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Research Article

An Explanation of Low-energy Nuclear Reactions (Cold Fusion)

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Abstract

A plausible nuclear-active-environment in which Low-energy Nuclear Reaction (LENR) occurs is identified by ruling out various possibilities and by identifying an environment that is common to all successful methods. When this environment is combined with a plausible mechanism, many testable predictions result. These insights and proposals are offered to help clarify understanding of LENR and to suggest future studies. The common environment in which LENR occurs is proposed to be cracks of a critical size, followed by a resonance process that dissipates energy by X-ray emission based on a laser-like process. The LENR behavior has the potential to test the Standard Model of nuclear interaction.
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1. Introduction

Twenty-three years have now passed since Fleischmann and Pons (F–P) announced discovery of "cold fusion", aka Low-energy Nuclear Reaction (LENR) [1]. This phenomenon has two unique behaviors that have confounded explanation. Significant energy along with several nuclear products is produced in what appears to be ordinary materials under ambient conditions, where no nuclear reaction should be possible. And, unlike conventional nuclear reactions, release of the resulting energy does not cause emission of energetic radiation. When radiation is detected, it has relatively low energy and intensity. Even the documented nuclear products of helium-4, tritium, and various transmutation products are unexpected. To make the explanation even more challenging, the latter two products have been detected when either deuterium or light hydrogen is used. Application of extra energy from various sources and modest increases in temperature increase the reaction rate but are not required to initiate the process. In other words, the process does not act like conventional hot fusion.

The initial rejection of the claim has been shown to be unwarranted by hundreds of replications [2]. These studies show consistent patterns of energy production and various nuclear products being produced using four different methods. Many books summarize the history of this discovery [3–9], and several websites[a] provide up to date information. Ignorance is no longer an excuse for rejecting the claims.

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This paper proposes to identify the location of the reactions within a material, how the process is expected to behave, and the general type of mechanism leading to the fusion and transmutation reactions. The goal is to find a productive approach to uniting and explaining all of the observations while resolving the apparent conflict with expected behavior based on conventional understanding of nuclear interaction. Of course, not all observations can be assumed correct. Nevertheless, enough well done studies are available to make rational judgment possible. Besides the acknowledged uncertainty in the behavior of LENR, flaws or gaps may also exist in conventional understanding of nuclear interaction, in particular in how the Coulomb barrier can be reduced and the role of the neutrino in the resulting reactions. As a result, demonstrating how LENR actually behaves may advance understanding of nuclear physics.

Attempts have been made by various theoreticians to propose a mechanism to explain how the Coulomb barrier can be reduced within the PdD lattice. These models generally involve changing the energy or local concentration of electrons. Initiation of a nuclear reaction in ordinary materials by such processes is prevented by chemical effects, as is shown later in the paper. Instead, the approach used here assumes a novel structure must form in the material before LENR is possible. The mechanism that causes the nuclear reactions occurs only within this structure, which is referred to as the "nuclear active environment" (NAE). Once this environment forms and is populated by any of the hydrogen isotopes, a fusion reaction follows. The challenge is to identify the NAE and create as much of it as possible. Identification can be accomplished by searching for a universal condition present during all successful production of LENR regardless of the method used or chemical system. Once the NAE is identified, search for the mechanism that produces LENR becomes easier. Many efforts to understand LENR have been unsuccessful because they reversed this process, i.e. by searching for the mechanism first within a single material, such as in PdD, while ignoring a unique NAE that would be present in all active material regardless of its composition or the method used.

2. Discussion

2.1. Nuclear active environment

The concept applies to an environment or location in which the mechanism leading to the nuclear reactions must operate. Consequently, it must form before the mechanism can start, the amount will limit the rate of energy production, and its nature will determine the mechanism that operates within it. The NAE must also be chemically independent of the normal chemical environment. Understanding and accepting these requirements are basic to what follows. Justification for this approach is provided later in the paper.

Identification of the NAE can start by finding a single condition that is present during all successful LENR studies. Requiring consistency with what is known about basic chemical behavior can set additional limits. These limits are created because electrons and nuclei in a chemical structure are arranged in tightly controlled relationships with respect to their energy and location relative to each other. Any change in this relationship will change the chemical structure and be resisted because energy is required to cause a change. This requirement cannot be avoided simply by using quantum mechanical models. Further justification for this insight is provided later in the paper.

Chemical structures, even highly modified ones at high temperatures and pressure, are known not to initiate spontaneous nuclear reactions based on experience over geological time. In other words, the nuclear mechanism rarely occurs and requires a very unique condition. The NAE is this unique condition. Its characteristics can be further limited by requiring the NAE and the nuclear mechanism to work together in a logical way. In other words, physics and chemistry have to work together to solve this problem.

LENR is proposed to involve three main events. NAE forms as the first event, the second event involves hydrogen atoms entering the NAE, and finally these atoms interact during the third event to cause a nuclear reaction. Each of these events can be described as a separate and independent process, starting with formation of the NAE. Slow formation of the NAE is proposed to cause the long delay typically experienced using the electrolytic process of F–P. Only the most general aspects of these events are outlined here, with more detail to follow in later papers.

The general principles that apply to any NAE need to be understood before a NAE can be proposed. First, the NAE must form. No matter how this happens or the final configuration, the formation process is expected to follow conventional chemical behavior and obey accepted laws governing such processes because it occurs in a chemical environment. A reduction in Gibbs energy must occur and the process that causes such reduction needs to be identified. Typical initiators of such changes involve a change in composition, a change in temperature, or accumulation of stress. In addition, the process of forming the NAE is probably endothermic. Obviously, a limit exists to how much NAE can form. Without a limit, power production would increase until the material is destroyed, which is not the case. A reason for this limit must be made part of a proposed process.

The second process, which involves insertion of hydrogen into the NAE, must also result in reduction of Gibbs Energy and the rate of insertion will be controlled by an activation energy[b]. This approach allows behavior to be predicted by applying the Laws of Thermodynamics to a collection of atoms rather than using quantum theory to describe how individual atoms might behave. In other words, focus is on the general behavior, as is typically used in chemistry, rather than on the quantum behavior of individual atoms, as is favored by physics.

The third process, involving the actual nuclear reaction, is required to be exothermic and to result in nuclear products known to occur. The details of this process will be discussed later in the paper.

Let us start by applying these basic requirements after the NAE has been created. Three major variables are expected to determine the amount of generated power.

