

Research Article

The Nature of Cold Fusion (Cold Fusion Made Simple)

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Abstract

The cold fusion process is explained using a new understanding of the observed behavior that shows how many of the behaviors are related to each other and to the mechanism causing cold fusion. A mechanism is described that can guide a more reliable initiation of the nuclear process. Methods are suggested by which the model can be tested. The need for a new understanding of nuclear interaction is identified.

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Keywords:

1. Introduction

Thirty-three years have passed since Profs. Martin Fleischmann and Stanley Pons (The University of Utah) discovered that a fusion reaction could be made to occur at ordinary temperatures in ordinary materials[1]. Initially, the behavior was called cold fusion. Now the preferred name is Low Energy Nuclear Reaction (LENR) because the process involves more than fusion. However, only the fusion process will be discussed here. Although much information has been discovered about how the process works, why it works is still unknown.

The distinction between HOW something works and WHY is important and needs to be understood. An example might help clarify the difference between these two concepts. When a person intends to fly an airplane, learning how the machine responds to the controls is important. This knowledge reveals HOW the machine works. Nothing needs to be known about the mechanism of lift, which is the WHY. Likewise, the LENR process can be made useful even when only the HOW is understood. The WHY does not need to be known at present. But, as is the case when flying an airplane, a flaw in understanding the HOW can cause failure. This paper describes a model based on HOW LENR behaves using the observed behavior as the teacher. Many papers supporting the idea can be accessed at www.LENR.org, only a few of which are cited here. More detail can be found in the book by Storms [2].

The role of impurities is important. Their effects were studied very early in the history because the nuclear process was thought to occur in the crystal structure where the impurities would be located. The fact that impure Pd worked

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more often than pure Pd supported the importance of impurities. How certain impurities might affect the occurrence of LENR is discussed.

Over the years, people realized that the LENR process appeared to require the creation of a special but rare condition in the host material. The question addressed here is, “Where in the material would this special condition form and what role would it play in causing LENR?”

The major nuclear product is thought to be ${}^4\text{He}$ because this element is found in the environment after excess energy is made when deuterium is used. In addition, tritium is occasionally produced without the expected number of neutrons. A nuclear process is described that can explain how these two observed nuclear products are produced.

2. GENERAL SUMMARY OF THE MODEL

The fuel for the fusion reaction can be any isotope of hydrogen. For simplicity, the word “hydrogen” or H is used when the comment applies to all hydrogen isotopes. This hydrogen is proposed to exist in a sequence of three different chemical relationships in a solid material before LENR can occur. These are as follows:

1. The crystal structure describes the conventional arrangement of the atoms in the material and provides a source of hydrogen to the two additional structures when they form. The crystal structure is face-centered-cubic (fcc) when Pd is used. The nuclear process does not occur in this structure because the rules governing this atomic arrangement require the atoms to be too far apart for the nuclei to interact. A violation of this requirement would require more energy than is available in the crystal arrangement. Nevertheless, this structure plays an indirect role in causing LENR as is described in Section II.1.

2. Next, a rare condition, called the Nuclear Active Environment (NAE), must form within the material. This condition is physically outside of fcc structure and chemically independent of the conditions that caused the crystal structure to form. The hydrogen atoms in the NAE have a conventional chemical relationship with each other, but one that is different from the chemical relationship on which the crystal structure is based. This process is described in Section II.2.

3. Finally, the H in the NAE interacts with electrons to form a unique chemical structure at a few random locations within the NAE. Although this process follows the rules governing chemical interaction, a shared wave function results with the ability to release mass-energy by a fusion-type nuclear reaction. As a result, this assembly, called the Nuclear Active Structure (NAS), has the unique ability to overcome the Coulomb barrier. It's proposed characteristics are described in Section II.3. The process of forming this structure and its ability to cause nuclear interaction is the great mystery revealed by LENR.

The nuclear process is not anticipated as the NAE and the NAS form. Instead, the nuclear process is the unintended result of a series of conventional chemical reactions, each of which obeys the laws of thermodynamics. After fusion takes place within the NAS, radiation, nuclear products, and energy are suddenly released as result of its destruction. Although these three different conditions have an important relationship to each other, each needs to be understood separately, starting first with the crystal structure.

2.1. Characteristics of the Crystal Environment and the NAE

Although the hydrides of palladium are most often used, this material is not the only one with the ability to cause this nuclear process. Therefore, the unique properties of PdH cannot be used to describe the universal mechanism. Instead, the general nature of the environment that can form in all materials needs to be understood and applied.

Crystal structures form because this arrangement of atoms and electrons has the lowest chemical energy compared to any other relationship for the applied conditions. Crystal structures cannot support nuclear fusion because the

nuclei are too far apart for them to interact. Any effort to force the nuclei into a closer relationship would require the application of enough local energy to overcome the chemical forces as well as the Coulomb barrier. This energy is normally not available, although many efforts have been made to justify a closer approach between the atoms based on various theories. [3]–[5] For example, the idea that enough energy to cause a fusion reaction could concentrate at a particular location by random chance is in conflict with what would happen if such a universal mechanism were to take place in a chemically unstable material. The stability of explosives demonstrates that this kind of energy concentrating mechanism does not happen in Nature. Therefore, this mechanism is an unlikely explanation for LENR.

Even the proposed metal atom vacancy model, called superabundant vacancies (SAV) [6], is not consistent with the observed behavior because the conditions required to form the SAV are not present when LENR is produced [7]. Indeed, if the proposed vacancy structure could be created within a crystal structure, this condition would be expected to occur throughout the crystal structure, thereby making LENR much more common and uniform at its locations in the material than is the case.

In addition, the ability to cause LENR is sensitive to how the material is manufactured, at least when Pd is used. The ability of a crystal structure to form metal atom vacancies would not be expected to be sensitive to the fabrication process. Therefore, for LENR to occur, the hydrogen nuclei in the host material must form a relationship that is independent of the behavior and chemical limitations characteristic of a crystal structure, which includes being independent of vacancy formation.

2.2. Nature of the NAE

The NAE has two important features. First, a physical condition able to acquire H must form physically outside of the crystal structure. Then, the NAE needs to be populated with H as a result of a conventional chemical process. The formation process is described first.

