Extensions to physics: what cold fusion teaches

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This article documents some condensed matter nuclear science work where contemporary physics models are re-examined, extended and/or supplemented. Primarily for DD fusion: (1) ability of two low-energy protons or deuterons to penetrate their mutual Coulomb barrier; (2) production of heat far in excess of that possible based on the measured particulate radiation; (3) high levels of ^{4}He measured; (4) enhanced coupling of nuclear energy to local lattice; (5) transmutation, and (6) selective 'scavenging' of radionuclides in the lattice have been explained in terms of several extended physics models. More than sufficient evidence now proves that low energy nuclear reactions occur and lead forward.

Keywords: Condensed matter nuclear science, deuterium, fragmentation, low energy nuclear reaction, transmutation.

Introduction

EVIDENCE for LENR (low energy nuclear reaction; the nuclear explanation for heat generated in cold fusion) has been covered in the many other papers in this special section of *Current Science*. The present article records how three arguments (challenges) presented against a nuclear source for excess heat two decades ago have been addressed in the literature[1]. It shows how those challenges helped guide the theoretical work needed to explain the experimental results and how, since that time, the field has evolved far beyond the original arguments. For brevity, many statements below will be referenced only to earlier papers of the author and to other papers within this special section, wherein one may find citations for the many sources on which the expressed ideas are based.

Coulomb barrier

The first argument against LENR was the inability of protons or deuterons to overcome the MeV-sized Coulomb barrier between them without having kinetic energies in the many-keV to MeV range. (While protons and deuterons – p and d, or hydrogen and deuterium – H and D, are often used generically and interchangeably in this article to describe the interacting particles, when specificity is required, it will be applied.) It was recognized early on in the development of cold fusion (CF) models that having one or more electrons closer than atomic orbitals about the protons was a necessary condition for bringing together the nuclei close enough for fusion to occur at a non-trivial rate.

The present author's growth into CF was in association with K. P. Sinha, who from his theoretical and solid-state physics background knew that in a lattice it was common to have transient (or longer-term) pairing of electrons giving a net negative charge about one site and an adjacent site with a positive charge because of a local shortage of electrons. This became the basis of his 'lochon model' (see Sinha in p. 516), which proposed a D^+D^- pairing that actually, at least for a brief time, cyclically produced an attractive force between the two ions[2]. The lochon (a <u>lo</u>cal <u>ch</u>arged bos<u>on</u>) is primarily a coupled electron pair (e.g. two fermions can become a boson, as in superconductivity). The paired s-orbital electrons of a lattice or sub-lattice (e.g. interstitial hydrogen or deuterium) atom are another example. This configuration might be energetically more favourable than a single-bound electron and, because of its locally excess charge, is likely to be the nearest neighbour to a hydrogen atom without a tightly bound electron. In particular, the lattice phonon electric fields can dynamically polarize the sub-lattice bound-electron population to greatly enhance the electron 'screening' of the Coulomb barrier between nuclei.

Other theorists chose different approaches to achieve similar results of overcoming the Coulomb barrier (see below). The present author chose to sequentially extend the lochon model to incorporate transient, classical deep-electron orbitals[3], then Klein–Gordon (K–G) quantum mechanical deep orbitals[4,5], and finally the quantum mechanics (QM) deep Dirac levels (DDLs)[6] described and calculated by Maly and Vàvra[7,8].

Akito Takahashi[9] (cluster fusion theory in p. 514), from a strictly standard nuclear physics approach, developed his tetrahedral symmetric condensate (TSC) model. As four or more hydrogen atoms, densely bound in a sub-lattice, are coherently moved together by phonons, the associated bound-electron density between the protons actually increases, rather than being reduced by the kinetic energy of the electrons, which keeps the atoms spread at a molecular distance from one another.

Ed Storms[10] (see his 'explanation' in p. 531), from his chemistry background, chose cracks (or crevices) occurring during the loading of a PdD lattice as a means of

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aligning hydrogen atoms and thereby reducing the average distance between electrons and protons – and thus the Coulomb barrier between the protons. Sinha[2] had earlier shown the benefit of such a structure, but the idea was not picked up at the time because it depended on the assumption that lattice spacing might not be a fixed quantity. With Storms' suggestion, a re-examination of the concept led to the recognition that a linear multi-H molecule in that environment resulted in a 'sub-lattice' that did not have a fixed spacing and could lead to fusion processes[11,12].

