these arguments and show how they have been repeatedly proven to be incorrect and how a self-consistent explanation has emerged. No model for CF, in general, and LENR, in particular, has yet been universally accepted, even by the LENR community. And, 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.

THE COULOMB BARRIER

The Coulomb barrier problem dominated much thought for 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, negativelycharged 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 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 in the vicinity of 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 Fleichman that started the whole cold fusion adventure, there was work going on that cast doubt on the standard model's extrapolation to low energies that nuclear physics used to predict the massive difference. The nuclear physics model was/is based on accelerator data for particles with energy greater than 1MeV. The cold fusion particle energies were assumed to be close to that associated with room temperature thermal motion (*i.e*., in the range of 25meV). Actual data at lower beam energies (down to 25keV) had confirmed the model; so the critics assumed that they were on firm ground with their arguments. Nevertheless, early papers, *e.g*., (Ichimaru, 1993), showed a deviation from the model beginning below 25keV for D-D fusion experiments in the presence of matter. This single work (at 10keV) had been ignored by nuclear physics because that energy range was of interest only to the astrophysics community. The result has now been fully confirmed and extended to the low-keV range (Czerski *et al*., 2004; Raiola *et al*., 2004).

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 (> 1 keV) and in dense matter, rather than at high energies (> 1MeV) and generally in low-pressure gases. Originally the deviation below 10keV was small, almost within experimental error of an individual measurement. However, as data accumulated over many refined experiments (Huke, Czerski, and Heide, 2007; Raiola *et al*., 2004), the trend has become clear. The 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 extrapolated down below the eV range. The critics would say, that doesn't 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 20^{th} Century nuclear physics was.

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 contributions to the system. Phonon interaction with the collective atoms, ions, and electrons of the lattice is such a contributor (Sinha, 2000). 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 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 (Vysotskii, and Adamenko, 2010; Sinha & Meulenberg, 2011). Here is another mature field of physics that, when updated to a realistic model, should suddenly change its predictions about CF.

There are two additional aspects of phonons that 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 phonon frequencies (Letts, Cravens, and Hagelstein, 2009). The second effect is related to the field enhancement associated with structural defects in a lattice. Electric fields, at surfaces or lattice defects, may be concentrated by orders of magnitude. The increased fields align charge pairs and thereby increase the interaction cross section (Sinha and Meulenberg, 2006). 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). Experimental evidence for this effect comes from post CF-experiment surface studies and other results that indicate 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 neighbors (a "collision" mode). If the two effects are synchronous so that the polarizing fields are maximum at the same time that two colliding deuterons are closest together, then it is possible for the covalently-bonded s electrons of the deuterons (shared with 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 so that they are effectively attracted to one another rather than being repelled by the Coulomb barrier (Sinha and Meulenberg, 2007). 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 shrink (electrons going deeper into the deuteron's Coulomb potential well) and thereby increase the electron screening of the Coulomb barrier (Sinha and Meulenberg, 2008). 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 (Meulenberg and Sinha, 2009 and 2010).

It seems that the 3 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. Furthermore, there are still other arguments made against CF and LENR that are now turned around.

'NUCLEAR ASH' PROBLEM

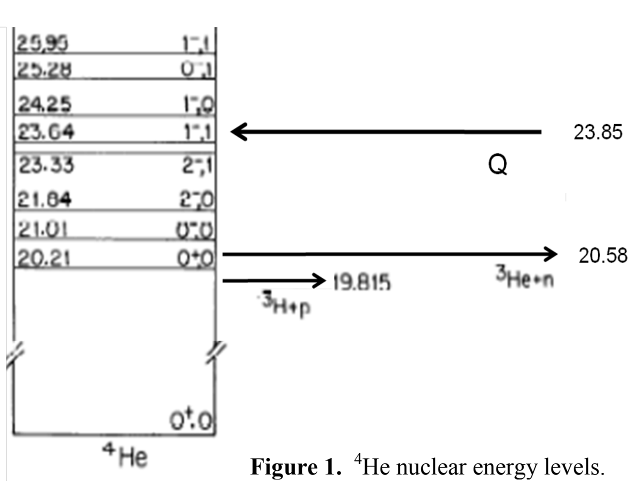

Figure 1. ^{4}He nuclear energy levels.