2.2.1. How is the NAE Created?

The conditions needed to form a suitable NAE are very limited, with flaws or gaps, sometimes called cracks, being the most likely possibilities. These can be created by chance or they can be created on purpose. Several occasions when the chance occurrence might have operated can be suggested. Suitable gaps might have formed when the Pd nanopowder used by Arata and Zhang [8] sintered into a solid mass during their study, as observed by McKubre et al. [9]. This process cannot be avoided and would quickly eliminate the initial small particles as active sites. Case [10] used coconut charcoal on which small particles of Pd were deposited. Random gaps located in the charcoal might have provided suitable sites, as suggested by the failure to produce excess power when different charcoal was used. Takahashi et al. [11] might have created gaps by ball-milling a brittle alloy containing Pd, Zr, and Ni after oxidation. When Pd is codeposited [12], suitable gaps are visible between the complex assortment of crystallites in the electroplated deposit. The Pd deposited on CaO by Iwamura et al. [13] would be γ . Extended electrolysis of PdD, as practiced by Fleischmann and Pons, is observed to create gaps at the surface as a result of changes in the surface purity and the creation of stress in the Pd cathode. In other words, many successes can be explained by the creation of the same unique condition. This possibility suggests that gap formation be considered as a requirement for LENR to occur.

In addition, the gap or flaw must have a critical size or dimension because the rare occurrence of LENR demonstrates that all possible sizes are not nuclear active. An estimate of the gap width can be suggested. It needs to be greater than the distance between the H atoms in the crystal structure but smaller than the size required for the H₂ molecule to form because this reaction would compete with the ability to form the less stable NAS. A method is suggested in Section II.2.3 that describes how the critical gap width might be formed on purpose.

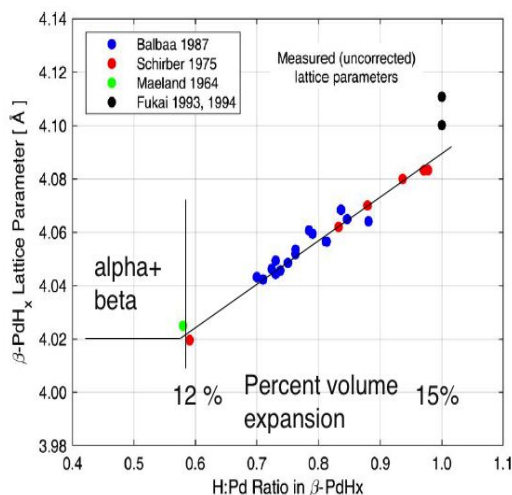


Figure 1. Change in lattice parameter when Pd reacts with hydrogen. The lattice parameter of pure Pd is 3.8916 Å.

2.2.2. How is the NAE Populated With H?

The process of populating the NAE with H would involve a chemical process as the H moves from its normal positions in the crystal and into this new atom arrangement. For the hydrogen to move, it must experience a loss of Gibbs energy. The resulting new chemical relationship between the H would then make possible the formation of a unique kind of chemical arrangement that is identified as the NAS. When theoreticians want to explain the nuclear process, they need to focus on the NAS because all of the processes are chemical and without novelty before the NAS forms.

The gap must have another characteristic for it to be consistent with the observations. The NAE would become stable after it has become populated with H because the removal of the H would require the return of the lost Gibbs energy. This energy is not normally available. As a result, the LENR process would be independent of the hydrogen content after the NAE has formed, as described in Section II.6.

2.2.3. How can the NAE be Created on Purpose?

Nano-machining of suitable grooves or holes in a metal sheet could be used to create a controlled number of active sites. This method has the advantage of providing total control of the power density and the amount of power. But first, the size of the gap needs to be known.

Another method involves the addition of small inert particles having a critical dimension to Pd. Such particles will become surrounded by a gap when the Pd is reacted with hydrogen. This effect occurs because the dissolved hydrogen causes the Pd to expand without changing the size of the particle. The magnitude of this expansion can be calculated using the lattice parameter shown in Fig. 1. The process of physical expansion has been studied [14–17] and found to be complex.

A cartoon in Fig. 2 shows an example of a gap formed around a particle of an arbitrary shape with a NAS present at an arbitrary location in the NAE. The magnitude of the gap width can be calculated using the fraction of expansion shown in Fig. 3. If the gap is assumed to be uniform around the particle, the gap (G) width can be calculated using the fraction expansion (F), times the dimension of the particle (D) divided by 2, as shown in the equations.

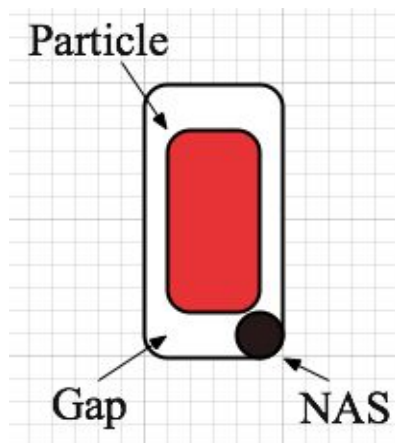


Figure 2. Cartoon of an embedded particle of inert material in the PdH structure around which a gap has formed as the result of the expansion after the Pd has reacted with H. The shape is arbitrary. A possible location of a NAS is shown. Many NAS would be expected to form in the same gap. The hydrogen atoms in the gap and the surrounding crystal structure are not shown. The figure is not drawn to scale.

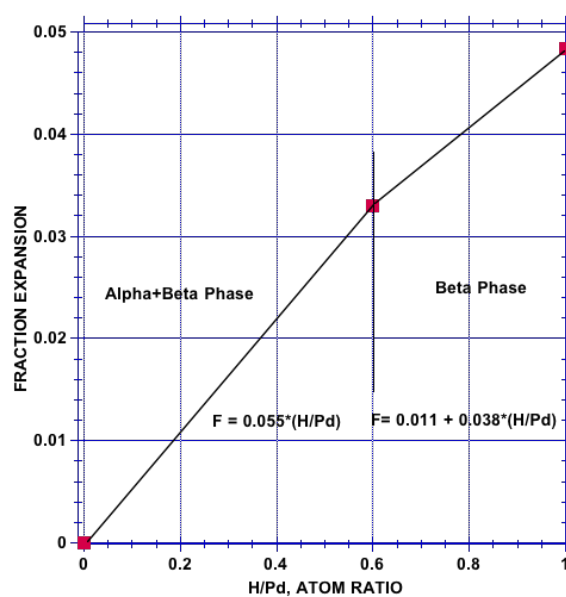


Figure 3. Fraction expansion of Pd when H is added as a function of the H/Pd atom ratio. The fraction produced by D would be similar.