Yeong Kim[13] proposed a region of depressed potential in a PdD lattice that could allow the deuterons to form a Bose–Einstein condensate (BEC)[13]. It is possible that the crevice is such a region where the collective electrons provide enough screening to allow the BEC. Widom and Larsen[14] proposed the existence of energetic electrons in the lattice that could induce formation of neutrons in the exothermic fusion process of p-e-p ⇒ D.

There are other reasons for looking beyond the accepted model for DD fusion reactions.

The standard nuclear physics model was/is based on accelerator data for particles with energies greater than 1 MeV. The cold fusion particle energies were assumed by the early critics to be those associated with room-temperature thermal motion (i.e. in the range 25 meV). Actual data at low beam energies (down to 25 keV) had confirmed the standard model, so the critics assumed that they were on firm ground with their arguments. Nevertheless, earlier astrophysics and nuclear physics papers (late 1980s), had already shown a major deviation from the standard model of capture cross-section beginning below 25 keV for DD fusion experiments in the presence of matter. More recent results and their interpretation have now fully confirmed these observations in the low-keV range for a large assortment of elements[15,16]. When compared to extrapolations of these new results, the early critics of CF had underestimated the probability of DD fusion at room temperature by nearly 100 orders of magnitude. CF results are much closer (by ~50 orders of magnitude) to the new DD fusion cross-section prediction than was 20th century nuclear physics. It is likely that few nuclear physicists are aware of this major discrepancy even today. Nevertheless, with the experimental evidence accumulating for a flaw in the standard model, when it is applied to low energies, the numerous theoretical models of cold fusion (most or all of which may be at least partially incorrect) must be examined more carefully for possible answers.

What has the exercise of 'overcoming' the Coulomb barrier taught us?

Catalysts are well known and used in many aspects of our life. Thus:

- Cold fusion is expected to involve some form of catalysis to overcome the barrier to nuclear fusion.
- Many versions of the lattice and its environment have been proposed for this function, and explored.
- Most involve a means of keeping an electron between the fusing nuclei for a greater time than 'normal' and/or a resonance phenomenon (e.g. phonons) to appropriately synchronize motion of the electrons and nuclei involved.

Since the phenomenon is well documented, but conventional models of nuclear reactions and the solid-state environment do not account for the observations, we must look beyond.

- We can look for: higher-order effects of accepted physics models (e.g. details of 'tunnelling'), configurations of a lattice that exist only under specific conditions of high loading (e.g. a 'nuclear active environment'), new (or unexplored) physics, and combinations of these.
- The difficulty of reproducibly generating excess heat and/or nuclear by-products indicates the combined involvement of multiple mechanisms.
- Unexpected pathways combining evidence of the excess heat, low energetic radiation, nuclear products and transmutations must be explored.
- The possibility of deep electron orbits, predicted classically and quantum mechanically, appears to be able to address the greatest number of issues – even beyond that of overcoming the Coulomb barrier.

Acronyms

CF – Cold fusion
LENR – Low energy nuclear reaction
CMNS – Condensed matter nuclear science
BECNF – Bose–Einstein condensate nuclear fusion
Lochon – Local charged boson (electron pair)
DDL – Deep-Dirac level
QM – Quantum mechanics
Q – Mass deficit between initial and final state, e.g. between D_2 and ^4He (MeV)
^4He – Helium atom (atomic mass 4)
$^4He^*$ – Excited nuclear state of a helium atom
^3He – Helium atom (atomic mass 3)
^3H – Tritium, T, hydrogen atom (atomic mass 3)
H, D – Hydrogen, deuterium atoms
$H^\#$ – Femto-H atom (p + DDL electron)
$^4He^\#$ – Femto-^4He atom = α + DDL electron(s)
p, d, t, α – Proton, deuteron, tritium, ^4He nucleus
E – Energy (typically MeV or keV)

DD-fusion decay products (nuclear ash)

The second argument against LENR has several subtopics. The general argument involved the incompatibility of the known radiation of protons, neutrons, tritium, ^{3}He and gammas (by-products of the D + D $\Rightarrow$ ^{4}He* fusion-decay process known as 'nuclear ash') with the measured heat generated from the CF process.