(1) The number of sites where nuclear reactions can occur, i.e. concentration of NAE. Obviously, the greater the number of active sites, the more power is produced.
(2) The concentration of H or D in the NAE, which is related to the applied H_2 or D_2 pressure when gas is used or chemical activity when electrolysis is used. The greater the concentration of hydrogen isotopes, the more power would be produced.
(3) The energy available at the NAE, which is normally provided by temperature. Temperature is expected to have an exponential effect within a limited range, typical of its effects on ordinary chemical reactions. This energy also can be applied using lasers or other sources. The more power applied to the sites, the greater the rate of fusion at each site and the more power is produced.

Different combinations of these variables affect each method differently. For example, the electrolytic method suffers from relatively low temperatures while benefiting from a high concentration of deuterium. In contrast, the gas loading method has low hydrogen concentration while being able to benefit from high temperatures. Both have unknown and highly variable NAE concentrations. The best way to increase the amount of energy would be to maximize all three variables. Consequently, LENR does not necessarily require a high concentration of H or D to function, as is frequently assumed. The conditions only need to combine to produce a rate that can be detected using available instruments. In addition, the variables interact in complex ways. For example, increase in temperature will lower the concentration of hydrogen, all else remaining constant, causing power to decrease when the temperature exceeds a critical value. Destruction of the NAE by too high a temperature or excessive local energy production can also reduce the rate.

Once the NAE forms, the subsequent mechanism operating at the nuclear level may be very unusual, but the researcher has no influence over this reaction. It occurs spontaneously and automatically. Trying to influence the

[b]Conventional chemistry uses the relationship ($k = A\ e^{-E/RT}$). This could be applied to LENR if "k" is related to power produced by the nuclear reaction, T is the temperature in the NAE, and E is the activation energy for forming the NAE or for making H^+ (D^+) available to the NAE. This assumes an energy barrier exists in all processes that precede the nuclear reaction. If several kinds of nuclear reactions occur at the same time, each could be described by independent equations having the same form, but different activation energies. For example, failure to detect tritium while helium is produced would result partly because the tritium producing reaction would have greater activation energy, hence a lower rate, for the local conditions.

nuclear process directly would be like lighting the fuse (creating the NAE) and then trying to influence the rate of the resulting explosion. The amount of energy being created locally is simply too large to control once the process starts.[c] Consequently, knowing exactly how this mechanism functions is not useful to making the LENR more intense or reliable. Nevertheless, this understanding can help identify the NAE and the expected nuclear products, which is important.

How many kinds of NAE-mechanism combinations are expected? Are all the observed nuclear products created by the same combination? These questions are difficult to answer based on present experience because each method producing LENR involves a different gross chemical environment. Nevertheless, a process so rare and unique would be expected to involve only one or, at most, a very few different combinations. Hints about the basic nature of the NAE and where it is located can be obtained from the Fleischmann–Pons effect, which shows:

(1) Almost complete loss of helium to the gas. (Shows that helium is produced within a few microns of the surface [10].)
(2) Appearance of tritium in the electrolyte rather than in evolving gas. (Shows that tritium is produced close enough to the surface to permit exchange with the arriving D^+ ions [11].)
(3) Transmutation products located only in the surface region. (Shows that some of the reaction occurs at the surface [12,13].)
(4) Presence of melted regions on the surface. (Shows that the major energy-generating reaction is concentrated at the surface.)
(5) Ability to generate LENR using thin layers of palladium on an inert substrate. (Shows that a large amount of material is not required [14].)

These behaviors point to the surface region as the place to look for the NAE when electrolysis is used, not in the interior of the cathode. What chemical and physical conditions are present in the surface of an electrolytic cathode? Many careful analyses of such surfaces reveal a complex alloy containing lithium, platinum, oxygen, elements provided by the Pyrex container, and impurities in the electrolyte, with sometimes no palladium present at all. This impurity layer appears to be necessary to maintain a high concentration of deuterium [15] and perhaps to create the NAE as well. Measurements of the surface composition place it above D/Pd = 1.5[d] [17,18], which is well above the measured average composition [17]. Deuterium is continuously lost from this layer through cracks, causing a steady but non-uniform flux of deuterons within the layer [19]. Further complicating the interpretation, high-resolution SEM examination shows a complicated morphology consisting of dendrites, cracks, well-formed crystal structures with preferred orientation [20,21], and a very uneven topology [21–25]. Deposition of palladium using the so-called co-deposition process creates even greater complexity [26]. Just where in this tortured landscape the NAE is located is not known, although it must have a very small size because all features on such a surface are very small. The observed energy is expected to result from the sum of many active sites, with each site being independent of the others. This kind of behavior can be seen clearly in the IR images taken by Szpak et al. [27,28] showing random flashes of light as a result of sudden local heating–cooling cycles in random locations. Fogging of photographic film placed against active material shows that tritium is also produced only in random locations very near the surface. Mosier-Boss et al. [28] found this effect after electroplating Pd from D_2O, and Sankaranarayanan et al. [29] observed the same behavior by loading and deloading Ni wire with H_2. Other studies have produced tritium and detected it using autoradiography, but we cannot be sure LENR is the sole cause when discharge voltages great enough to cause some hot fusion [30,31] are used. From these observations we can conclude that the NAE has a very small size and it is not uniformly distributed within a complex

[c]Of course, denial of fuel will control the overall power, as described above.
[d]The fcc lattice of PdD does not exceed D/Pd = 1. Compositions in excess of this limit suggest formation of a crystal structure (a new phase) that can accommodate the extra D [16], similar to formation of ZrH_2 following ZrH in the Zr–H_2 system.

surface. Presumably, the observed melting can occur where concentration of NAE is especially great. In summary, these observations show that the NAE exists only near the surface, it is not pure PdD, and the measured D/Pd ratio is too large to result from beta-PdD alone. Therefore, any model must be rejected when it is based on the NAE being in the bulk of the sample and when it requires the presence of pure PdD having the measured average composition.

Arata [32] and Case [33] focused attention on the importance of small particle size. This idea was carried to extreme by attempting to place a few atoms of Pd in the small atomic cage present in Zeolite [34], but without obvious success. Arata [35,36] proposed creating nanoparticles of Pd by oxidizing an alloy of Pd + Zr. The dilute Pd–Zr alloy that remains in the final matrix of ZrO_2 appears to produce a small amount of LENR [37,38], but not enough to identify the small size of the metal particles as being the only important condition. The material Case [33] used, which is a typical chemical catalyst consisting of nanoparticles of Pd on charcoal, does not work unless special carbon is used and the material is given special treatment. My many attempts to apply finely divided Pd to various materials, including carbon, failed to produce predictable LENR. Obviously, the size of the Pd particles is not the only important variable using this method. After all, any attempt to form nanosized particles will usually create a wide range of sizes, some of which will cause LENR and detectable energy if size were the only important condition. While small size is beneficial, probably because of increased surface area, the total experience shows this is not the only important condition.