$$G = F \cdot D / 2$$

$$F = 0.055 \cdot (H/Pd) \text{ for } H/Pd = 0.0-0.6$$

$$F = 0.011 + 0.038 \cdot (H/Pd) \text{ for } H/Pd = 0.6-1.0$$

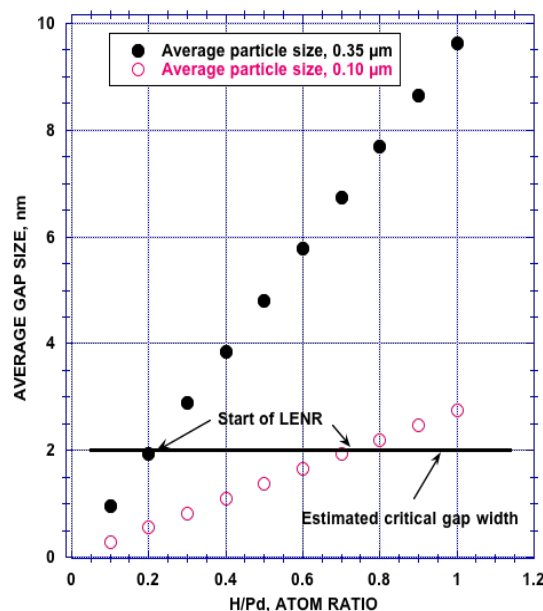


Figure 4. Example of how the particle size affects gap width as the H/Pd ratio is changed. The size needed to produce LENR is estimated to show how the H/Pd atom ratio might affect the onset of LENR.

However, the expansion will not be uniform unless the particle is a perfect cube. The actual particles will show a greater gap forming in the direction of their long axis than in the direction of the short axis, with the gap at other locations having values between these two extremes. While this behavior complicates the interpretation, it does not distract from the understanding of how the gap-forming process operates to form the NAE.

The rate of expansion changes when all of the alpha-phase has converted to the beta-phase, which is assumed to happen at $H/Pd = 0.6$ for this example. The actual composition at which this change in slope occurs will depend on temperature and hydrogen pressure. Nevertheless, this approximation is useful to show how the process is expected to work.

If the particle size were $0.35 \mu m$ and the active gap size is assumed to be 2 nm, the material would be expected to become active when the H/Pd ratio had reached 0.2, as shown in Fig. 4. When a particle with an average dimension of $0.1 \mu m$ is used, the H/Pd ratio would have to reach 0.8 before the material would become active. The challenge is to determine the required gap size so that a material could be made active at a known and easily obtained H/Pd ratio.

How do observations support this explanation? Two observations apply. According to Martin Fleischmann, Johnson-Matthey used cracked-ammonia to maintain a reducing atmosphere over the molten Pd while calcium boride was added to remove any oxygen during the purification process. The CaB_6 would react with oxygen to produce particles of CaO and a liquid consisting of the boron oxides. Some small particles of CaO would be expected to remain in the Pd after it had solidified. These would allow gaps to form when the Pd was later reacted with D or H. A relatively uniform distribution of these particles throughout certain batches of Pd metal would explain why, when LENR occurred, it was found to be produced by the entire batch regardless of its physical form, whether as wire or flat plate. After the Pd was further purified, for example by zone melting, it was never found to be active.

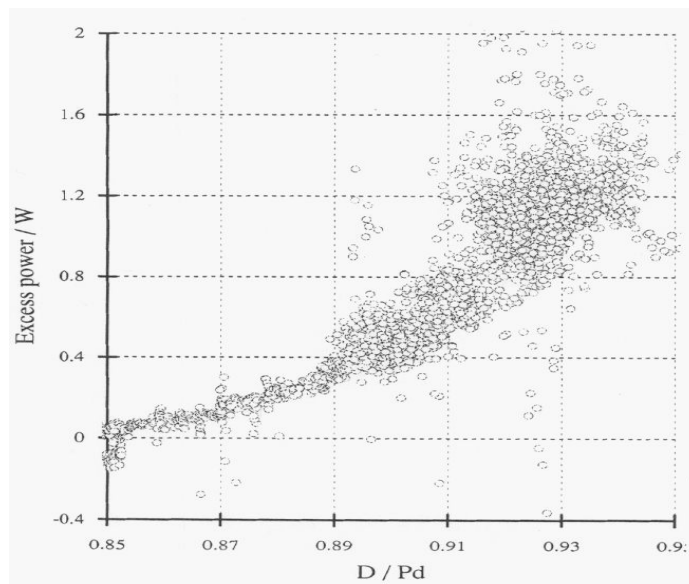


Figure 5. Relationship between the amount of power and the D/Pd atom ratio [18].

McKubre et al. [18] found that the amount of power produced at 20°C when a particular batch of Pd was used increased when the D/Pd ratio was increased, as shown in Fig. 5. A similar behavior was reported by Kamimura et al. [19] Two features shown by the behavior are important. The power-composition relationship shows a wide variation in values and a nonlinear increase as the D/Pd ratio is increased. How do these two behaviors relate to the proposed role of gaps created by embedded particles?

If the particles had a size distribution as shown in Fig. 6, some power would be produced when the D/Pd ratio reached 0.8, based on the values shown in Fig. 5. However, the number of particles being activated would be too small to produce enough power for it to be detected. As the D/Pd ratio was further increased, an increasing number of smaller particles would become active, thereby causing more power to be generated. If the distribution had the form shown in Fig. 6, the amount of power would increase with a nearly exponential relationship as the data in Fig. 5 shows. The observed wide scatter in values can be partly explained by the distribution of particle size not being uniform throughout the batch of material.

This description is used only as an example of how the particle size might affect the amount of power. The critical particle size is still unknown and needs to be determined. Meanwhile, studies are underway to study the effect of adding various high melting compounds having particles of various sizes to Pd. Particles of CaO, SiO₂, and BN have been found to produce behavior consistent with this explanation.

Because the gap becomes chemically stable after it has been populated with hydrogen, LENR will not be affected by the D/Pd ratio after the LENR process starts. This behavior is discussed in Section II.6. Nevertheless complete removal of H by using either high vacuum or high temperatures would be expected to stop the LENR process from occurring even after the D had been replaced because the gap size would have become too large to become active. This expectation has been tested and found to be true. This behavior might account for the occasional failure to replicate excess power after a sample has been allowed to lose too much D. That remelting has been found to reactivate a previously active material supports this explanation.