Where have all the neutrons gone?

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'. Takahashi[9] addressed this problem by avoiding the direct DD fusion and achieving the end result of ^{4}He via a different fusion/fission route. Storms' approach[10] was to propose a system that permitted the pre-fusion direct extraction of nuclear energy to the lattice so that fusion finally occurred only when the involved deuterons were already deep in the nuclear energy potential well.

The present author addressed this particular issue by looking closely at the known energy levels of the ^{4}He nucleus. Some energy levels exist that cannot be directly accessed by 'hot' fusion. It became obvious that, if these energy levels existed, then introducing deuterons into them, rather than into the higher levels resulting from hot fusion, would alter the expected decay paths of the excited nucleus ^{4}He*. Thus began a search for a means of DD fusion beneath the ^{4}He* fragmentation levels[3].

Recognition that an atomic decay process, with the emission of a photon, reduces the total mass of the atom led to an extension of the concept to the electron decay process into a deep electron level. A study by Jan Naudts[17] that showed the existence of a deep level (binding energy of ~507 keV) as the 'anomalous' solution to the relativistic K–G equation provided an answer (see note 1). The fact that the K–G equation does not include spin was a problem. However, the Schrodinger equation also does not include spin and yet it is taught as a useful model for the atomic hydrogen atom. Furthermore, the lochon, as a pair of 'coupled' electrons, is a boson and therefore the K–G equation should apply to that case, even if it might not apply to a single electron[4].

In the search for similar solutions for the deep electron orbits, numerous examples were found. The most useful was an earlier paper that computationally solved both the relativistic Schrodinger equation and the Dirac equations[7]. Both produced very similar results (BE = ~507 and 509 keV respectively) and the Dirac equations do provide for spin-1/2 particles.

If the deep electron levels exist, then populating them with electrons automatically explains most known phenomena associated with CF experiments. However, this is a problem since these levels and decays to or from them have never been observed. Electron decay, via photons, between atomic levels when both have 'zero' angular momentum (such as most atomic ground states and DDLs) is highly forbidden. Therefore, another mechanism is required to absorb the excess potential energy produced in such decay. The lochon model[2], the linear-hydrogen molecule model[11,12], and the TCS model[9] can all do that.

Fragmentation ratios

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 DD fusion reactions provided a 1 : 1 ratio ($P_n = P_p$). The observed CF results gave 10^7–10^9 tritium atoms for every neutron (see Srinivasan in p. 619). Since the 1 : 1 ratio of standard DD 'hot' fusion results and models is not observed, it 'cannot' be occurring. The Qs in the equations for the known DD reactions are the mass deficit between the decay product atoms and the helium atom ground state, ^{4}He. It is known that this decay to ^{4}He produces the greatest Q (and therefore has the greatest heating potential) of the three observed paths in hot fusion. 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 as a possible source for the observed excess heat of cold fusion. They seemed to overlook the facts that some neutrons and many more tritium atoms were observed in these experiments. If CF was not the known DD fusion reaction, what kind of nuclear reaction was it?

High levels of ^{4}He

The third sub-topic related to the DD 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 DD fusion. Thus, the probability of forming ^{4}He from DD fusion is less than one per million fusions. This is almost as low as the percentage of neutrons that were 'missing' in the CF experiments. Nevertheless, with these discrepancies ('impossible' results) and the apparently 'random' production of excess heat in the numerous CF experiments, the image of 'sloppy' experimental work of CF researchers was confirmed in the minds of its critics. What was overlooked was the nearly 100% reproducibility of measurable excess ^{4}He (qualitative, not quantitative) only when excess heat was produced (see Lomax in p. 574).

