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Research Article

The Role of Voids as the Location of LENR

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Abstract

A proposed model explaining the low-energy nuclear reaction (LENR) process is described. The process occurs in voids of a critical size and involves a string of resonating hydrons, each of which is separated by an electron. This unique structure, called a "hydroton", is proposed to make LENR possible and provides a process that can explain all reported observations and predict several new behaviors while using only three basic assumptions.
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Keywords: Cold fusion, Crack structure, Energy

1. Introduction

The phenomenon labeled low-energy nuclear reaction (LENR) or cold fusion [1] has now emerged from the shadows of rejection to become a demonstrated phenomenon [2]. Over the last 22 years, numerous attempts were made to explain how this novel effect functioned, but without any theory gaining wide acceptance. This failure resulted partly because insufficient information was available and basic laws of nature were frequently ignored.

The following basic information is now known. The effect does not to follow the rules used to describe hot-fusion, its close relative; the main nuclear products are at least helium and tritium without significant energetic particle emission; the process functions when either deuterium or ordinary hydrogen is used; the effect is very difficult to produce; and it does not require application of high energy as is needed to initiate hot-fusion. These features all need to be explained without violating basic laws and experience. The first problem is to identify where in the active material the LENR process occurs, because it obviously does not happen throughout the sample. This environment must be identified because its characteristics will limit any proposed process to only a few possibilities. For the sake of discussion, I call this active region the nuclear-active-environment (NAE) [3]. This paper proposes a location for the NAE and a process causing LENR within the NAE.

This is the third in a series of papers [4,5] justifying the role of voids (cracks) as the NAE [3]. The previous papers show why the LENR process does not occur in a chemical environment, as is commonly assumed, but instead requires a special structure that is independent of chemical restrictions. Several authors in the past have suggested cracks, a form

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of void or gap, as the location of the LENR process, as discussed in Section 3.1. These ideas are not useful because the exact characteristics of the crack were not identified and the proposed mechanism did not fully account for observed behavior. This paper attempts to address these deficiencies. Once the need for a void-like structure is accepted, a mechanism must be proposed that can operate in such an environment while delivering the observed reaction products. This paper will suggest such a mechanism. All previous models have either focused on concentrating enough energy to tunnel through the Coulomb barrier or by forming a structure, such as a neutron [6] or a Bose–Einstein Concentrate (BEC) [7] that ignores the barrier. The model proposed here takes an entirely new approach.

The word "void" includes many different structures having one thing in common – a space in which atoms making up the surrounding material are absent, i.e. a gap. The word "void" will be used in this paper to identify this general condition. These voids can take the form of typical cracks with parallel walls, as tubes grown in or formed by a material, or with a cage-like structure. The carbon nano-tube is a common example [8] of a tube-like structure, although similar structures can be formed by many other materials [9]. Zeolite [10] is an example of a cage-like structure. Regardless of the shape, the main feature important to the LENR mechanism described in this paper is the distance between the walls and local symmetry. It is essential that the maximum distance be no more than a few atomic diameters. Otherwise, the hydron molecule can form, which is known not to allow fusion. Most voids form with too great a distance between the walls to support the LENR process. The proposed mechanism also requires the void to have a length sufficient to hold a string of hydrons.[a]

In summary, LENR has no relationship to the hot-fusion process, does not occur in or on a chemical structure, and requires a void of a critical size and shape with nano-dimensions to function. These voids are apparently formed occasionally by random chance during attempts to initiate the LENR process, thereby accounting for the difficulty in replicating the claims. The first step is to identify how the voids might be created by chance.

2. Void Formation and its Characteristics

Voids form in solid materials as a consequence of stress and its release. This stress can result from applied external forces, as a result of concentration or temperatures gradients within the material, or changes in crystal structure. Several examples of this process are provided in the following figures, but any nuclear-active voids would be too small to detect at the resolution used. In most cases, a range of void sizes is present, with only the largest being visible. The depth of the void can also be variable, with only its penetration of the surface being visible.

Figures 1–3 show several different kinds of voids that have been associated with LENR. Figure 1 shows cracks that form as hydrogen is lost after beta-PdH is plated on copper (1.2 μm). Shrinkage of about 12% as the beta phase converts to alpha-Pd creates obvious gaps, but ones too large to support LENR and too unstable to be useful because the width of the crack will change as the hydrogen content of the layer changes. Nevertheless, a 2 μm layer of Pd plated on Pt was found to make excess energy during electrolysis [11]. Reducing the layer thickness reduces the size of the openings and increases crack density, a condition which might be achieved using the Fleischmann–Pons (F–P) [1,12] method.

Figure 2 shows many pits of many sizes formed after Ni and Pd interact on the surface at high temperature followed by exposure to H_2. Such pits are frequently seen after electrolysis of Pd and are sometimes attributed to local melting. Figure 3 shows complex cracking when a thin deposit of Cr delaminated from a surface. Such cracks are not a NAE and can actually stop the process because the hydrons could be too easily lost from any remaining NAE. All of these materials shown in the figures might contain voids small enough to support the proposed mechanism, although the visible voids are much too large.

[a]The word "hydron" identifies the bare nucleus (ion) of any hydrogen isotope.