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. The energy level of interest in the standard 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. All of these levels are well and accurately known. The decay paths and the ratios of the different paths are also well known. Therefore, when the 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 $\ell = 0$ ^{4}He ground state from low-energy, $\ell = 0$, D-D fusion 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 measurements, they 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 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 a nuclear power source. Furthermore, measurements of ^{4}He indicated anomalously high levels of this isotope in LENR experiments. This observation could 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 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 (Kelley *et al*., 1987). It tells a clear story of what is happening. Notice that, as the energy level approaches Q (at 23.85MeV), from below, the decay path approaches 50/50% neutron/protons. When the energy level (*e.g*., at the 20.21MeV level) is below the neutron fragmentation level (at 20.58MeV, from Figure 1), the decay path is 100% via protons. There is the expected monotonic-increasing n/p transition ratio between these and the Q levels. It is obvious that if there existed energy levels much below the proton fragmentation level (at 19.82MeV, from Figure 1), the decay path could no longer be via protons: another path to ground would dominate. Such lower-energy levels (or even resonances) had been proposed, and sought, to explain the observed CF results. They have not been found; therefore they 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.) Recent work (Czerski *et al*., 2006B) has suggested that, even in keV-energy D-D collisions, these n/p ratios may depend on the target material. This, or some other, explanation must be proposed to account for the 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

BELOW THE FRAGMENTATION LEVEL

If the Q value for D+D => ^{4}He 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.

To account for the high ^{4}He concentrations and low neutrons in CF experiments several model types have been proposed. Chubb, (2009) has talked about an ion-band state model (these proceedings). Takahashi (2009, and references therein) has detailed some "cluster" models, so this material will not be repeated here.

Several models have addressed the means of getting the deuterons through their Coulomb barrier. However, if they can't 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, they say nothing about the fragmentation-ratio dilemma. Two models of direct D-D fusion that seem to have promise in being able to do both are the Extended-Lochon Model (Meulenberg and Sinha, 2009; 2010), and a Bose-Einstein Condensate Nuclear Fusion BECNF Model (Kim, 2009).

The BECNF model makes important contributions in that it addresses the coupled D-D pair immediately before and after the fusion process. Kim addresses the issues of paths (including selection rules) from the D-D pair to various ^{4}He* states (including fragmentation) both directly and through the intermediate ^{4}He* states. He also addresses the n/p fragmentation ratio and several other mechanisms that may be secondary – or could be fundamental to the

LENR process (Kim, 2010). A potentially important point is made on the calculated tunneling of the deuterons into the upper energy edge of the ($\ell = 0^+$) 20.21MeV state in Figure 1 (Csoto and Hale, 1997). Kim did not consider the 21.01MeV state since it is a negative parity state. In the decay process, or from the fusion point, the deuteron pair, now an excited, unstable, helium nucleus, rapidly moves down to its more-stable resonance level below the one leading to neutron fragmentation (the excess energy is assumed to be absorbed by the BEC state). This is a first step away from an apparent fixation on tunneling into the normal D-D fusion channels, the energetically-closer $\ell = 1$ levels, or into the lower-range of the upper ($\ell = 0$) level at 25.28MeV. (The $\ell = 0$ levels are the only option, given the very low energy of the CF deuterons and the tunneling requirements.) Tunneling into the 25MeV level automatically leads to fragmentation with neutrons or protons departing. Tunneling to the 20MeV level is a major step toward "tunneling below the fragmentation levels;" and, it can explain the low levels of neutrons, relative to protons, observed in LENR data.

The Lochon Model provides a means of, and calculation for, D-D fusion from the Pd-lattice-defect sites. 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 the D-D pair by the phonon-induced electric fields into an attracting $D^+ D^-$ pair. The Coulomb barrier between the deuterons is reduced in both length and height and the deuteron energy at contact with the barrier is much higher than that for neutral deuterium atom collisions. Thus, for multiple reasons, fusion probability is greatly enhanced by the lattice phonons.

While it provided a mechanism for fusion, the Lochon Model did 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 used a concept introduced by Tom Barnard that enhanced aspects of the lochon model that deepen the atomic-electron energy levels during a portion of the phonon-induced oscillations of the deuterons within their lattice sites. Part of this energy goes into the electron kinetic energy and part into accelerating and drawing the deuterons together. The deepened energy levels also mean that the electron orbitals are greatly reduced in size and therefore the electrons are much better at screening the deuterons' Coulomb field.

The extended-lochon model recognized that this net energy transfer (from deuterons to electrons) came from the total energy (field and mass as potential energy) of the deuterons and the electrons. However, the electrons gained kinetic energy at the same time. Therefore, when the Q value of the fusion reaction is calculated, the result must be for the nuclei, not the atoms. This is not normally done since the electrons seldom change energy very much relative to the fusion-process energies. Therefore, the Q value can decrease and the greater electron density within the nuclear region reduces the proton repulsion and increases the attractive nuclear potential. This raises the fragmentation levels relative to the ^{4}He excited-state levels and the total energy of the deuteron pair.