Simply causing deuterium to diffuse through palladium or other materials apparently can initiate LENR reactions at a low level. Iwamura et al. [39] diffused deuterium through alternate layers of calcium oxide (CaO) and Pd. The presence of CaO was necessary for transmutation to occur on the surface where various elements were deposited. The behavior during this study reveals an even more complex process because the CaO layers were separated from the targets on the surface by 400 Å of Pd. Did the CaO create a special species that diffused through the Pd without reacting, only to cause the deposited elements on the surface to transmute? Or did the mechanical and electronic stress introduced by the CaO cause a NAE to form at the surface? In contrast, Liu et al. [40] and Biberian and Armanet [41] were able to achieve LENR by simple diffusion of D^+ through pure Pd, again using a relatively low deuterium concentration. Possible features these studies might have in common are described later.

2.2. Additional requirements for evaluating an explanation

Behavior initiated by hot fusion needs to be identified and not used to explain LENR. Because both hot fusion and LENR can occur in the same materials and sometimes at the same time, the results of these two independent reactions need to be separated. Crack formation is known to initiate nuclear reactions in material containing deuterium. This process, called fractofusion [42–45], creates brief high voltage in the crack that can cause fusion by the hot fusion process with the expected energetic nuclear products. Because neutrons result, they are frequently detected as brief pulses, which must be carefully evaluated before they are attributed to LENR. Another example of potential hot fusion is obtained when solid materials are bombarded by energetic deuterons [46–48]. The resulting hot fusion-like reaction is sensitive to the electron concentration in the material when applied energy is low. This is not an example of LENR because the reaction products are very energetic and are the ones expected to result from conventional hot fusion, not LENR. A clear separation between how LENR and hot fusion are caused to happen must be maintained because entirely different mechanisms are apparently operating.

Two very different assumptions have been applied to the process of creating a theory. One approach assumes a spontaneous nuclear reaction can occur within a normal lattice or on the surface of normal material simply because a proposed mechanism starts to operate, usually because the deuterium concentration reaches a critical level. The other approach, which is encouraged here, assumes a significant and observable change must take place *before* LENR can occur and this results in a new environment in which the nuclear reactions take place.

This unique environment avoids conflicts with how common materials are known to behave and is consistent with just how rare and localized the behavior appears to be.[e]

Ordinary materials cannot be the location of LENR because of how chemical systems are known to behave, which can be understood several different ways. Materials are made up atoms arranged in characteristic crystal structures, the form being determined by the energy of electrons associated with the atoms and the thermal energy experienced by the crystal. These energies cannot be altered without changing the structure or, if increased enough, cause melting.[f] The electrons do not shift spontaneously from one energy level to another in any observable way in a stable chemical system unless energy is applied from outside the structure or changed conditions make the present structure unstable. When such a change takes place, it is always associated with a reduction in Gibbs energy[g]. Consequently, any proposed spontaneous change that can initiate a nuclear reaction must also show why the Gibbs energy would be reduced. In addition, the atoms act as a collective so that when any change is made in one location, this change is communicated to all parts of the crystal at well-understood rates. The Laws of Thermodynamics describe this collective behavior. Metals such as palladium or nickel and compounds such as PdD are all stable chemical systems under the conditions normally used. Even if a spontaneous change were to take place because of unexpected release of internal energy, the limited magnitude is known not to cause nuclear reactions.[h] This understanding is so basic, it cannot be ignored without clearly stated and demonstrated reasons. Indeed, the role of energy in materials is so important and well understood that arguments based on quantum mechanics or any proposed increase in energy must be consistent with this behavior.

A list of proposed requirements a theory must satisfy are summarized below.

(1) LENR does not happen in pure beta-PdD, but requires formation of a unique condition (NAE) before LENR can occur. Regardless of the condition, a high deuterium or hydrogen concentration is not the only requirement.
(2) The mechanism causing the nuclear interaction occurs only in the NAE and is logically related to the nature of the NAE.
(3) This NAE-mechanism combination must be consistent with what is known about the behavior of materials, the Laws of Thermodynamics, and basic rules governing nuclear interaction.
(4) The NAE-mechanism combination must explain all observed products of LENR, including results of fusion, transmutation, and the source of radiation.
(5) The explanation must logically explain both how LENR is initiated and how the resulting energy is dissipated without apparent radiation.

[e]As an aside, these two different approaches to finding an explanation reveal a basic difference in how different branches of science look at Nature. People trained in physics focus on mechanisms while trained chemists tend to focus on the environment and conditions. The phenomenon of LENR requires a marriage between these two fields of science, which has not yet happened. Rejection of the observations has generally resulted because a mechanism could not be imagined based on currently accepted "theory". Successful understanding will only happen after the conventional mechanisms are abandoned and a new mechanism is applied to the correct kind of material.

[f]As an example of how a typical material would behave, palladium will melt if more than 0.17 eV is applied to each palladium atom. This amount of local energy is not enough to cause a nuclear reaction. Any energy accumulating process operating within a lattice of Pd atoms would cease once the local amount had reached this level because melting would commence. As a result, energy would be absorbed from the proposed energy-accumulating process and the region in which this mechanism operates would be destroyed.

[g]Gibbs energy is defined as being equal to the enthalpy change minus the entropy change times absolute temperature: $\Delta G = \Delta H - T\,\Delta S$. The enthalpy is the measured energy given off or taken up by the reaction.

[h]An exception is found in the fractofusion process. In this case, rapid separation between atoms, resulting in a crack, creates a large voltage difference within the space that can ionize and accelerate any deuterons present to energies sufficient to cause hot fusion. This event is normally detected as a burst of neutrons.

2.3. Published explanations

What basic requirements can be accepted so far? Although the answer is incomplete, a few can be provisionally accepted and used to evaluate suggested mechanisms. Hopefully, this process will make the requirements easier to understand.