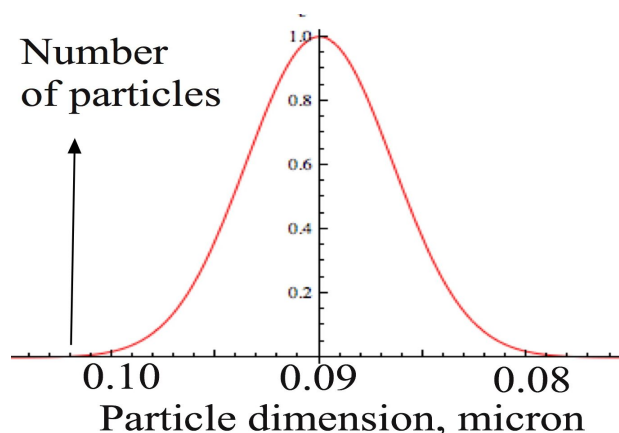


Figure 6. A hypothetical particle size distribution.

2.3. Creation of the NAS¹

For a nuclear process to occur, the nuclei must get close enough for their nuclear energy states to interact. This requires the strong repulsion created by the Coulomb Barrier to be overcome. However, the required energy is not present in a chemical structure. Because nuclear reactions are now known to occur without the need for applied energy, the mechanism now needs to be identified. A plausible mechanism involving the ability of the electron charge to offset the positive charge of the nuclei can be suggested. This kind of shielding has been studied by applying extra energy, which triggers the hot fusion mechanism. Although electron shielding is now known to occur, it has only a very small effect [20], [21]; not nearly enough to account for the LENR behavior. Some people have suggested either neutron formation, an interaction with unusual exotic particles, or the accumulation of phonons as the source of the required energy. The flaws in these mechanisms are too complex to discuss here.

Instead, a new kind of nuclei-electron interaction is suggested, perhaps similar to that operating in the EVO, as discovered by Shoulders and replicated by Fox [22]–[24]. A similar but larger-scale process called ball lightning is suggested by Lewis. [25] These clusters are described as consisting of a collection of positive ions and electrons with about 10^6 electrons for each positive ion. [24] Although these structures are obviously real, their common feature is difficult to understand. Nevertheless, the possible relationship of this common feature to LENR makes their understanding more urgent.

Because this structure is normally made in air, it would be based on the nuclei of oxygen and nitrogen. Perhaps, the Coulomb Barrier is too large in this case to allow a nuclear reaction to take place. But, what might happen when the nuclei are those of the hydrogen isotopes? Might the presence of these nuclei allow the structure to experience a nuclear interaction as a consequence of a relatively smaller Coulomb Barrier being present?

In addition, the nature of the radiation emitted from LENR suggests the process involves a cooperative relationship between many nuclei, which would require the formation of a complex structure involving many components. The need to conserve momentum when nuclear energy is released also requires a cooperative interaction between many

¹I called the structure that supports fusion the Hydroton in my book [2]. At the time the book was written, I suggested a linear interaction between the electrons and nuclei. Further consideration suggests, instead, a symmetrical and highly localized interaction as described here.

Table 1. Proposed reactants and resulting nuclear products and energy

$(D+e+D) = {}^4\text{H} = {}^4\text{He} + e \text{ (fast decay)} + \nu$	23.8 MeV
$(H+e+D) = {}^3\text{H} = {}^3\text{He} + e \text{ (slow decay)} + \nu$	4.9 MeV
$(H+e+H) = {}^2\text{H} \text{ (stable)}$	1.9 MeV
$(T+e+D) = {}^4\text{H} + n = {}^4\text{He} + e \text{ (fast)} + \nu$	<19 MeV
$(T+e+H) = {}^4\text{H} = {}^4\text{He} + e \text{ (fast decay)} + \nu$	<21 MeV

components. This paper is not designed to explore the nature of this assembly. Nevertheless, some words about how it might be created are warranted.

After the NAE forms, the formation of the NAS would require the electrons and hydrogen nuclei to spontaneously concentrate at the same location. Laws of thermodynamics must guide this process because the process occurs in a chemical environment. The nuclear process would not be anticipated by the atoms and would occur as an unexpected consequence of forming an unusual assembly by normal chemical interaction. In other words, the assembly process must shed Gibbs energy as it forms, perhaps as the detected X-ray emission. Only later after the assembly process is complete, does nuclear interaction take place followed by the release of the nuclear products along with the nuclear energy. Amazingly, Nature has found a new method to cause nuclear interaction but only after the required chemical conditions have been satisfied.

The process of forming the NAS might be accelerated by passing a high current through the material, as done by Godes [26], [27], or by using laser light of certain frequencies, as Letts and others have reported. [28]–[31] The presence of certain elements in the NAE might also provide a greater than normal supply of electrons. Even the electron current used to cause electrolysis might play a role instead of an ion flux [32] being the important variable. Nevertheless, some NAS seems to form spontaneously without additional effort after the NAE has formed.

The fusion reaction destroys the NAS, after which it reforms as hydrogen is resupplied first from the local NAE [33] and then from the surrounding crystal structure. In other words, this process rapidly repeats at the same locations. Because each NAE can contain many such assemblies, the amount of generated power is determined by how many NAS form in each NAE and how rapidly the H can be replaced after it has been converted to a different isotope. When the local concentration of NAS is too large, local melting would be expected, as has been observed [34].

2.4. The Nature of the Nuclear Reaction

The process is observed to produce at least helium and tritium as well as several kinds of energetic emissions. The production of transmutation products is not discussed here. If we assume all the fusion reactions take place as a result of the same mechanism, what nuclear products can be expected to result from each combination of hydrogen isotopes?

When this assumption is applied, the observed nuclear products can be explained ONLY when an electron is added to each fusion product. This electron-proton interaction does not take place outside of the NAS, hence does not produce a free and independent neutron. Addition of an electron to the final nuclear product is plausible because electrons are involved in lowering the Coulomb barrier, which would increase the probability of their capture by the final nuclear energy state.

Table 1 [2] summarizes the suggested reactions, their products, and the resulting energy. The fusion of hydrogen isotopes is proposed to make other isotopes of hydrogen, several of which then decay by beta emission to form isotopes of helium. The antineutrino (ν) is assumed to carry a small but unknown fraction of the nuclear energy. Besides being consistent with the observations, as described below, the fusion products have a satisfying symmetry to each other. Although being novel and not generally accepted, this idea allows many behaviors to be explained and many predictions to be tested, as follows.