The lochon, being tightly coupled to the fusing nucleons, provides a new path for their decay to the ^{4}He ground state that is not much different from internal conversion (Kálmán and Keszthelyi, 2004). 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 and could take longer. On the other hand, the average electron-proton separation is much less, if the lochon model is correct; thus, the amount of energy transferred during each pass can be much 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 k-conversion electron. Thus, when they interact with the protons and the adjacent lattice 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. This process explains the high concentration of ^{4}He atoms that violates the nuclear physics data based on energetic-particle collisions.

Both the Extended-Lochon and BECNF models are based on starting assumptions that must be validated. Kim (2010) assumes that, to form the Bose-Einstein Condensate, hydrogen in metal lattices is mobile, even when the readily-available sites are completely filled. 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 rather than just a screening potential between hydrogen nuclei.

CONCLUSION

Three major objections were made 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 low-energy nuclear reaction (LENR) 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 is addressed in terms of dynamic processes in a solid-state environment. Experimental work over the last 2 decades within the field of nuclear and astro-physics has demonstrated that this objection, which was based on extrapolation of a well-known and accepted model into a region far from its base, was further from the present nuclear data than was the CF data. The nuclear-ash problem actually identifies the CF process rather than proving it wrong. The production of ^4He 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 addressed here, can be treated similarly. There are even some surprises coming from quantum mechanics that now support LENR. It is to be hoped that, with the new knowledge obtained over the last two decades, more physicists and chemists will recognize that there is something real here and will look for ways of applying their specialties to the field.

NOMENCLATURE

Q = mass deficit between initial and final state *e.g.*, between D_2 and ^4He (MeV)

E = energy (MeV, or keV)

ACRONYMS

CF	- Cold Fusion	^4He	- Helium atom, (atomic mass 4)
LENR	- Low-energy-nuclear fusion	$^4He^*$	- excited nuclear state of helium
CMNS	- Condensed Matter Nuclear Science	^3He	- Helium atom, (atomic mass 3)
BECNF	- Bose-Einstein Condensate Nuclear Fusion	^3H	- tritium or T, hydrogen atom, (atomic mass 3)
Lochon	- local charged boson (electron pair)	H, D	- hydrogen, deuterium atoms
γ	- gamma ray	p, d, t, α	- proton, deuteron, triton, helium-4 nuclei

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APPENDIX: Similarities between LENR and keV-beam experiments

An interesting side issue of the new low-energy colliding-beam work is that the mathematics on which the original criticism of CF was based, is being preserved. However, there are terms that are modified (Czerski *et al*., 2004). It turns out that the effect of electron screening σ_{scr} can be accounted for by assuming (to first order) that the incident particles have more energy than the known energies of the experiment (effective particle energy = center-of-mass beam energy + screening energy = E_{cm}+ U_e in equation (A.1), with E_G = the Gamow energy).

$$\sigma_{scr}(\mathrm{E_{cm}}) = \frac{1}{\sqrt{\mathrm{E_{cm}}(\mathrm{E_{cm}}+U_e)}}\, S(\mathrm{E_{cm}}) \exp\sqrt{-(\mathrm{E_G}/(\mathrm{E_{cm}}+U_e)} \qquad \text{(A.1)}$$

The models of the screening needed to fit the multi-keV data give an "effective screening energy" that in some cases reaches above the 500 eV level (Raiola *et al*., 2004; Czerski *et al*., 2006A). Since this energy is nearly of the order of that in the deuteron-beam experiments, one would still expect to see some fusion fragmentation products when the deuteron beam was turned off. However, fusion rates from beams at these sub-keV energies are too low to make statistically-significant measurements. Is it possible to produce a measurable radiation signature?

The multi-keV beam-current densities are typically in the μA/cm^2 range. However, the electrolysis experiments are in the eV range at 10-100 mA/cm^2. Therefore, the heat input is comparable in the two cases; but, many of the surface-contamination effects are dramatically changed. Furthermore, if in fact the deuteron flux rate is increased by 4 orders of magnitude, this means that the statistics are improved by perhaps 2 orders of magnitude. However, the high electrolysis current does not necessarily mean that the deuterium current *into* the lattice is as high. At saturation, a percentage of the deuterium forms D_2 gas and boils off the pd surface. If the pre-exponential factor in equation 4 is the dominant term at low energies ($E_{cm} << U_e$), then the magnitude of the cross-section, assuming deuteron energies below 1 eV, would also increase by two orders of magnitude. The net result is that the electrolytic-loading LENR experiments could actually be observing the same effect that the multi-keV-beam experiments are measuring. There are differences in the CF and keV-beam experiments, *e.g.*, in the fragmentation-ratio (however, neutrons are not measured in the beam experiment?); but, there are also similarities, *e.g.*, measured proton, tritium, and ^{3}He fluxes, with no measured energetic-gamma rays.

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