Hundreds of attempts have been made to explain the LENR effect, yet no theory has successfully shown how the effect can be made more reproducible and robust, and no theory has gained acceptance outside of a select group. Nevertheless, a few examples of published explanations will be discussed below to give an understanding of the approaches being explored and their limitations in view of the proposed requirements listed above. Rather than describe each theory, the general principles are applied to a few models to show how similar ideas might be evaluated.

2.3.1. *Role of metal atom vacancies*

Hagelstein and Chaudhary [49] propose vacancies in the palladium sub-lattice where Pd atoms are missing is the location of the NAE. This approach is based on three assumptions: (1) that a sufficient number of metal atom vacancies are present in PdD, (2) that more than two deuterons can enter such a site in a PdD lattice, and (3) that once there, the deuterons can fuse to form helium. Failure of any one of the three assumptions would invalidate the model. We start by examining each assumption separately. Flanagan et al. [50] report that metal atom vacancies introduced by cold-working palladium were removed by heating between 473 and 573 K, which would eliminate such vacancies at temperatures known to produce LENR. If metal atom vacancies are present in large concentrations in PdD, the upper phase boundary is expected to exceed D/Pd = 1. McKubre and Tanzella [51] determined this boundary at room temperature using the behavior of resistance. They found a break in slope between resistance and D/Pd to occur very close to a value of 1, indicating formation of a two-phase region at higher compositions; not a continuation of the beta phase. Norlander et al. [52] conclude, based on calculations, as many 6 D can occupy a Pd vacancy. But, even at this number, they conclude the deuterons are not close enough to fuse. The more atoms needed to be assembled in one place for a reaction to occur, the lower would be the probability of this happening. Therefore, the reaction rate would be small and the rate would be very sensitive to the applied D_2 pressure. The observations do not show a large pressure effect, but this variable needs to be studied more carefully. If fusion were to occur, another set of assumptions have to be used to explain absence of radiation. Consequently, violation of requirements Nos. 1, 4 and 5 (listed above) do not encourage use of this approach as an explanation.

2.3.2. *Role of neutrons*

Obviously, if neutrons were involved in the nuclear mechanism, the Coulomb barrier would not be an issue. Therefore, several people have proposed a source of potentially reactive neutrons. These neutrons are thought to be initially present in the material as stable clusters [53] or as stable polyneutrons [54], which are released from this stable condition by some mechanism. No direct evidence exists for trapped neutrons, neither as clusters nor as polyneutrons, being present or released in ordinary material. Indeed, if enough neutrons were present to support the large reaction rates being occasionally observed, their presence would be obvious from their effect on the density of such repositories, which has not been found. Also, just how neutrons or polyneutrons would remain in the palladium or any material after chemical purification requires use of implausible assumptions. Although a few observations are consistent with a rare and low-level nuclear process being caused by what might be polyneutrons [55], the explanation does not identify the NAE and violates requirements Nos. 4 and 5.

On the other hand, neutrons have been proposed to form [56–61] by fusion of an electron with a proton or deuteron, which requires about 0.76 MeV to be present at the time and place of the reaction. Because this explanation of LENR has gotten wide attention, it needs to be fully understood. The idea is flawed because it assumes enough energy to form a neutron can be concentrated in a chemical environment at one location. Energy is a real and basic quantity that is not

observed to accumulate spontaneously beyond well-understood limits.[i] If such large energy were to concentrate in an electron or the target nucleus, it would have to be harvested from an environment in which the average energy is much less than 0.1 eV. Consequently, packets of energy would have to spontaneously seek out and add to individual electrons in which the accumulating energy must be stored. How is this storage accomplished? The electron is a fundamental particle that cannot store energy. If it could, its rest mass would not be constant and, at the very least, the TV would not work. Perhaps energy can be stored by another process. Particles are known to store energy as increased mass if enough energy is added to accelerate them to near the speed of light. Traveling at this speed in a lattice with many electrons and nuclei in the way would seem implausible[j]. So, we are asked to imagine an electron being able to pass through a collection of atoms at near the speed of light while accumulating energy from the surrounding energy fields without losing this energy before a hydrogen nucleus is encountered. Calling this a weak interaction, introducing the concept of plasmons, or proposing a super-heavy electron provides no justification for or insight about how the process might actually work. Unless this process can be shown to actually occur, rather than assumed to be possible, formation of a neutron is not a plausible explanation for LENR. Indeed, when electrons are given the required energy and used to bombard a material containing p or d, very few, if any, neutrons are detected [62]. In addition, if so much energy could be concentrated in an electron, observed chemical effects would be expected long before the electron could make a neutron. For example, no explosive would be stable once this process started. Furthermore, if neutrons were present from any source, radiation from their own normal beta decay and gamma resulting from their interaction with various nuclei would be expected, but is not detected. In addition, the various nuclear products cannot be explained only by neutron interaction because this reaction produces a new isotope, not a new element. Subsequent radioactive decay is required to produce the observed elements, which is not observed. Consequently, even though this mechanism has gained some attention, it is not consistent with how LENR behaves or with conventional science. This explanation does not identify the NAE and violates Nos. 3–5.

On the other hand, many people have speculated about what would happen if the electron could get sufficiently close to the nucleus to form what they call a "virtual neutron". In this way, the electron might provide enough shielding for the proton or deuteron to enter a nucleus without the impossible task of creating a real neutron. Mills [63] provides a theoretical basis for allowing the electron to closely approach the nucleus, with the formation of the so-called Hydrino. Dufour et al. [64,65] proposed a structure called a Hydrex where many electrons and photons cluster together in a stable collection that might lower the Coulomb barrier. The formation of Rydberg or BEC structures could be viewed as variations on this approach. Such variations on a pseudo neutron-like structure seem worth exploring. The kind of NAE-mechanism combinations required for such structures to form and be involved in LENR has not been identified, but will be explored below. Nevertheless, the explanation violates Nos. 4 and 5.

2.3.3. *Role of phonons*

A phonon is a pseudo-particle used to describe how energy is transferred between or interacts with atoms or electrons in condensed matter. The model is used to describe how heat energy moves through a material as vibrations of atoms and electrons located within a material. When the concept is applied to LENR, these vibrations are proposed to cause a few atoms to approach one another within nuclear reaction (strong force) distance [66–69] or to cause energy to accumulate within a nucleus [70] so that the nucleus becomes unstable. In the process, a basic assumption is made – the vibration energy is focused on one nucleus and does not affect the general chemical bonds between the surrounding atoms in

[i]Such an abnormal energy distribution conflicts with the well-known Boltzmann distribution and the Second Law of Thermodynamics

[j]Electrons of this energy have a very small range in palladium because their energy is lost to the surrounding material by generating X-rays [271]. This means the mysterious transfer of energy must take place at an impossibly fast rate and a proton must be found within a small fraction of a micron after this energy has been acquired, all without generating X-rays that are not observed.