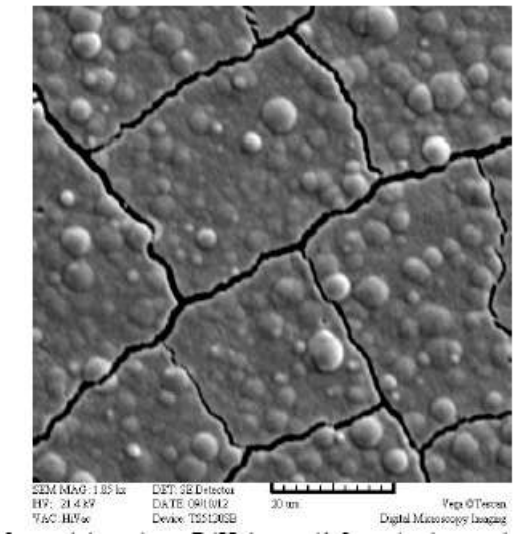

Figure 1. Cracks formed in a beta-PdH layer (1.2 μm) electroplated on copper after the contained hydrogen is removed.

Electrolysis using the F–P method causes an assortment of impurities to deposit on the Pd cathode surface, including Li, Si, and Pt [13–16]. Lithium is present in the electrolyte and silicon comes from the Pyrex. The Li is retained on the surface because it can react with Pd to form various Pd–Li alloys [17] that are stable in the aqueous environment.

Figure 2. SEM image of a surface of Ni plated on Pd on which voids and cracks have formed.

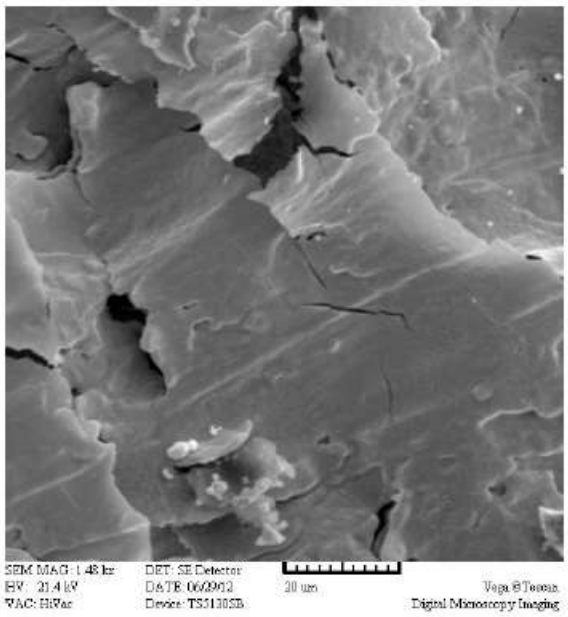

Figure 3. SEM image of surface of Cr on Pd after exposure to H_2.

Formation of such alloys can cause crack formation as the dimension of the surface changes. In addition, absence of care can provide copper from exposed wires and carbonates from the air, both of which can deposit on the cathode. Gradually platinum transfers from the anode and coats the cathode surface. All of these elements can deposit a surface layer in which voids can form. Bockris [18] was the first to attribute the frequently observed long delay in detecting extra energy to slow formation of nano-sized cracks in the surface layer. However, once a crack has grown too wide, it is able to allow loss of deuterium as D_2 from the surface, as shown in Fig. 4, thereby reducing the required high D/Pd ratio [19] and stopping LENR. Consequently, success in initiating LENR by the electrolytic process requires formation of very small cracks rather than a fewer number of large ones. This means, the best palladium for this purpose would have to be specially treated [20] to create many sites where stress can be relieved by crack formation, thereby increasing the number of sufficiently narrow gaps. Indeed, impure Pd in which many potential sites for crack formation would be present has been found to give greater success than pure Pd [21]. McKubre et al. [21] take note of a surface layer as an apparent requirement to achieve LENR. In addition, the observed nuclear products (helium and tritium) [22,23] are only observed to occur at the surface because this is the only location where the required cracks might form. Figure 4 shows several cracks large enough to permit escape of D_2 from a Pd cathode held under acetone, but too large to support LENR. Such large cracks form easily in Pd, which makes this metal a less than ideal cathode. The Pd–Ag alloy is less prone to forming large cracks and has been noted for its success in producing LENR [24–29], presumably for this reason. Titanium has been reported to produce excess heat when used a cathode or when plated on Pd. In this case, crack formation is ongoing and extensive, which may supply a steady number of suitable cracks even though they will rapidly grow too large [30–33]. Beta-PdD can be co-deposited to form a complex surface structure [34] that has been found to produce excess energy. A typical morphology is shown in Fig. 5. These clusters would be expected to produce voids between each one as its size changed owing to loss of Hydron or additional deposits of Pd. In summary, many people have noted and explored conditions that would be expected to create cracks or voids using the F–P method

Figure 4. Bubbles of D_2 arising through acetone from cracks in PdD after electrolysis. The bright lines at which bubbles are forming are surface scratches that focused formation of a deeper crack structure.

and these efforts have been frequently successful in producing LENR, but without the success being attributed to void formation.