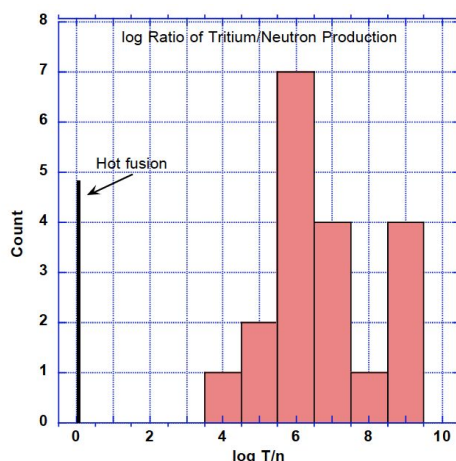


Figure 7. Relationship between the number of reported values and the log of the measured tritium/neutron ratio. The ratio resulting from the hot fusion mechanism is well established at a value near unity or $\log T/n = 0$.

When tritium is produced by the fusion between H and D, a small number of neutrons are formed that are correlated with the amount of tritium, as shown in Fig. 7. The large difference between the T/n ratios produced by cold- and hot-fusion demonstrates that these two nuclear reactions are caused by entirely different mechanisms. Instead of many neutrons resulting from the fragmentation of the helium nucleus, a few neutrons result when tritium fuses with deuterium. The large variation in the reported values would result from a different T/D ratio being present during each measurement. A comparison of the T/n ratio to the T/D ratio when future measurements are made would test this idea.

Please note, the equations in Table 1 only identify the reactants and the products. They do not describe the mechanism or imply that only three reactants are involved. In fact, conservation of momentum when the energy is dissipated requires many carriers of the energy and momentum to be ejected from the site of the nuclear reaction. As noted previously, these energy carriers appear to come from a novel and complex nuclear process.

In summary, the combined energy state consisting of hydrogen nuclei and electrons decomposes by emitting the nuclear products along with many electrons, each containing part of the resulting energy. The nuclear products consisting of photons and ions have been detected. Emission of energetic electrons has also been observed [35]. Anti-neutrino emission is expected to carry some energy that would not be captured in the calorimeter. This radiation has not been observed although it has been considered [36].

2.5. Evidence Supporting the Formation of ${}^4\text{H}$.

The ${}^4\text{H}$ isotope, when made by bombarding T with D at high energy, is found to decompose immediately by ejecting a neutron. The model suggested here assumes that when ${}^4\text{H}$ is made at low energy, the nucleus remains stable and eventually loses its energy by beta emission to produce ${}^4\text{He}$. What observed behavior supports this assumption?

Karabut et al. [37] measured the ion spectrum emitted during gas discharge in D_2 using a silicon barrier detector and confirmed the presence of energetic ions using CR39. The spectrum is shown in Fig. 8. Three behaviors are important. The spectrum consists of separate ion energies having about the same energy separation; the intensity decreases as the energy increases, and most of the energy lies between about 1 and 6 MeV. They concluded some of the ions were ${}^4\text{He}$.

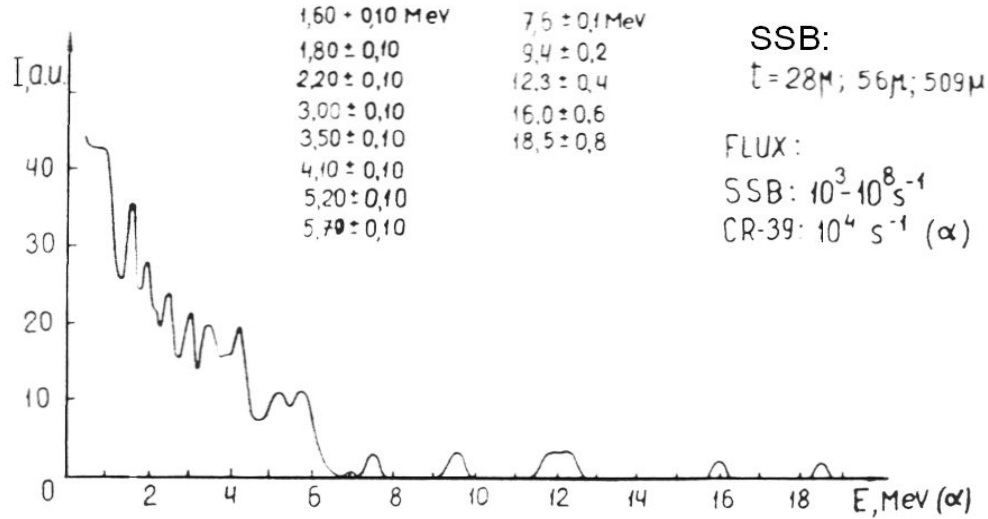


Figure 8. Ion spectrum was measured as the result of gas discharge in D_2 while using a silicon barrier detector located within the apparatus [37].

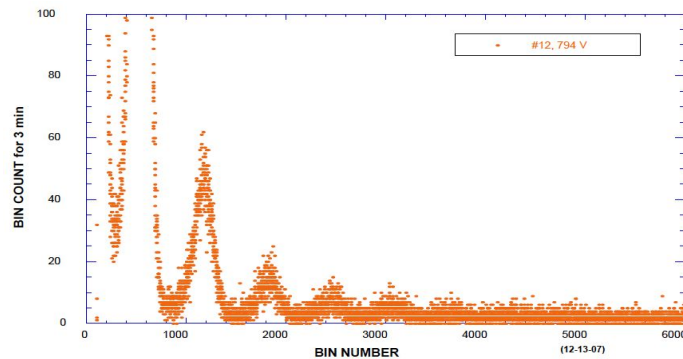


Figure 9. The typical spectrum produced during gas discharge when either H_2 or D_2 is used.

Eight years later, Storms and Scanlan [38] measured the spectrum produced during gas discharge using a silicon barrier detector, shown in Fig. 9. As can be seen in Fig. 10, the different energies all have the same energy separation equal to 0.417 MeV. The values in Fig. 11 show that the decrease in intensity can be fit by an exponential relationship. Also, the energy range falls in the same range found by Karabut et al. In other words, these two measurements that were made using different detectors and done at different laboratories show very similar behavior. Also, the same spectrum was produced by Storms and Scanlan when either H_2 or D_2 were used. The same spectrum would result because 4H would be produced after the fusion of H had created enough D to allow some D+D fusion to take place. The D ions emitted when H+H+e fusion occurred would not have enough energy to be detected, although a similar spectrum would be expected.