PdD. This assumption is in basic conflict with how phonons are observed to behave and the requirement that energy always moves "down hill". Indeed, phonons are proposed to provide this "down hill" transfer of energy once a nuclear reaction occurs as the released energy is communicated to the surrounding atoms. Use of this concept must show a plausible reason why phonons can produce an "up hill" transfer of energy without causing chemical changes, followed by the expected "down hill" transfer after the nuclear reaction is initiated. As a result, the explanation violates all of the proposed requirements.

2.3.4. *Role of particle-wave conversion*

The Chubbs [71] proposed that a deuteron can convert to a wave under proper conditions. As such, it can interact with another deuteron wave without a Coulomb barrier being directly involved. This interaction briefly forms a helium wave, which slowly converts to a helium particle by losing small quanta of energy to the surrounding lattice. This model solves a few problems, but it does not account for how transmutation products are produced or what unique property of the lattice encourages particle-wave conversion. Simply having a periodic array of atoms, as they propose, is not sufficient because this a universal condition existing in all materials, while nuclear reactions are rare and localized in special regions. Although this general approach could be applied to a special NAE, as is described below, the concept violates all of the proposed requirements as it is described by the authors.

2.3.5. *Role of "Strange" particles*

Explanations based on rare particles have been proposed. These include the Erzion [72] the NATTOH [73], fractionally charged particle [74], massive negative particle [75], electron cluster [76], and super-heavy nucleus [54]. While some of these particles obviously exist in Nature, how each might cause the full range of behaviors produced by LENR at the observed rates has not been explained. Remember, generation of 1 W of power by helium formation requires 10^{12} helium atoms be made per second. This would seem to be too heavy a burden for an explanation based on strange particles to carry.

2.3.6. *Role of tunneling or enhanced cross-section*

The process called "tunneling" is used when a reaction appears to require an abnormally small amount of energy compared to an expected amount. Of course, this idea assumes the full (expected) amount is known accurately for the conditions being used. Instead of using the tunneling metaphor, an unexpectedly large rate is sometimes described as resulting from an increase in cross-section. In either case, the expected energy or cross-section needs to be justified, not just why less energy is apparently required. For example, expected behavior for LENR under various conditions is based on a model obtained using the hot fusion process. The rate of the hot fusion-type reaction is measured as a function of applied energy, from which the expected barrier height is calculated. Application of this barrier height to LENR would only be valid if LENR were caused by the same mechanism, which is very unlikely to be the case. In addition, requirements Nos. 2–5 are violated. Nevertheless, early theoreticians including Preparata [77] used this incomplete description and this approach was favored by Fleischmann [78]. Many other people also have proposed the same idea [79–84].

A source of screening electrons has been suggested to exist between two materials having different work functions, the so-called swimming electron theory [85–87]. These electrons are proposed to reduce the Coulomb barrier and explain the transmutation observations reported by Miley [88,89]. Unfortunately, this theory ignores how the required number of protons can enter the available nuclei in the sample without producing radioactive isotopes, which are seldom detected. Miley et al. [90] try to avoid this problem by creating another problem. Their mechanism involves formation

of a super-nucleus of $^{306}X_{126}$ from a large cluster of H and D. This structure then experiences various fission reactions. The cluster is proposed to form as local islands of ultra dense hydrogen [91] using Rydberg-like process [92]. Why so many deuterons would spontaneously form a cluster in a lattice in apparent violation of the Laws of Thermodynamics has not been explained. Why No. 5 is not violated is not explained.

2.3.7. *Role of multi-body fusion and Bose–Einstein condensates*

Multi-body fusion was first suggested by Takahashi et al. [93] who arrived at this model using the energy spectrum of the few neutrons being emitted from an electrolytic cell while anomalous energy was detected. A later study using energetic D^+ bombardment of PdD is consistent with the neutron spectrum obtained using electrolysis [94], which suggest the neutrons might have actually resulted from a hot fusion-type reaction, as would be expected to result from the ion bombardment method. On the other hand, Iwamura et al. [95] show evidence for up to six deuterons entering a nucleus simultaneously when no extra energy is present, adding additional support to a multi-body model. Formation of such clusters [96] solves many problems, not the least of which is a method to release momentum after fusion without emitting a gamma ray. In this case, the resulting nuclear energy is distributed between a few alpha particles and many un-reacted deuterons in the cluster. However, unless the clusters were improbably large, energetic emissions would be detected [97], which has not been the case. Requirements Nos. 4 and 5 are apparently violated.

Kim [98,99] justified cluster formation by calling it a Bose–Einstein Condensate (BEC) [100,101], which would be the NAE. He proposes this type of structure is able to form on the surface of very small particles of PdD. Typically, BEC is only observed near absolute zero because the bonding energy is too small for the structure to survive higher temperatures. Formation of a BEC at the temperatures used to initiate LENR would be an amazing event even without LENR being a consequence. Nevertheless, Kim proposes special conditions exist in a lattice to stabilize a BEC. Even if BEC could initiate fusion, explaining how the resulting energy is dissipation into the lattice without detected radiation requires many assumptions, resulting in violation of No. 5.

2.3.8. *Theory of Rossi and Piantelli*

Piantelli et al. [102–112], in a series of papers, have described how energy, radiation, and transmutation result when N–Cr and Ni tubes are exposed to H_2 after extensive pretreatment. The process is proposed to involve clusters of nickel on the surface that interact with H^- ions dissolved in the metal to cause conversion of nickel to copper when the metal is heated above 350°C. The authors suggest a mechanism for this reaction.

Rossi [113] increased the amount of power over that obtained by Piantelli et al. by using specially treated nickel powder and proposed the same source of energy. Furthermore, Rossi [114] believes that positrons result from decay of the resulting radioactive copper isotopes and these generate annihilation radiation of 511 keV that is absorbed in a lead shield, thereby heating the apparatus. No evidence supports this implausible claim. Instead, Piantelli reports detecting gamma emission at 744 keV, which is not consistent with the energy from positron annihilation.