A number of researchers sought answers to these questions in possible pathways from the deuteron pair to the

^{4}He ground state. Kim's[18] Bose–Einstein condensate nuclear fusion (BECNF) model makes important contributions in that it addresses the coupled DD pair immediately before and after the fusion process. He addresses the issues of paths (including nuclear selection rules) from the DD 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. Twenty years earlier, Nobel laureate Julian Schwinger[19] had made this first step away from an apparent fixation on energetic D + D tunnelling into the normal fusion channels.

The extended-lochon model recognized that a 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 during the decay of the latter to a deeper (non-nuclear) energy level. Since the electrons gained kinetic energy (perhaps >1 MeV each) and binding energy (~1/2 MeV each) during this decay to the DDLs, the energy must come from the potential energy of the proton(s) binding them. This story is fully told in papers[3,4,6,16] on 'beneath the fragmentation level'. The how and why of these results and some of the implications of this model are identified below as 'lessons taught'. The implications go much further and are identified in the remainder of this article.

What does the search for a means of avoiding fragmentation teach us? It is proposed here that:

1. The anomalous solutions to the relativistic Schrödinger, K–G and Dirac equations are valid.
   a. Their validity is challenged based on the consequences of the singularity of the Coulomb potential (and of the anomalous solution) at $r = 0$.
      (i) However, no nuclear physicist considers the singularity to exist in the nucleus. Therefore, this argument against the anomalous solution is untenable.
      (ii) No deep levels have been experimentally confirmed.
   b. Is it possible that halo nuclei[20] are in fact femto-molecules (i.e. a nucleus with a tightly bound femto-hydrogen atom)?
   c. If halo nucleons can be detected and determined to be protons or neutrons[21], is it possible to consider DDL electrons or femto-H atoms to be measureable? The mass difference between p and n is over a MeV. The mass difference between p and $H^\#$ is likely to be ~1% of that. The difference between halo protons and halo femto-H will be in the Coulomb potential.
   d. Is it possible to experimentally differentiate femto-hydrides with DDL electrons from halo nuclei? Based on this model, it is possible that the claimed halo nuclei with halo protons are in fact femto-hydrides with femto-H as the halo.

2. Fragmentation (fission) and photonic decay (gamma rays) from excited nuclei are not the only means of exchanging energy between ^{4}He* and the environment[22].
   a. Electron capture[23] by a nucleus with resulting neutron production is well known. Atomic electrons about a proton-rich nucleus can be 'captured' by a nuclear proton if they have a strong probability of being in the nuclear region. The resultant neutron formation is a weak interaction, but it is not rare. Such capture by a proton of a DDL electron, in orbit about itself or from a proximate femto-atom or femto-molecule, would be much more probable than that of an atomic electron.
   b. Internal conversion[24] is a means of removing an electron from atomic levels by adding nuclear energy during the time an electron is near the nucleus. As a direct (near-field) interaction, it does not have the selection rule forbidding $0 \Rightarrow 0$ transitions. Such interaction with a DDL electron, within femtometres, would be much more probable than with an atomic electron. The difference is in the proximity and strong binding energy of the DDL electron.

3. If decay to DDL is achieved.
   a. Without radiation or other means of exchanging energy with the environment, the femto-atom would not lose energy.
      (i) However, since the electron gains relativistic mass and energy is conserved, the *proton must lose mass*.
      (ii) With radiation emission (photonic or phononic), or if work is done during the decay process[4], the DDL electron is still relativistic, so the proton must lose even more mass.
   b. Protons losing mass prior to fusion lowers the mass defect of the nuclear interaction (i.e. Q gets smaller).
      (i) Reduced Q from one DDL electron allows the DD fusion process to proceed beneath the neutron fragmentation level.
      (ii) Reduced Q from two DDL electrons (e.g. a lochon) allows the DD fusion process to proceed beneath both the n and the p fragmentation levels.
   c. The difference between hot and cold fusion ($d + d \Rightarrow$ fragmentation and $D + D \Rightarrow {}^4He$ respectively) is in the electrons.
      (i) In cold fusion, electron(s) extract energy from the proton(s) (via the Coulomb field) prior to, during and/or following the fusion itself.