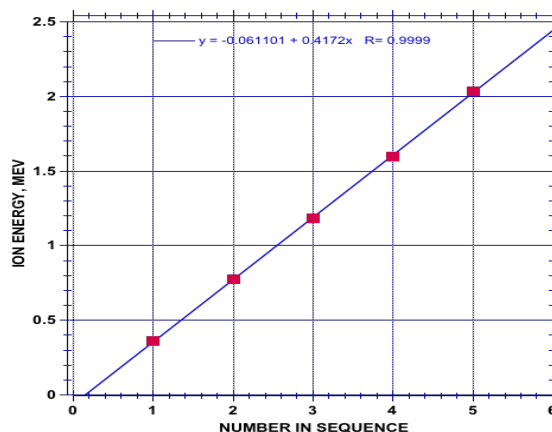


Figure 10. The relationship between the sequence in the spectrum and the ion energy when the first peak is given a value of 1.

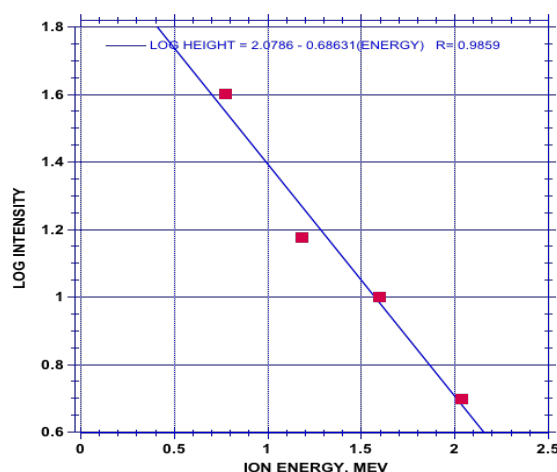


Figure 11. The relationship between log intensity and ion energy. The intensity is given a relative value.

Unlike, Karabut et al., Storms and Scanlan determined the nature of the ions by determining the change in energy produced when various absorbers were inserted. The change in energy was compared to that described in the NIST tables (NSRDS-NBS29) to identify the element being emitted. They determined that the emissions were consistent with the ions of a hydrogen isotope, not helium! However, at the time the work was done, emission of ^4H , which is also consistent with the behavior, was not considered.

An important question remains unanswered. If the ions are ^4H , approximately 23.8 MeV would have been released when each was created. The ions in the spectrum shown in Fig. 9 have, on average, much less energy than the amount released by their creation. Where is the missing energy? The missing energy is not in the antineutrino because a nearly correct total energy is measured using a calorimeter. The answer requires several possibilities to be considered, starting with the behavior shown in Fig. 10.

For the ions to have an equal separation of energies, all of the ions must result from a single fusion reaction occurring at the same location in the material. An unknown amount of energy would be removed as the ions passed through the material between the source and the detector. As a result, the measured energy of the ions would be a lower limit compared to the actual energy released at their creation. In addition, the difference in energy shown by the two spectrums suggests that the depth was slightly greater during the Storms and Scanlan study compared to the depth when Karabut et al. measured the ion energy.

On the other hand, significant absorption of energy as a result of the ions passing through different amounts of material would cause the values not to extrapolate to zero in Fig. 10 and cause much greater smearing of the energy in the spectrum shown in Fig. 9. The absence of these expectations suggests the ions resulted from events happening very near the surface.

Because absorption is not likely to have subtracted significant energy, perhaps the missing energy is emitted as photons [39]–[41] and electrons [42]. The photon energy has been measured. A measurement of the energy contained in the emitted electrons and that resulting from beta emission should be the next step in solving the mystery of the nuclear process.

What implications result from this description?

1. The ^4H would escape much more rapidly and more completely from the Pd compared to helium. This means the LENR process would not need to occur near the surface, as has been assumed based on the limited diffusion ability of helium to escape from the Pd structure. Consequently, the LENR reaction could take place throughout the sample with most of the ^4He forming after the ^4H had diffused out of the material. Future studies of helium production need to measure both the helium content of the gas and the Pd.

2. The failure to detect the expected fragmentation of the energetic ^4He nucleus would not have to be explained.

3. Use of pure D would not produce tritium.

4. Fusion of pure ^1H would very gradually produce an increasing amount of tritium. This nuclear product would gradually produce ^4He as the tritium fused with ^1H .

5. Tritium would be produced immediately when a mixture of D and H is used with active material, with the rate being related to the D/H ratio. The slow onset of tritium formation in previous studies using D_2O would result from the slow contamination of the D_2O with H_2O .

6. Increased numbers of neutrons would be produced as the T/D ratio approached unity.

These expectations can be tested by future measurements. These implications also have to be considered when a large energy generator is designed using LENR because a potentially large amount of dangerous tritium could be created along with a smaller neutron flux when ^1H is used.

2.6. Effect of Temperature and D/Pd Atom Ratio

The amount of power is increased when the temperature is increased, with a linear relationship being produced between log power and $1/T$. This relationship is shown in Fig. 12 for four separate samples of solid Pd having different D contents, with the electrolytic method used during each study.

Each study has the same slope above a critical temperature even when different amounts of power are produced. For example, the sample designated B was measured while the current was applied, which produced a D/Pd ratio of 0.85. The current was then turned off and the sample was again heated several times, which resulted in a steady loss of D. Nevertheless, the values all fell on the same line. In other words, the amount of power and the effect of temperature were not affected by the D content. The activation energy that affects the power production is 0.303 eV/atom, which can be compared to the activation energy for the diffusion of D in PdD which is equal to 0.230 eV/atom [43].