The descriptions of the process offered by Piantelli or Rossi cannot be considered a theory. The proposed process is not consistent with what is observed nor is it plausible based on the listed requirements. Transmutation cannot be a source of significant energy even if the significant Coulomb barrier could be overcome. Once an Ni nuclei has been transmuted, energy production can only continue at that site if another H or D is added to the fixed target. Such a process will eventually produce radioactive isotopes, yet these are not found. Furthermore, the amount of energy released by each transmutation reaction is small, requiring a large reaction rate to account for the measured energy[k] as well as many active sites. Explaining how so many sites can form in ordinary material is a challenge not met so far. Nevertheless,

[k]The reaction $Ni^{62} + p = Cu^{63}$ produces 5.6 MeV/event. For 1 kW of power to be generated, this reaction must occur at 10^{15} times/s or produce

both workers apparently have been successful in creating enough NAE sites to make significant energy using ordinary hydrogen.

2.4. The process of finding an explanation for LENR

In the previous sections, the requirements a theory must satisfy, the behaviors in need of explanation, and the flaws in a few explanations are discussed. The challenge now is to propose a model consistent with these requirements and behaviors.

The general features of a plausible NAE will be used to start the search. The goal is to eliminate most environments by applying these requirements and focus on the few that remain. Environments surviving this process can then be tested against proposed mechanisms to determine which combination is consistent with the most observations. The intent is to use as few assumptions as possible.

Four different kinds of NAE have been proposed by various authors.

(1) A normal arrangement of atoms and electrons that create a crystal structure, so-called bulk atoms, including vacancies in the nonmetal and metal sublattices. Cubic PdD, either pure or impure, is an example of such an environment. This violates requirement No. 1.
(2) A novel arrangement of atoms not normally present. The BEC structure, Rydberg matter [115,116], nanostructures [117–119], diamondoid or Zeolite molecules [120,121], cracks [122–124], or carbon nanotubes [125] are variations of this condition. In addition, the NAE might also be where Hydrinos [126] can form because the required catalyst is uniquely present. No requirements are violated if several plausible assumptions are used.
(3) An interface between two different structures having different energy or electron concentrations. Examples are two different crystal structures in contact at a surface. This includes contact between two different phases, including contact between a gas and a solid or contact between a liquid and a solid. This condition violates requirement No. 3 and perhaps Nos. 4 and 5 unless assumptions are applied.
(4) Absence of material, such as cracks, gaps, or voids within structures [123,127–129]. Carbon nanotubes or stress cracks in solids would be plausible examples. The dimensions and shape of such a structure would determine its behavior. This condition violates no requirement as explained below.

Involvement of particles having nanosized dimensions has been proposed but this is not considered to be a unique environment in this discussion. Such nanoparticles, at least at the size being used for LENR, differ from ordinary material only because they have a high surface area, which would create a large interface and place them in category (3). If the size is really small (submicron), they no longer act like ordinary material and would fall in category (2). Because of rapid sintering, nanoparticles do not remain in a material for long once the temperature in increased much above 150°C.

The condition No. 4 holds the greatest promise as the NAE. Most metals form cracks of various sizes when they react with hydrogen as stress is generated by increase in lattice size and is then relieved. The number of cracks has a limit determined by the treatment and material, thereby creating a natural limit to the amount of NAE. A crack or void has the potential to act as the site for a resonance process without being limited by the nature of a chemical lattice. Therefore, cracks having suitable shape and dimensions are proposed as the location of LENR. These would be rarely produced, have limited concentration, and could be formed in all materials. At the present time, success in producing LENR relies on accidental and random formation of these structures, which would account for why replication is a challenge.

8 mg/day of copper. This would result in 15 g of copper after 6 months while producing 10 kW, which would represent a significant and impossible fraction of nickel powder being transmuted during the proposed lifetime of the e-Cat.

Having identified a plausible NAE, what mechanism causes the nuclear reaction? For a search to be successful, it must follow a series of perhaps ambiguous clues in the correct logical order. The first clue in this search involves tritium and how it can form. Because it apparently forms in the same region of the material as does helium and no detectable radiation typical of hot fusion is produced, tritium and helium can be assumed to result from the same general mechanism and NAE. Absence of neutrons rules out direct D + D fusion, as would result from the hot fusion process. What other reaction might be the source? Tritium seems to be produced when both H and D [130] are present, but simple fusion would give He^3, as first proposed in 1990 by Schwinger [131]. This reaction can be ruled out because the amount of detected He^3 is only consistent with that expected to result from decay of tritium, which means tritium is formed before He^3. Tritium could form if an electron is absorbed into the fusion reaction and is later ejected by normal beta decay. Let us see if this process has a plausible general application.

If electron absorption is universal regardless of the isotopes involved, then the reactions listed in Table 1 can be predicted. In every case, except for tritium and deuterium, ejection of the electron from the product nucleus could be too rapid to detect as a half-life. In addition, like tritium, the energy of this beta could be too low to allow easy detection. In fact, were it not for the slow rate of tritium decay, this proposed addition of an electron could not be observed and might be ignored because it violates expected behavior. By accepting this clue, a general pattern for the fusion reaction can be suggested. In addition, a mechanism can be proposed that would not only add this electron by a plausible process during the fusion reaction, but explain how the resulting energy is dissipated. But first, the conflict with expected behavior needs to be addressed.

Table 1. Predicted nuclear reactions involving isotopes of hydrogen.

d + d + e = H^4 = He^4 + e	Q = <23.8 MeV
d + p + e = T = He^3 + e (18.6 keV)	Q = <4.9 MeV (t = tritium = H^3)
p + p + e = d	Q = 1.4 MeV
d + t + e = H^5 = He^4 + n + e	Q = <18.1 MeV
p + t + e = H^4 = He^4 + e	Q = <20.4 MeV
Role of the neutrino is ignored when calculating Q	

Conflict with conventional understanding involves the role of the neutrino. Addition of an electron to a nucleus causes ejection of an electron-neutrino. Ejection of an electron as beta decay requires ejection of an antineutrino, which carries much of the energy that never appears as heat. If this interpretation were correct, the reactions listed in Table 1 would not produce the calculated energy and probably would not occur at all. However, unlike "normal" nuclear reactions, the LENR process proposed here takes place gradually, with most of the energy being released from the fusion process before the electron is absorbed by the final nucleus, thereby releasing a neutrino. Consequently, the amount of energy available to the neutrino might be very small. Nevertheless, the LENR process provides a test of how neutrinos are generated and emitted. In other words, LENR might provide a test of the Standard Model, similar to the studies being done at Caltech using a different nuclear reaction[1]. In addition, decay of H^4 is expected to produce tritium and a neutron [132], not He^4, if conventional beliefs are correct. The question is, "Does the proposed H^4 made by LENR decay as expected or does it decay by beta decay?"