(ii) In hot fusion, the electrons do not interact and are considered constants.

4. Production of femto-H or femto-D by electron decay to a DDL could be the same.
   a. However, in matter, the resulting femto-atoms of such decays are short-lived, because the resultant is a strong transmutant in either case.
   b. Because of the presence of neutrons, there are differences between femto-H (ref. 25) and femto-deuterium atoms and molecules[26]. This greatly alters the lifetime, and therefore the 'range' of the femto-atoms and molecules.

Alternative DD-fusion decay processes

The third argument is somewhat related to the second. How does the excited $^4He^*$ nucleus decay to the ground state without the expected fragmentation or gamma decay processes? The previous section discussed how it is possible to avoid fragmentation in DD fusion that forms the highly excited $^4He^*$ nucleus. Assuming that the Coulomb barrier between the protons can be tunnelled through by minimum energy and minimum angular momentum deuterons, the available excited state energy levels $^4He^*$ are well-known zero angular momentum ($l = 0$) levels[27] with decay characteristics that lead to the second argument (a nearly equal number of neutrons and protons and almost no ^4He). There was 'no conceivable' means of resonant tunnelling below these levels because there are no states between the lower fragmentation level and the ground state. Furthermore, the energy between even zero kinetic energy deuterons and the ^4He ground state would be too high to access such levels if they did exist.

Nevertheless, only by tunnelling below the fragmentation levels can a fusing deuteron pair attain the ^4He ground level by other than a highly forbidden energetic $l = 0$ to $l = 0$ gamma transition. This is the basis of the 'below fragmentation' model. With no energy levels in this sub-fragmentation region, resonant tunnelling is not an option; so, the tunnelling rate is much lower than would otherwise be expected. On the other hand, if one or two DDL electrons are present (with orbital radii in the 2 fm range), they provide super-strong screening and the deuterons or protons of the resultant femto-molecule would be well within the nuclear fusion range. No tunnelling is required. This deep-orbit option is the basis for fusion below fragmentation and provides a distinction between HH and DD fusion and their consequences[25,26]. At these femtometre distances, the neutrons in the deuterons will come close enough together to force fusion. A femto-hydrogen molecule, without the neutrons but with sufficient angular momentum, might have a meta-stable state.

While the extended-lochon model provides an explanation for the observed CF effects, it does not yet have sufficient information to suggest a 'best' path to the goal of heat-without-energetic-radiation from LENR. However, it also provides more possibilities to explain the 'inexplicable', such as 'how the excited $^4He^\#$ nucleus decays to ground state[22] without energetic radiation and how CF produces transmutations and scavenge radio isotopes in the lattice'[24,25].

The lochon or a single DDL electron, either 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[28]. However, there are differences. The primary one being that, after DD tunnelling, 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 electric and magnetic field coupling, is chaotic and would therefore-take longer and would not be nearly monoenergetic[6]. On the other hand, the average electron–proton separation is orders of magnitude less if the extended-lochon or Dirac 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 between DDL energy transfer and internal conversion of atomic electrons is that the deep-orbit electrons (lochon) are energetic (in the MeV range) and tightly bound, instead of in the many electron volts range of the normal *k*-conversion electron. Thus, their acceleration-induced electromagnetic (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 neighbouring Pd electrons. The expected energetic gamma ray needed to de-excite a nuclear level requires a more stable state as a starting point. Since the only states that exist below the D^+D^- entry energy in the lochon model are (0, 0), these highly forbidden (i.e. very slow to form) gamma rays are not observed. This process explains the high concentration of ^4He atoms that violates the nuclear physics data are 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 electron pair 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 stable 'pe' or a '2p2e' nucleus (a femto-sized $H^\#$ atom or $H_2^\#$ molecule) will be present. Thus, a neutral but active nucleus can drift at will through the electron clouds of the lattice-atoms and it can drift into range of the nearby nuclear potentials. Entering another nucleus means transmutation. Since in the case of $H^\#$, $H_2^\#$ and $D_2^\#$, the freshly combined 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. The ability to shed excess energy by forming neutron(s), by proximity coupling of nuclear energy to lattice electrons via deep-orbit electrons, and/or by ejection of tightly bound electrons and heavy particles, means that the slower decay process of energetic radiation is not a common by-product.