A sample was made by pressing powdered Pd with CaO powder and studied using electrolysis (Fig. 13). Electrolytic current was applied during the first heating and then it was turned off. A greater amount of excess power

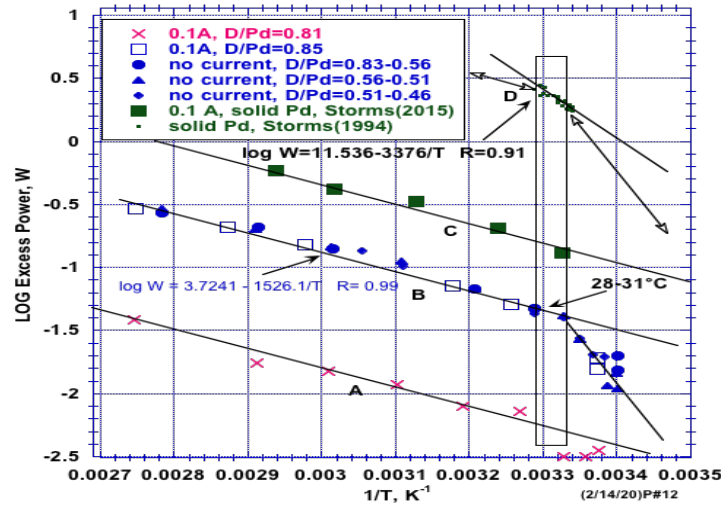


Figure 12. Relationship between log (excess power) vs $1/T$ for solid samples heated in an electrolytic cell. The studies labeled A, B, C, and D were made at different times using different materials.

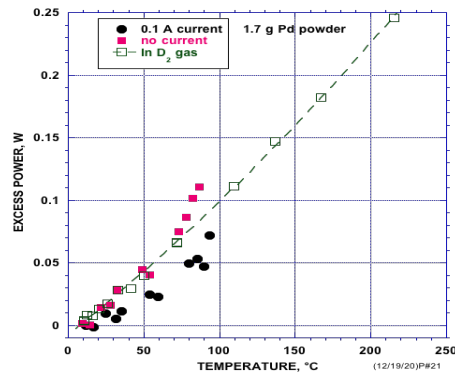


Figure 13. A sample of activated Pd powder was first heated in an electrolytic cell to 90°C. The sample was then transferred to a cell containing D_2 gas and heated to 225°C. The values are taken when the temperature is increased and then when it is decreased with a delay of 110 min between the values.

was produced even though the D content had decreased. Then the sample was removed from the electrolytic cell and placed in a cell containing only D_2 gas while using the same calorimeter. This cell was heated to higher temperatures, as shown in Fig. 13. Notice that the temperature effect

was largely unchanged and similar amounts of excess power were produced at the same temperatures. In other words, the amount of power produced by the LENR process was not affected by the change from electrolysis to gas loading. In addition, the effect of temperature remained unchanged even though the D/Pd ratio had changed. Other

studies have shown that the slope of $\log(\text{Excess Power})$ vs $1/T$ of samples exposed to gas loading is less than the slope produced when electrolysis is used perhaps because the gas can more easily access the NAE.

The slope is related to the activation energy of the process that controls the amount of excess power. This activation energy is similar to the activation energy for the diffusion of D through PdD. [43], [44] Consequently, the temperature appears to be affecting the diffusion process that allows the D to travel from its location in the surrounding crystal structure to the NAE and replace the D lost as a result of fusion. Some samples show similar behavior when heated in D_2 gas at temperatures up to at least 500°C .

Notice that the amount of power produced at 20°C , the temperature used during many reported studies, is very small. Significant power is only produced when the material is heated. Perhaps many of the failures to make detectable energy might have been successful if a higher temperature had been used.

3. SUMMARY

A model is proposed that describes a series of events required for spontaneous nuclear fusion to occur in a material. The model identifies the mechanisms unique to LENR including the final event that requires a new understanding of nuclear interaction. The description is logically consistent with observed behavior and the laws that govern chemical behavior. Predictions are made that can be used to test the validity of the model.

The LENR process is proposed to take place in gaps. The gaps can be formed by several methods, including around embedded particles when the Pd expands as it reacts with H or D. The addition of the properly sized particles to Pd can be used to cause LENR with improved reliability.

These gaps have a critical width in which nuclei and electrons can assemble by a chemical process to produce a structure that can create a common energy state between all the nuclei and electrons. As a result, fusion can happen between any of the hydrogen isotopes to produce another isotope of hydrogen as a result of electron capture by the assembly.

Tritium results from the fusion between H and D. Fusion involving only D does not make tritium. Instead, ^4H is formed and rapidly decays to ^4He as the final product. Fusion involving only ^1H will slowly make tritium, deuterium, and ^4H , with ^4He being the final nuclear product.

All of these reactions dissipate their energy by the emission of energetic ions, electrons, and X-rays with each being unable to pass through the walls of the apparatus. Very few free neutrons are produced.

The rate of the fusion reaction is determined by the number of nuclear active structures (NAS) that form in the nuclear active environment (NAE) and by the temperature. The temperature controls the rate at which the hydrogen is replaced in the NAE after it has been converted to a nuclear product in the NAS.

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References

- [1] M. Fleischmann, S. Pons, M.W. Anderson, L.J. Li, M. Hawkins, Calorimetry of the palladium-deuterium-heavy water system, *J. Electroanal. Chem.* 287 (1990) 293.
- [2] E.K. Storms, *The explanation of low energy nuclear reaction*, Infinite Energy Press, Concord, NH, 2014.
- [3] G. Preparata, Cold fusion '93': Some theoretical ideas, *Trans. Fusion Technol.* 26 (1994) 397–407.
- [4] A. Meulenbergh, K.P. Sinha, Composite Model(s) for Low Energy Nuclear Reactions in the solid state: II, (2020).