Before going to the next clue, let us see if the proposed process helps explain any observed behavior, assuming the reactions occur as summarized in Table 1. First, the presence of a few neutrons when tritium is produced now makes sense. As tritium accumulates, t + d + e fusion can occur, resulting in the very small but variable flux of neutrons with a n/T ratio less than 10^{-6}. Support for this reaction is given by Mosier-Boss et al. [133] using CR-39 detectors in

[1]See: http://media.caltech.edu/press_releases/13520

which neutrons having the energy expected from d + t fusion were found in small numbers. Unfortunately, the tritium content was not measured. Second, the expected energy from each reaction (Q) can be used to explain other behavior[m]. Note that energy from the p + p + e fusion reaction is much smaller than from the d + d + e reaction. Consequently, the former reaction would require many more NAE sites to achieve the same amount of detected power compared to when deuterium is used, thereby energy from the d + d + e reaction easier to detect. Consequently, failure to detect heat when hydrogen is used as a null test means only that too little NAE was present to make detectable energy from the weak p + p + e reaction. In fact, the claims for extra power made by Fleischmann and Pons during their null tests using H_2O can be understood to mean enough NAE was present on a few occasions to actually produce detectable heat. Consequently, light water would apparently act as a poison simply by reducing the amount of power compared to when D_2O is used, not by stopping LENR altogether. Third, the weak beta emission could produce the occasionally reported low-level Bremsstrahlung from cells containing D_2O [134].

What kind of mechanism and NAE would be consistent with observed behavior? The hot fusion process, as well as muon fusion, rely the nuclei getting close enough to engage the strong force. The resulting sudden release of energy naturally causes emission of energetic particles, which are not produced by LENR. Therefore, a different mechanism must be operating. To avoid detectable emission, the energy released by the nuclear reaction could involve many emitted atoms, with each carrying a small fraction of the energy. This idea, which has been suggested by other authors, requires a large collection of atoms ($>$10,000), all of which have the ability to take their required fraction of the total during a very fast process. Consequently, this method does not seem plausible, as previously concluded.

This paper proposes a resonance takes place in a string of hydrogen nuclei with each separated by an electron. As this resonance takes place, coherent photons (X-rays) are emitted, similar to what takes place in a laser. In this case, the energy does not come from outside sources, but from gradual conversion of the hydrogen nuclei into another element, with the intervening electron being absorbed into the final nucleus. As a result, mass is converted to energy as the two nuclei get closer together. Obviously, the relationship between the nuclei and the intervening electron is not conventional. This unconventional relationship is forced on the system by the walls of the crack in which the process occurs. A future paper by Brian Scanlan will explore this process in detail.

Other models might also describe the process. Sinha and Meulenberg [135] proposed a structure, called a Lochon, that might describe the unique relationship between the electron and the hydrogen nucleus. Kim and Ward [136] propose a resonance process between deuterons in a BEC when it forms on the surface of a nanoparticle of PdD, a process that might also function in a crack or nanotube. Chubb [137] uses the metaphor of particle to wave conversion, with the deuteron waves gradually converting to a helium wave as energy is lost from the wave structure. Clearly, the process is opened to several interpretations at this stage.

What evidence can be offered to suggest cracks are actually present? First, can cracks form in the materials being used? PdD is well known to form cracks [138,139]. Titanium, another successful metal, cracks readily when it reacts with hydrogen. When this metal is used as the cathode during electrolysis of D_2O, extra energy and transmutation are reported [140–144]. In addition, neutrons [145–147] are emitted when it is temperature cycled in D_2, further indicating active crack formation, but not necessarily producing LENR. Nickel does not form cracks easily when exposed to hydrogen, but thermal or pressure cycling in hydrogen [102,103] is expected to produce some cracks in the surface. The oxides that produce LENR by electromigration [148–150] all have the Perovskite crystal structure. This structure

[m]The effect of neutrino formation when an electron is added or ejected is ignored. Nevertheless, this would reduce the amount of measured energy by some unknown amount because energy added to the neutrino would not be converted to measured heat. The behavior of tritium decay can be used to estimate the fraction carried by the neutrino when the neutron decomposes. The energy expected is 529 keV, based on mass change, while the beta is measured to have 18.6 keV. This means only 3.5% of the expected energy can be recovered from the final decay process because the remainder is carried away by the neutrino. However, most of the detected energy results from initial formation of the final nucleus, not from its subsequent decay. As a result, the values listed in Table 1 are, in most cases, upper limits.

is susceptible to distortions as a result of small changes in component atom concentrations that could cause local cracks. The slight flow of hydrogen caused by applied voltage would move hydrogen atoms to these locations and help accelerate the LENR process. Layers of palladium applied to various materials, as used by Patterson [151] and later by Miley [92,152], are observed to crack when reacted with hydrogen. Layers containing possible cracks have also been applied to wires by Celani et al. [153]. In this case, a current flow through the wire is found to enhance the process, perhaps by making deuterons more readily available to cracks. Sonofusion [154] would be expected to cause cracks at the site of bubble collapse on a target metal. In addition, to cracks formed as a result of stress, all materials are known to contain imperfections unless efforts are made to remove them. While a large number of active cracks would produce obvious power, the small number in ordinary material might result in detectable amounts of unexpected LENR if enough deuterium ions were available and careful measurements were made. Nanotubes are expected to be more difficult to make, but might be present and occasionally active.

Other behaviors consistent with cracks being the NAE are observed on occasion, adding support to the idea. For example, placement of X-ray sensitive film near an active electrolytic cell has shown X-radiation having a very narrow beam width [155,156]. Gas discharge has also produced similarly tightly focused X-rays that act like a laser [157,158]. Such behavior requires emission only in favored directions, which requires a beam defining structure. As an example from conventional experience, small structures similar to cracks have been observed to produce laser emission [159]. Failure to detect radiation could result when most X-radiation is completely absorbed, or because most beams are pointed away from the detectors. A diffuse source could be produced when many cracks were pointed in random directions. Consequently, laser-like radiation would be rare and only observed when detectors are in the right place or the sources are all pointed in the same direction, which apparently has occasionally happened.