Since the excited ^{4}He nucleons and the DDL electrons have insufficient angular momenta to form transverse photons, normal photonic radiation is not an option. Nevertheless, longitudinal photons (Maxwell's 'near-field' radiation) can couple energy between the nucleons and the proximate DDL electrons. However, resonant coupling of nuclear or DDL electron energies to atomic and lattice electrons is nearly impossible because of the many orders of magnitude difference in orbital frequencies. Longitudinal photon and direct coupling of nucleon and DDL electron are reasonable since they are physically and frequency-wise so close. Because of their high fields from relativistic velocity and extreme acceleration, DDL electrons would then direct-couple excess energy to lattice electrons via non-photonic, strong-field interactions. This would be the principal energy transfer mode between nucleus and lattice[25,26]. Because of the high frequencies of the inner atomic electrons and the nature of the s orbitals, there is a higher probability of ionizing the more energetic inner electrons during the early nuclear de-excitation process. As the excited nucleons decay and approach the ground state, their frequencies diminish and those of the excited DDL electrons do so as well[29]. Thus, eventually, resonant coupling between DDL and nearby atomic electrons becomes dominant. Thus, energy transfer rates go up and the more numerous outer electrons become excited. This establishes a short-term, steady-state energy transfer between the nucleus and lattice, via the DDL electron.

The direct coupling of energy to the lattice electrons causes intense local ionization that would result in recombination radiation into the kilo-electron volt range (the maximum binding energies of the lattice atom electrons). This low-energy radiation (relative to the normal ^{4}He* decay modes) can take many forms that have been observed in CF experiments. These include collimated X-rays (see Hagelstein in p. 601) and even RF (see Kidwell in p. 578). Because of the intense local ionization and preferential coupling to tightly bound atomic electrons, population inversion within the nearby lattice atoms can produce lasing action from the soft X-ray into the RF regions.

As the nucleons approach the ground state, their rate of energy transfer to the DDL electrons also decreases. H owever, another option (one observed in nuclear energy transfer to atomic electrons) can dominate. In internal conversion, the nucleus does not first emit an intermediate real gamma ray, and therefore need not change angular momentum or electric moment; no gamma ray is emitted, and the DDL electron may leave its orbit with the remaining nuclear energy[6].

The implications of the DDL electrons go beyond the 'three challenges'. What does the search for additional means of transferring nuclear energy to the lattice teach us? It is proposed here that:

1. There are reasons that nuclear energies do not readily transfer to atomic electrons (fortunately).
2. The presence of DDL electrons can increase the rate of energy transfer between nucleus and lattice by many orders of magnitude.
3. The high rate of excited nucleon energy transfer to DDL electrons provides a faster and more probable decay mode than gamma emission (and perhaps fragmentation as well).
4. The intense local ionization of atomic electrons provides a basis for rapid energy dissipation from the region via recombination radiation from the fusion site.
5. The preferential ionization of the inner electrons provides a basis for population inversion and lasing action (from the soft X-ray region into the RF regions).

Steps beyond

The steps to LENRs 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 ubiquitous and nearly incontrovertible (see Srinivasan in p. 624 and Iwamura in p. 628). In the extended lochon model, this is a natural consequence of tightly bound electrons easing protons or energetic deuterium and helium nuclei into adjacent atoms and their nuclei[25,26]. Furthermore, there is mounting evidence that the immense laboratory of nature has actually provided a catalytic (enzymatic?) path to biologically induced transmutation (see Biberian in p. 633 and Vysotskii in p. 636). The ability of the DDL electrons to receive energy from excited nucleons provides a means of lowering the energy of nearby radioactive nuclei[25,26]. This change in energies establishes an attractive force between femto-atoms and such nuclei in the lattice and allows them to decay without having to resort to the standard (often very energetic) radiation pathways. Thus, not only are the cold fusion-induced transmutations (always radioactive by normal processes) brought to the ground state by a multi-body radiative decay process, but the femto-atoms are highly mobile and can therefore be useful for remediation of radioactive waste[25,26].