Clusters are also found to form on cathodes of palladium subjected to gas discharge, as shown in Fig. 6, where cracks are apparent at a few locations. On occasion, voids take the form of pits, shown in Fig. 7, as an alloy forms on a surface.

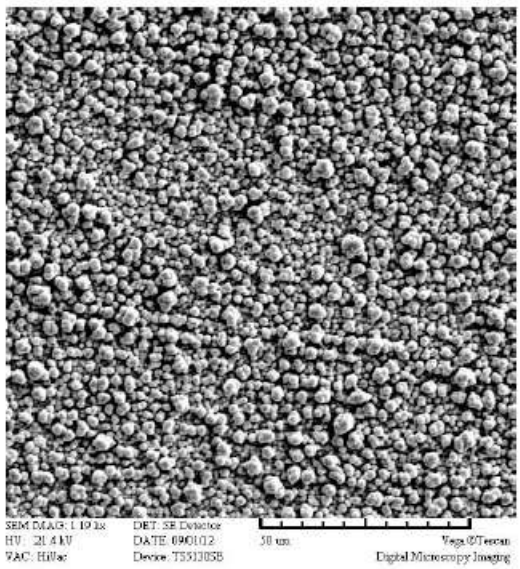

Figure 5. PdH deposited on copper using the slow co-deposition process.

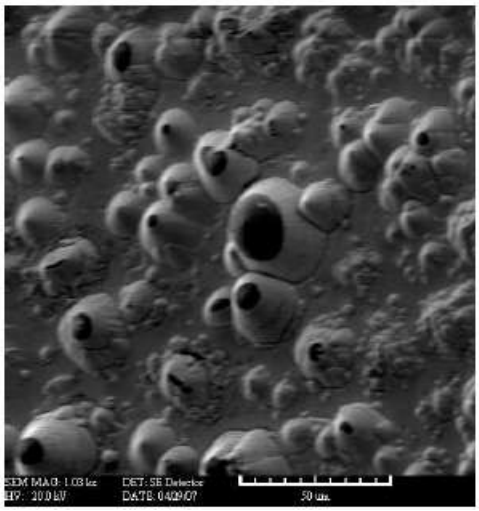

Figure 6. Deposit created by bombardment with D_2 ions. A few local cracks can be seen. Active cracks would not be visible at this magnification (Storms and Scanlan [35]).

3. Proposed Models Based on Voids

3.1. Proposals from the Literature

Although considerable attention has been paid to the surface as a potential site of LENR, crack or void involvement has been largely ignored, with the few exceptions described below.

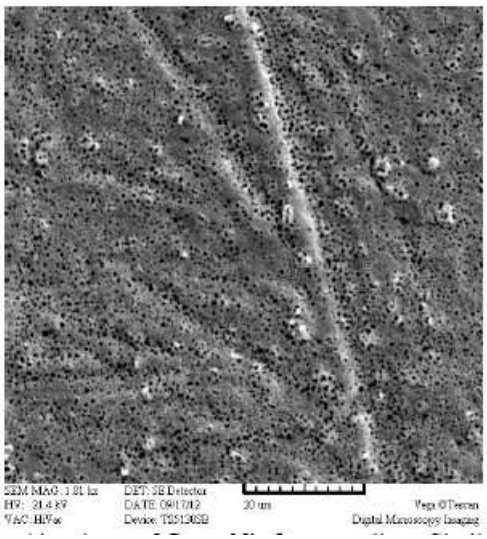

Figure 7. Pits formed in a layer of Cu on Ni after annealing. Similar pits are frequently observed in Pd after electrolysis.

The act of crack formation in many materials generates sufficient charge separation to produce a very brief hot-fusion reaction in the crack. Initially, the role of cracks was attributed to this process, which is called fracto fusion [36–39]. This process has no relationship to LENR.

Bockris [40] noted in 1996 the discrepancy between the short time required to fully react the Pd with deuterium and the long delay before excess power was detected. He proposed this delay allowed cracks to form, which would be influenced by the thickness of the deposited impurity layer, the history of how current was applied [41], and the purity of the Pd metal. High internal pressure within a void was proposed to initiate a nuclear reaction by an undefined mechanism [42,43]. Such a process involving high pressure would not be possible when the gas-loading method is used, which limits application of the process he described.

Frisone [44–49], in a series of papers, calculated the increased rate of what he calls deuteron–plasmon fusion by assuming electron screening can cause tunneling that would be increased by an increased concentration of deuterons in a crack. The model does not address how the resulting energy would be dissipated while conserving momentum and avoiding detection of the resulting energetic radiation.

Godbole [50] using my paper [4] as a starting point, offers an approach best described in his own words; "Unification of the electromagnetic and weak forces at low energy scales. Re-gauging in the lattice to produce attractive EW forces over lattice-constant distances. Periodic Bloch field replacing Higgs field." The proposed model obviously requires a clearer description.

None of these models has shown consistency with observation or has addressed the full range of observed behavior.

3.2. Proposed new mechanism

Having identified where and how voids can form, the next step is to examine the conditions present in a void that might support a fusion reaction.