The study by Iwamura et al. [160] provides an opportunity to test the role of cracks in explaining transmutation. As explained previously, these workers deposited CaO + Pd layers on palladium, which was over-coated by 40 nm of palladium, after which various elements were applied to the surface. When deuterium diffused through this sandwich, the deposited nuclei were transmuted by addition of deuterons. Amazingly, only the deposited nuclei experienced transmutation, not the much larger concentration of palladium also present on the surface. In addition, the CaO layer was found to be essential for the process to work. This behavior can be explained if stress-cracks formed in the thin palladium layer between the CaO and the surface where the target element was deposited. The deposited material filled the mouths of the cracks, thereby sealing them and creating a cavity in which deuterons could accumulate and resonate. This resonance process is proposed to release energy and cause deuterons to enter those nuclei located at the end of the cavity, i.e. the deposited target. Only nuclei present at this exact location can be transmuted according to this model. Patterson [151] provided further support when he produced many cracks in layers of Pd and Ni applied to plastic beads. Many transmuted elements were found in these layers by Miley [152,161]. Obviously, the thickness of the crack would be important because at some width, the normal hydrogen molecule is known to form, which is not able to fuse. The difficulty in causing LENR is proposed be related to formation of a closed crack of exactly the right dimension, after which enough D or H ions might be present to fuel a fusion reaction. Naturally, these requirements would be very sensitive to conditions and treatment, thereby accounting for the difficulty in replicating the transmutation results.

The claim for nuclear reactions being possible in bacteria and other single-cell organisms is a challenge for any explanation [162]. Obviously, the chemical conditions are greatly different from these within inorganic crystals and the mechanisms applied to such crystal structures would not be expected to apply to a living cell. On the other hand, existence of voids created by complex protein molecules can be imagined to form in which the proposed resonance might take place provided hydrogen ions are available to the void. While this assumption has no evidence as yet, the suggestion can be tested.

No single observation provides a smoking gun. Nevertheless, a total analysis of all observations and patterns leads to one plausible conclusion – cracks or nanotubes of a particular size and shape are the only NAE that does not conflict with the known behavior of materials, allows a plausible mechanism to operate, and leads to testable predictions, many

of which are consistent with behavior already observed. The puzzle still lacks a clear description of the mechanism operating within the crack. Once a mechanism is found to apply, later mathematical analysis can be used to further support the model and generate other predictions.

2.5. Testable predictions

The model suggests the following testable predictions as a guide to future studies.

(1) X-ray radiation is produced at a wavelength determined partly by the mass of the nuclei in the crack and it is emitted in opposite directions among the axis of the crack. The process is proposed to have laser-like behavior. Some of this radiation would appear to result from Bremsstrahlung.
(2) Rate of tritium production is sensitive to the H/D ratio in the NAE.
(3) Rate of neutron production is sensitive to the D/T ratio in the NAE.
(4) Energy production from normal hydrogen results first in production of deuterium and then tritium, followed by a small but increasing neutron flux.
(5) Diffusion of H or D through a material containing suitable NAE causes detectable LENR because H or D would become available at the NAE. Increased applied pressure of D_2 or H_2 has the same effect.
(6) Laser light increases the rate of LENR as energy is added to the resonance process. Increased temperature would have the same effect, but would not be as localized and would have a counter effect by lowering the available concentration of H or D.
(7) Transmutation is occasionally experienced by nuclei located at the ends of active cracks or nanotubes.
(8) The rate of LENR using deuterium gradually decreases as active NAE sites became choked by immobile helium. This lifetime limiting process is less important when H is used because D and T can move out of the NAE or enter into subsequent fusion reactions without choking the site. Nevertheless, the growing concentration of D will increase the activation energy for resonance, thereby reducing its rate, and producing trapped helium.
(9) No difference exists between the conditions required to cause fusion involving pure D or pure H. However, many more NAE sites are required to obtain a detectable amount of energy when H is used compared to D.
(10) A mixture of D and H in a NAE makes LENR more difficult to start (increased activation energy) because the mixture, consisting of different masses, disrupts resonance. Apparent "poisoning" of the reaction is the result. Adding laser energy at the location of the crack can reduce the effect of this disruption.
(11) A material producing significant power will self-heat and reach a stable temperature determined by how effectively hydrogen can reach the NAE at that temperature. The greater the amount of NAE, the higher this temperature limit will be.
(12) Any metal or alloy able to catalyze decomposition of the hydrogen molecule into ions will support LENR once the NAE forms.

3. Summary

A model is described that summarizes all reported observations by using only a few assumptions. The LENR process is proposed not to take place in a lattice structure. Instead, a novel and rare structure must form in which the process occurs. This structure is common to all LENR reactions regardless of the reactants, nuclear products, or method used. The general structure is called the Nuclear Active Environment (NAE) and is proposed to take the form of a crack or gap that forms by stress relief in conventional structures.

Fusion reactions involving isotopes of hydrogen are proposed to occur in the same NAE. Deuterium is made by p + p + e fusion, tritium by d + p + e fusion, and helium by d + d + e fusion followed by beta emission, with the relative rates being determined by the relative concentrations of the hydrogen isotopes in the NAE. Occasional neutrons can

result from the t + d + e fusion reaction when tritium is produced. The number of active sites in a material, the temperature and/or applied energy, and the concentration of hydrogen isotopes determine the rate of each reaction. Energy is released to the surrounding environment by a resonance process between the hydrogen nuclei and the intervening electrons as many X-ray photons are emitted in a laser-like beam in opposite directions along the axis of the crack. Conditions required to create this resonance are forced on the hydrogen–electron combination by the structure in which they are located. This structure, consisting of cracks or nanotubes, must have a critically small size in the submicron range.

This model is based on observed behavior, not on the physical or mathematical models favored by modern science. While some of the proposed consequences of this behavior might conflict with what conventional science believes is possible, the paper identifies the important evidence required to resolve this conflict. If correct, the model places limits on the kind of mechanism causing the nuclear process, explains why energetic particles are not detected, and shows why such reactions are not "impossible" as conventional science believes. Analysis using mathematical tools will follow if the suggested model is found to be correct.

The model proposed in this paper has an immediate application to understanding the claims made by Rossi. He claims significant energy is made in a device he calls an E-Cat by conversion of nickel to copper. As discussed in the paper, this source of energy is not plausible. On the other hand, the other potential source based on the proposed p + e + p = d reaction would appear not to qualify as a source of useful energy because of energy loss to neutrino emission, as the Standard Model requires. Consequently, a careful study of the energy-producing reaction involving light hydrogen is important not only to understanding LENR but also to understanding the Standard Model.

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