In addition to the many years of CF results that could support the deep-orbit model, there are nuclear physics data and models from the last two decades for 'halo' nuclei[20]. These nuclei that exist far outside (e.g. 7 fm) of the nuclear potential are still difficult to explain (or accept) in terms of contemporary nuclear physics, but they fit well with the LENR model presented above and extended more recently in terms of 'femto-molecules'[25,26]. The experimental techniques now available with capabilities to distinguish halo neutrons from halo protons can also validate or disprove some of the models presented above.

Recent tests of a high-temperature (>1000°C) cold fusion reactor ('Hot Cat') have produced some extremely unusual results[30]. All nickel isotopes, but ^{62}Ni, nearly disappeared during operation. If validated and studied more carefully, and halo nuclei are found, these data could provide the basis for (or confirmation of) a theoretical breakthrough in cold fusion. One reported result addresses a point made above about the longevity of the femto-hydrogen. Is the reported excess ^{62}Ni in the 'ash' of the reactor really ^{62}Ni or is it a $^{61}\text{Ni} + \text{H}^{\#}$ femto-molecule (or a halo nucleus)? While the femto-H is mobile in the lattice, its lifetime is severely limited by the probability of its entering a nucleus and transmuting it. If, for some reason, the femto-H is stably bound to a lattice atomic nucleus by its Coulomb field and angular momentum (to form a femto-molecule), rather than fusing with it, then it will not be free to move through the lattice and fuse with another nucleus. Under this condition, its lifetime could be greatly increased. Would it exceed the multi-millisecond lifetime of most halo nuclei? That would likely depend on the stability of the core nucleus.

Another surprising Hot Cat result was the loss of ^{7}Li and relative growth of ^{6}Li levels. This violates the expectations of, and a CF model based on, ^{6}Li going to ^{7}Li (see Liang in p. 519). If CF are correct, then there are many additional things that this exploration can teach us.

Conclusion

Three major objections were made over two decades ago against the CF claims of a nuclear source for the observed excess heat in the CF experiments. These objections have been carried over to the present against the last 20 years of 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. (1) The Coulomb barrier problem is 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 physics and astrophysics 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 are the CF data (at $E < 1$ eV). (2) The nuclear ash problem actually identifies the possible CF process(es), rather than proving it wrong. (3) The dearth of neutrons and protons, relative to the heat produced, and the means of producing ^{4}He without energetic radiation are a natural consequence of alternative DD-fusion decay processes that extend the answer to these three problems into the nuclear region. The key to all three problems is recognition of the reality of the anomalous solution to the accepted Dirac equations.

Other objections and their solutions not detailed here, particularly those involving p–p fusion, can be treated similarly. Methods of transferring energy from an excited nucleus to the lattice, without a high-energy decay product, have been addressed. A means of actually scavenging radioactive nuclei, induced or native, in a lattice and reducing them to stable states with low-energy decay processes has been proposed. Observed transmutations in LENR, and even in biological systems, have immense implications.

The differences between 'hot' fusion, with its known physics but difficult technology, and cold fusion, with its 'unknown' physics and simple technology, are worth noting[31]. It is proposed that tightly bound electrons are intimately involved in the CF process and are the distinguishing feature. In the standard hot fusion process, electrons are not involved, do not significantly change their energies in the fusion process, and therefore are not considered.

There are even some surprises coming from quantum mechanics that now support LENR by providing the theoretical basis for a relativistic deep-electron orbit[32]. It is to be hoped that, with the new knowledge obtained over the last 25 years, more physicists and chemists (and biologists) will recognize something real here and will look for ways of applying their specialties to the expanding field.

Note

1. The solution is 'anomalous' because no experimental evidence for the predicted level existed (prior to CF) and mathematical physicists, for over 55 years, have only admitted a solution without a singularity at $r = 0$. No nuclear physicist would consider extending the $1/r$ Coulomb potential to the origin; but, apparently the mathematical physicists do not read the same journals.

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