Electrons populate the void wall, giving it a net average negative charge similar to all clean surfaces. The positive charged hydrons find their way into this negative environment by diffusion from the surrounding material. If the dimension is correct, the hydrons can become suspended in the space at equal distance between the walls. In other words, each wall supplies an equal attractive force that allows the hydrons to be suspended without significant restraint to their movement. A slightly positive energy-well would occur between each positively charge hydron to which an electron would be attracted, thereby creating what appears to be a periodic chemical structure. Up to this point, normal rules of chemistry and physics would apply.

For such a structure to be suitable for the purpose proposed here, the intervening electron must not form a conventional molecular bond, as normally occurs in large cracks. Instead, the electrons on the wall of the gap are proposed to interfere with formation of a conventional molecular structure. As a result, the intervening electrons orbit[b] the virtual (image) charge located between the protons. In addition, the structure is free to vibrate without being constrained by rules governing such behavior in a chemical lattice, such as PdD or NiH. In summary, a linear structure of hydrons separated by electrons having an assumed novel behavior is proposed to form. Figure 8 shows a populated string of hydrons in the gap before resonance starts. The distance between the protons and electrons is controlled by the space between the atoms in the wall, which initially causes the p to be too far apart to allow nuclear interaction.

Once formed, the Hydroton string would vibrate in the normal random, chaotic way as is typical of all atoms. Eventually, local or applied alternating magnetic fields are proposed to cause the vibration to harmonize so that all

[b]Based on the model created by Brian Scanlan, this electron orbits around a virtual (image) charge between the two hydrons. Consequently, its behavior is unique and not determined by rules normally applied when an electron orbits a nucleus. Scanlan is exploring the required rules and expects to publish a paper soon.

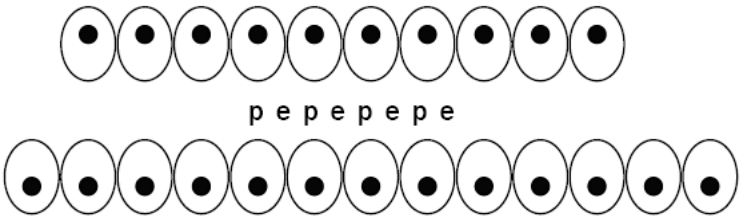

Figure 8. Diagram of a gap within an atomic lattice of metal atoms containing the proposed Hydroton structure. The distorted electron cloud around each metal atom is approximated as an oval. The "p" designates a proton and "e" designates an electron trapped in the potential well between each proton. The alignment between the surrounding atoms and the Hydroton structure is only approximate as drawn. The number of "p" and "e" pairs in the Hydroton structure is arbitrary.

members of the string are vibrating in phase along the line of the components, thereby accounting for the reported effect of applied magnetic fields [51–53].

How can energy be released from such a structure? Normally, energy is released from a chemical structure when it rearranges to a lower energy with emission of photons, called X-rays. In the case of the proposed mechanism, the structure is proposed to rearrange with release of nuclear energy as photons. The process is proposed to start as a resonance within the structure during which its energy becomes greater when the distance between the hydrons is momentarily reduced. This additional energy is released by photon emission. Once this energy is released, the distance between the components in the hydroton is reduced. This process repeats many times until the reduced distance allows direct nuclear interaction, at which point very little energy remains in the structure. In contrast, hot fusion causes the distance to be reduced too rapidly for energy to be released by photon emission. As a result, the nuclear energy must be emitted immediately as kinetic energy, which requires emission of two particles in order to conserve momentum. In contrast, when cold fusion occurs, momentum is dissipated gradually in the form of many photons so that very little momentum or energy remains when the final nuclear product is formed. This process is proposed to explain the lack of energetic radiation, except as photons, when LENR occurs. The small amount of energetic particle radiation occasionally detected is proposed caused by a small amount of hot fusion occurring at the same time. This structure and process are unique and may create a new way to describe nuclear interaction, as revealed by LENR.

The product of the fusion reaction depends on which isotope of hydrogen is present. For example, a string of -d+e+d+e+d+e-[c] etc would condense to form a series of H^4 nuclei, –e+p+e+d+e+p-, etc. would form tritium nuclei, and -p+e+p+e+p-, etc. would form deuterons. The extra electrons not added to the final nucleus would be released from the structure and join the conduction band in the surrounding material. In each case, mass would be lost and energy would be released at each vibration cycle, with two photons being emitted in opposite directions in order to conserve momentum. In addition, weak interaction between the string and the surrounding electrons is expected to transfer some energy into the surrounding atoms as phonons. Because the photons all originate from a common source with the same repetition rate, they would be coherent and have laser-like properties, as first identified by Karabut [54].

This approach is novel and is different from how other models propose fusion takes place. The present approach recognizes that enough energy is already present and only requires a mechanism for its release. In this case, release is gradual as the Coulomb barrier is gradually overcome. In other words, the mechanism acts like a catalyst by providing many small occasions for energy release rather than a single, sudden release as the Coulomb barrier is overcome by a single event during hot-fusion.

[c]Bass [49] proposed a similar vibrating string of -d-e-d- to form within a lattice and concentrate energy by resonance until enough energy is localized to allow the d to tunnel though the barrier. This process would be expected to produce hot fusion products, not cold fusion.

In this model, the photon frequency is determined by the vibration frequency of the string. A string made mostly of d will have a smaller frequency than a string of p, because the mass is greater. The smaller the frequency, the greater the fraction of generated photons will be absorbed by the wall of the apparatus. Consequently, most radiation produced by a deuteron-containing string would not leave the apparatus. On the other hand, a mostly proton-containing string would produce photons of sufficient energy for some to be detected outside of the apparatus. For the same reason, a short string will emit photons with a higher frequency than a long string. As a result, photons produced by a short string of p are expected to have enough energy for many of them to leave the apparatus and be detected. Short strings would be more common when the hydron concentration is low, such as is the case when the material is first exposed to ambient gas. As a result, detected radiation is predicted to be greater when an active sample is first exposed to gas and will gradually drop in intensity as the strings grow longer, as Rossi and Celani have claimed to observe when the material first starts to become active. In addition, the spectrum of measured frequencies will change and become broad as different active voids achieve different sizes for the resonating strings. In other words, easily measured radiation is predicted to occur only when protium is used and then only initially before excess energy is detected. This expectation is consistent with reported experience.

What are the predicted consequences? The LENR process is independent of the material, depends only on the size of voids, and the nuclear product is determined only by which isotope of hydrogen is present. The process is not expected to be unique to Ni–H and Pd–D. In fact, these metal–hydron combinations are not expected to be the best choices. Of all possible combinations of hydrons, pure deuterium will produce the most energy without significant radiation being detected outside of the apparatus, with helium being the only detected nuclear product. A mixture of deuterium and protium will make tritium and have less energy production than the pure d system. Use of pure protium will result in production of deuterium, which will subsequently react with protons to form tritium. This system will produce the least amount of energy, the most radiation, and eventually an inconvenient amount of tritium. Therefore, use of ordinary hydrogen as a practical energy source is not advised, although its use during studies of the process is convenient.

An odd number of protons in an active void will result in neutron emission as the extra electron is occasionally absorbed into the extra proton. Likewise, an odd number of deuterons will result in a dineutron as the odd deuteron absorbs the last electron. These low-energy neutrons and dineutrons can be emitted from the apparatus or combine with surrounding nuclei to produce transmutation. Absence of significant neutron radiation indicates an odd number is much less probable than an even number in the hydroton.

If the number of active voids is small, increased LENR can be obtained by causing the hydrons to move, either as a result of a concentration gradient or by applying an electric field. This flux of moving hydrons will eventually encounter and become available to an active void. In the absence of such a flux, the hydrons must find an active void by random diffusion, which is a slow process. This explanation is consistent with the claims by Liu et al. [55–60] who were able to generate a small amount of power simply by diffusing D_2 through palladium metal. This effect was replicated by Biberian and Armanet [61,62]. The heat reported to result from applying a voltage to a proton conductor ($LaAlO_3$, $SrCeO_3$) containing deuterons is also explained by this process [63-69]. The Cohan-effect proposed by Preparata and Fleischmann [70] and the observations by Celani et al. [71] and McKubre et al. [21] are all consistent with this explanation.

The frequent failure to detect excess energy using normal hydrogen is proposed to result from the great difference on energy produced by the respective fusion reactions. Fusion between two deuterons is observed to produce 25±5 MeV/helium [23] while the same reaction between p-e-p is expected to produce no more than 1.4 MeV/event. Unless a high concentration of NAE is present, the energy resulting from p fusion might be too small to detect. Consequence, the apparent absence of reported power does not necessarily prove that p does not produce energy in the same material as when d is used.

Although the basic predictions are consistent with many seemingly unrelated observations, some aspects of the

proposed processes may seem unlikely and are in conflict with conventional nuclear understanding. Nevertheless, this is the first model to show how all aspects of LENR are logically related and can make predictions not possible using any other model. This fact should encourage acceptance of the less-than plausible suggestions in order to maintain the usefulness of a logically consistent tool. After all, errors and omissions in the model can only be identified by directed research encouraged by the model. A mathematical description of this model will be provided in later papers.

4. Summary

A string of hydrons is proposed to form a novel structure; with each hydron separated from its neighbor by an electron have a novel relationship to the structure. This structure, called a "hydroton", is created by unusual conditions present in a nano-void having critical dimension and shape. Once formed, this structure has the ability to resonate freely and emit photons having a frequency determined by the total mass of the string. As energy is lost from the structure, it collapses into a collection of nuclear products that are determined by the hydon composition of the string. If the string contains only deuterons, the nuclear product is H^4, which immediately decays into He^4 by emission of an electron. When the string contains a mixture of protons and deuterons, a mixture of tritium, deuterium, and He^4 result, with the amount of each determined by the p/d ratio in the string. A string containing only protons will initially produce only deuterium. In the latter case, the photon radiation may have enough energy to be detected outside of the apparatus, especially when the p concentration in the material is small.

This model is based on three basic assumptions:

(1) All LENR products result from the same process in the same NAE.
(2) No basic law of chemistry or physics is violated.
(3) An electron can form a novel relationship to a string of hydrons.

While the assumptions lead to a model that is consistent with all observed behavior of LENR, it predicts two behaviors that are unexpected. The H^4 that results from the process is proposed to decay by prompt beta emission rather than by the expected emission of a neutron. In addition, the role of the electrons in the process does not appear to involve the neutrino as the Standard Model expects. These two important conflicts with expectation should encourage a detailed study of the LENR, aside from it being an important source of ideal energy.

Appendix A. Reviewer Comments

The publication of this paper will likely be controversial, so I thought it might be useful to contribute some reviewer comments to be published following the paper. Ed Storms is of course well known in the field, and has made a great many important contributions over the years. He has published previously many important and relevant experimental papers; on excess heat measurements; on the loading ratio; excess heat versus loading and current density; temperature dependence of excess power; orphan oxygen measurement to estimate the loading in a co-deposited Pd layer; and more recently results on charged particle emission. From my perspective, Storms has more than earned the right to speculate, based on his long record of previous accomplishments.

In the last few years Storms has taken an interest in the theoretical problem as to what is going on microscopically in excess heat experiments. As documented in his book, Storms has over the years accumulated an enormous number of experimental papers; from his own experimental work and his strong interest in experiments generally done in the field, he brings a unique perspective to the theory problem. Consequently, I am interested in his ideas, and in the publication of his thoughts on the problem. At the same time, there are specific issues and details in his paper that I very much do not agree with. The resolution for this is to develop a set of reviewer comments that draw attention to some of these issues. The thought behind this is that some of what Storms proposes goes against what is in the literature, and what

would be expected given physical law; it seems useful here generally to develop some discussion of the associated issues, especially since Storms is not alone in the views presented.

As a reviewer who has recommended for publication of this paper, I have a responsibility to the members of the community on the one hand to help my colleagues get their ideas published (in the hope that the community benefits and the authors get recognition for their work), and also to help make sure that what is published is correct. If I view the Storms paper as speculative, then the question of correctness is not the primary issue, as a speculation can be useful even if incorrect. Since Storms views the paper less as speculative, and more as the way things are, then input from the literature as to how things are is warranted.

The field itself is very much a multi-disciplinary one, and this is reflected in the Storms paper. Part of the discussion concerns voids, and proposed configurations of hydrogen isotopes and electrons within the voids; some of my comments will be specific to this topic. And part of the discussion concerns proposed nuclear mechanisms; some of the comments below will focus on these issues.

Appendix A.1. Proposed p–e–p–e–p–e . . . string

Storms proposes that protons and electrons would alternate forming a p–e–p–e–p–e . . . string inside of a sufficiently small void. Such a structure would not be expected based on what is in the literature. From calculations, and also from experiments, it is known that when molecular H_2 approaches a clean metal surface (such as Pd) that when far away (a few Angstroms) the H_2 molecule is intact [72]. As the molecule gets closer to the surface and the background electron density increases, occupation of anti-bonding orbitals causes the bond length to increase. This starts at an electron density near 3×10^{22} electrons/cm^3, and by the time the electron density has reached about 7×10^{22} electrons/cm^3 the molecule has split apart and the hydrogen atoms individually seek locations where the embedding energy is minimized (which correspond to an electron density near $7 - 8 \times 10^{22}$ electrons/cm^3 [73]).

In a Pd monovacancy in PdD, the electron density at the position of the missing Pd atom reaches its lowest point, and takes on a value of about 2×10^{22} electrons/cm^3 [74]. This is sufficiently low for molecular H_2 to form with a bond length nearly indistinguishable from that of the molecule in vacuum. Storms requires his void to be sufficiently small such that molecular H_2 does not form; this seems to restrict the background electron density to be higher than about $4 - 5 \times 10^{22}$ electrons/cm^3. Since a Pd monovacancy does not satisfy this condition, presumably Storms is thinking of a smaller defect, perhaps a dislocation boundary. In any event, we have a pretty good idea of what hydrogen looks like and how it behaves in the background electron density range from $4 - 5 \times 10^{22}$ electrons/cm^3 and about $7 - 8 \times 10^{22}$ electrons/cm^3 (where the minimum embedding energy occurs). The hydrogen atom under these conditions is reasonably close to the vacuum hydrogen atom (in that it is an atom with slight additional occupation of the 1s orbital), and we would very much not expect to see a bare proton next to a localized electron. The p–e–p–e–p–e . . . string proposed by Storms would cost more than 10 eV per ionized electron to form in this regime.

Appendix A.2. Energy release as X-rays

A key issue associated with the Fleischmann–Pons experiment is the absence of energetic nuclear radiation in amounts that correspond to the energy produced. Any model that seeks to address the excess heat effect must deal with this. Storms proposes x-ray emission in connection with local vibrations of a p–e–p–e–p–e . . . string for this. There are all kinds of problems with this. For example, electrons or protons with keV level energy would quickly leave the structure, so that it is hard to understand why such a structure should remain intact (much less exist at all). Storms connects this with the collimated x-ray emission observed by Karabut, which seems to me to be a different effect. For example, Karabut sees X-ray emission under conditions where no hydrogen or deuterium is present (collimated X-ray emission is shown in his work with a Pd cathode and Kr gas in one example, and with an Al cathode and He in another example); so

one would not expect any p–e–p–e–p–e . . . structure to be present since there is no obvious source of hydrogen isotopes. Moreover, there is no correlation between this collimated x-ray emission and excess heat in Karabut's experiments.

Appendix A.3. Proposed p–e–p reaction mechanisms

The nuclear reactions proposed by Storms in this paper are essentially weak-interaction-based fusion reactions; we consider first

$$\mathrm{p + e + p \rightarrow d + \nu_e + 1.44\ MeV.}$$

A headache with this reaction is that almost all of the reaction energy goes into the neutrino, so it would not be so great for producing excess heat. A second headache is that would expect it to compete with the more probable two-step reaction

$$\mathrm{p + p \rightarrow {}^2He \rightarrow d + e^+ + \nu_e + 0.42\ MeV.}$$

Since this reaction results in positron formation, there would be a very large amount of 511 keV annihilation gammas present (which can be ruled out experimentally). Hence, one would not expect the p–e–p reaction to occur in the absence of the p–p reaction that results in gamma emission.

I note that since the weak interaction is involved, the associated reaction rates once the protons get close enough to interact is extremely slow.

Appendix A.4. Proposed d–e–dreaction mechanisms

Storms describes a d–e–d reaction which he suggests will lead to ^{4}H which he expects to subsequently beta decay to ^{4}He. This reaction again suffers from the headache that for the first step, almost all the reaction energy would go into the neutrino. Next, if ^{4}H were made, there is the question of how it decays. For example, in years past it was thought that ^{4}H might beta decay [75] as proposed by Storms. However, nearly all recent literature (such as [76]) has it decaying kinetically into $^3\mathrm{H} + \mathrm{n}$, which would happen in a very short time (which is to say that the branching ratio for beta decay would be exceedingly small). As was the case above, one would expect competition from the conventional d-d fusion reactions, which should be more likely by roughly twenty orders of magnitude.

Appendix A.5. Tunneling

The reactions proposed by Storms are at the end of the day fusion reactions, so there are issues associated with tunneling as in other theoretical proposals.

Appendix A.6. Discussion

One issue that remains concerns the reconciliation of the experiments with theory more generally. Modern physics has accumulated a stunning array of success in accounting for a wide variety of phenomena, and correspondingly a relatively small number of failures. There are those in the physics community that are of the opinion that pretty much all physics relevant to cold fusion is exceedingly well understood, with the conclusion that cold fusion can be ruled out [77]. On the other hand, those familiar with the experimental results on the Fleischmann–Pons experiment know that the excess heat effect is real. Consequently, there must be something amiss in the physics textbooks, since something very big and very important has been left out (otherwise physics would be able to account for this effect as well).

At issue then is what response might be appropriate in light of this situation? Should we take the position that most of physics is solid, and there is probably some small warranty on a theorem somewhere that needs to be revised so that overall consistency with both the existing experimental set and the Fleischmann–Pons experiment is obtained? Or should we take the position that since physics has gotten it so wrong in the case of the Fleischmann–Pons experiment that we should distrust it in other areas. The answer probably is in the area of philosophy, but it is this issue that seems to make clear the difference between how Storms looks at the theoretical problem in contrast to how this reviewer looks at it.

Appendix B. Response to Reviewer's Comments

I appreciate the comments by the reviewer and the willingness to not only discuss the issues but to encourage publication even though full agreement has not been achieved.

This paper addresses three different assertions. These are:

(1) The LENR phenomenon does not occur in a chemical lattice because to do so would violate basic laws of thermodynamics.
(2) LENR takes place only in cracks having a special dimension.
(3) The fusion process involves creation of a string of hydrons that emit photon energy from a resonance process before the fusion process is finally achieved.

The reviewer has focused only on item (3)

The paper is a preliminary description of a proposed mechanism and a summary of the basic reasons for using this approach. The paper is not a final description or is it intended to answer all questions. Nevertheless, the reviewer has asked some questions I will answer here.

First, I view my description with just as much speculation as, for example, Kim, Takahashi and Hagelstein view their own models. I therefore ask the reviewer to examine my speculations in the same manner he would any other explanation and not assume that I do not believe I'm engaging in speculation. Nevertheless, what would be the purpose of publishing an idea unless its author considered it to be plausible and worth making public?

In contrast to previous models, I am attempting to describe a proposed process in much greater detail than has been done by anyone else while using the model to explain the full range of observed behavior. As expected, the model is in the process of growing in understanding in my own mind and in the detail I have used for its description. Therefore, I would hope a reviewer would provide encouragement to develop the ideas rather than trying to find as many ways possible to reject the basic approach.

The hydron string is basic to the process I am proposing. It is basic because I believe a dynamic mechanism must be proposed that can dissipate energy in the form of low energy photons and phonons before the fusion process is finished. It must operate outside of the lattice and the process must occur rarely to be consistent with well-known laws of chemistry and observed behavior. Other theoreticians have chosen to use different approaches, with each having flaws. In contrast, I am proposing a single universal process involving any isotope of hydrogen during which energy is lost while the observed or expected nuclear products are produced. My approach is well within the accepted style of how theory in this field is reported and developed.

Appendix B.1. Proposed p–e–p–e–p–e . . . string

This concept is not fully understood by the reviewer, and indeed by most readers, because they mistake the diagram I show in the paper as describing the true condition rather than as a cartoon. The true condition requires much more detail

than can be shown in a single figure or was described in this paper, partly because the concept is still being developed.

My present view is that the proposed string of hydrons forms as a large covalent molecule in a gap or crack. Let us start by imagining the situation when the gap is large. The atoms of hydron and the their molecules would be absorbed on each wall in the "normal" manner. This absorption process is known to be exothermic and is spontaneous. Therefore, it satisfies the requirement I discuss in assertion item (1) (above). As the gap is reduced, a distance will eventually be achieved at which the atoms and molecules will be equally absorbed on both walls simultaneously. This is the condition I propose is required for the resonance process to function. To be clear, I use this shrinking description only to make the process easier to understand. The real process starts with the gap being small and growing big enough for the described conditions to form.

Once the required gap dimension is achieved, the contained atoms and molecules can be considered to be suspended at equal distance between the walls. Because the walls are not uniform in charge, they would appear to be "lumpy" because the atomic structure forming the walls is uneven at this scale. Consequently, the hydron atoms will have to move through charge valleys in the process of assembling the proposed structure. This detail in no way distracts from the proposed process.

Formation of the chain requires one additional condition not present in large cracks, on normal surfaces, or within the lattice itself. When the walls are very close together, the spherical form or "cloud", in which an electron orbits the nucleus, is perturbed into a disc shape. In other words, all paths taken by the electrons are forced to align roughly with a plane passing through a line between the photons and parallel to the walls. This shift in position occurs without any change in energy or angular momentum because the distance from the nucleus does not change. Such a structure would be expected to cause the two protons to come closer together because the average negative charge between them would increase as the electrons more often pass through the line between adjacent nuclei. As an example, this reduced distance occurs when H_2 forms under normal conditions for similar reasons. Suppose another proton with an electron in a similarly distorted orbit were to come close. This similar alignment would increase the probability that its electron could be shared in the orbits of the other two atoms by a process of exchange. Addition of more hydrogen atoms would cause this molecular structure to grow in length with the bonding energy being released into the surrounding lattice as heat [d]. Up to this point in the description, the proposal is based on conventional behavior typical of a chemical structure created by covalent bonding. Granted, no such large molecule has been detected or proposed before, but creation of such a structure is not impossible based on any law of Nature, as far as I know. It is the next step that enters uncharted territory.

Appendix B.2. Energy release as X-rays

We know that helium is produced with nearly the expected energy without significant radiation. This means the energy *MUST* be released before fusion occurs in a form that cannot get out of the apparatus. Phonons have this ability but they can carry so little energy that dissipating 23.8 MeV/event seems unreasonable without the environment being disrupted or destroyed. Photons can carry away such energy and, indeed, small fluxes have been detected outside of the apparatus, especially when H_2 is used. The challenge is to identify a process that can generate photons before a fusion reaction is complete and helium, tritium, or deuterium forms. Because the photons would be coherent if they originated from my proposed process, I offer the claims reported by Karabut as an example of what has been observed, not proof that a laser is actually present. Proof will come only after people have an incentive to look for this kind of radiation, which I'm trying to encourage.

[d] Brian Scanlan has a somewhat different view of this process that he will describe in later papers. I am sure that other people can find additional ways to describe the proposed structure. Too little information is known about this stage of the fusion process to make any explanation the final one.

Appendix B.3. Proposed p–e–p reaction mechanisms

The role of the neutrino is complex. First of all, if most energy is lost as photons before the fusion reaction actually occurs, only a small amount of energy would be available to be lost by neutrino emission when the final fusion occurs. The reviewer uses values based on ALL the energy being released at the final moment of fusion, which is not what I propose. The second question is, "Does the neutrino play any role at all during the cold fusion process"? Typically, the neutrino is known to carry energy away when beta emission occurs. Theory must be used to suggest neutrino emission during the proposed fusion process, which might not apply. I suggest a measurement of the energy/D ratio would provide some very important insights into this process. This measurement has not been made. Consequently, the comments by the reviewer are still speculation.

I did not propose direct p + p fusion. This is an idea introduced only by the reviewer.

Appendix B.4. Tunneling

I have no idea how the concept of tunneling applies to the model I am proposing and it was not suggested in the paper

Appendix B.5. Discussion

Yes, I agree, something is a miss in the physics text books. Otherwise, cold fusion cannot be explained. I have proposed a mechanism that has the ability not only to explain more than any other previous explanation but it does not violate known laws. Because many of the comments made by the reviewer were based on a misunderstanding of what I propose, I do not yet know what the reviewer thinks about what I actually propose.

No matter how physics is understood, the behavior *MUST* be explained using the same mechanism regardless of the method used to initiate the effect or the isotopes of hydrogen present, because I do not believe that more than one mechanism can operate to produce such a rare and unusual nuclear process. An attempt to explain all observed behavior has not been attempted before. And yes, I have not applied the model to all observed behavior in this paper. That challenge will come later because this paper is one of a series in which the ideas will be expanded and applied. The purpose is to develop a plausible explanation in stages and use it to guide research from which support might be obtained. What more does the reviewer require of a theory at this early stage?

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