- [5] P.L. Hagelstein, I.U. Chaudhary, Phonon models for anomalies in condensed matter nuclear science, *Current Science* 108 (2015) 507–13.
- [6] M.R. Staker, A model and simulation of lattice vibrations in a superabundant vacancy phase of palladium–deuterium, *Modeling Simul. Mater. Sci. Eng.* 28 (2020) 0650066.
- [7] Z.M. Geballe, M. Somayazulu, N. Armanet, A.J. Mishra, M. Ahart, R.J. Hemley, High-pressure synthesis and thermodynamic stability of $\text{PdH}_{1\pm\epsilon}$ up to 8 GPa, *Phys. Rev. B* 103 (2021) 024515.
- [8] Y. Arata, C. Zhang, Presence of helium ($^2\text{He}_4$, $^2\text{He}_3$) confirmed in highly deuterated Pd-black by the new detecting methodology, *J. High Temp. Soc.* 23 (1997) 110 (in Japanese).
- [9] M.C.H. McKubre, F. Tanzella, P. Tripodi, V. Violante, Progress towards replication, in: X.Z. Li (Ed) *The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science*, Tsinghua Univ. Press, Tsinghua Univ., Beijing, China, 2002, pp. 241.
- [10] L.C. Case, Catalytic fusion of deuterium into helium-4, in: F. Jaeger (Ed) *The Seventh International Conference on Cold Fusion*, ENECO, Inc., Salt Lake City, UT, Vancouver, Canada, 1998, pp. 48.
- [11] A. Takahashi, H. Ido, A. Hattori, R. Seto, A. Kamei, J. Hachisuka, T. Yokose, Y. Mori, A. Taniike, Y. Furuyama, Latest Progress in Research on AHE and Circumstantial Nuclear Evidence by Interaction of Nano-Metal and H(D)-Gas, *J. Cond. Matter. Nucl. Sci.* 33 (2020) 14–32.
- [12] P.A. Mosier-Boss, L.P. Forsley, F.E. Gordon, Overview of Pd/D Co-deposition, *J. Cond. Matter. Nucl. Sci.* 29 (2019) 34–40.
- [13] Y. Iwamura, T. Itoh, N. Yamazaki, J. Kasagi, Y. Terada, T. Ishikawa, D. Sekiba, H. Yonemura, K. Fukutani, Observation of low energy nuclear transmutation reactions induced by deuterium permeation through multilayer Pd and CaO thin film, *J. Cond. Matter Nucl. Sci.* 4 (2011) 132–44.
- [14] E.K. Storms, The nature of the energy-active state in Pd-D, *Infinite Energy* #5-6 (1995) 77–81.
- [15] R. Griessen, R. Feenstra, Volume changes during hydrogen absorption in metals, *J. Phys. F: Met. Phys.* 15 (1985) 1013.
- [16] O. Beeri, D.C. Dunand, Transformation mismatch plasticity in Pd induced by cyclic hydrogen charging, *Mater. Sci. and Eng. A* 532 (2009) 178–83.
- [17] N. Armanet, M. Bonnard, Lattice volumic expansion of Palladium vs Hydrogen concentration : classical trend questioned, 2015.
- [18] M.C.H. McKubre, S. Crouch-Baker, A.M. Riley, S.I. Smedley, F.L. Tanzella, Excess power observations in electrochemical studies of the D/Pd system; the influence of loading, in: H. Ikegami (Ed) *Third International Conference on Cold Fusion, "Frontiers of Cold Fusion"*, Published by: Universal Academy Press, Inc., Tokyo, Japan, Held at: Nagoya Japan, 1992, pp. 5.
- [19] H. Kamimura, T. Senjuh, S. Miyashita, N. Asami, Excess heat in fuel cell type cells from pure Pd cathodes annealed at high temperatures, in: M. Okamoto (Ed) *Sixth International Conference on Cold Fusion, Progress in New Hydrogen Energy, New Energy and Industrial Technology Development Organization*, Tokyo Institute of Technology, Tokyo, Japan, Lake Toya, Hokkaido, Japan, 1996, pp. 45.
- [20] K. Czerski, Enhanced electron screening and nuclear mechanism of cold fusion, in: V. Violante, F. Sarto (Eds), *15th International Conference on Condensed Matter Nuclear Science*, ENEA, Italy, Rome, Italy, 2009, pp. 197–202.
- [21] E.N. Tsyganov, V.M. Golovatyuk, S.P. Lobastov, M.D. Bavizhev, S.B. Dabagov, Registration of energy discharge in $\text{D} + \text{D} \rightarrow ^4\text{He}^*$ reaction in conducting crystals (simulation of experiment), *Nucl. Instr. and Meth. in Phys. Res. B* 309 (2013) 95–104.
- [22] K. Shoulders, EV, A Tale of Discovery, www.LENR.org, 1987.
- [23] K. Shoulders, Projectiles from the dark side, *Infinite Energy* 12 (2006) 39–40.
- [24] H. Fox, J.S. X., Low-energy nuclear reactions and high-density charge clusters, *Infinite Energy* 4 (1998) 26–30.
- [25] E.H. Lewis, Evidence of microscopic ball lightning in cold fusion experiments, in: J.-P. Biberian (Ed) *11th International Conference on Cold Fusion*, World Scientific Co., Marseilles, France, 2004, pp. 304.
- [26] F. Tanzella, R. George, R.E. Godes, Nanosecond Pulse Stimulation in the Ni–H₂ System, *J. Cond. Matter. Nucl. Sci.* 29 (2019) 202–10.
- [27] R.E. Godes, D. Correia, R.D. Gremban, Control of low energy nuclear reactions in hydrides, and autonomously controlled heat generation module, 2015.
- [28] P.L. Hagelstein, D. Letts, D. Cravens, Terahertz difference frequency response of PdD in two-laser experiments, *J. Cond. Matter Nucl. Sci.* 3 (2010) 59–76.

- [29] L. Holmlid, Heat generation above break-even from laser-induced fusion in ultra-dense deuterium, *AIP Advances* 5 (2015) 087129.
- [30] V. Violante, M. Bertolotti, E. Castagna, I. Dardik, M.C. McKubre, S. Moretti, S. Lesin, F. Sarto, F. Tanzella, T. Zilov, Progress in excess power production by laser triggering, in: A. Takahashi, K. Ota, Y. Iwamura (Eds), *Condensed Matter Nuclear Science, ICCF-12*, World Scientific, Yokohama, Japan, 2005, pp. 55–64.
- [31] M.R. Swartz, Photo-induced excess heat from laser-irradiated electrically polarized palladium cathodes in D_2O , in: P.L. Hagelstein, S.R. Chubb (Eds), *Tenth International Conference on Cold Fusion*, World Scientific Publishing Co., Cambridge, MA, 2003, pp. 213–25.
- [32] M.C.H. McKubre, F.L. Tanzella, Flux Effects in Metal Hydrogen Loading: Enhanced Mass Transfer, *J. Cond. Matter Nucl. Sci.* 15 (2015) 1–10.
- [33] S. Szpak, P.A. Mosier-Boss, J. Dea, F. Gordon, Polarized $D^+/Pd-D_2O$ system: hot spots and "mini-explosions", in: P.L. Hagelstein, S.R. Chubb (Eds), *Tenth International Conference on Cold Fusion*, World Scientific Publishing Co., Cambridge, MA, 2003, pp. 13.
- [34] D. Nagel, A.E. Moser, High Energy Density and Power Density Events in Lattice-enabled Nuclear Reaction Experiments and Generators, *J. Cond. Mater. Nucl. Sci.* 19 (2016) 219–29.
- [35] F.E. Gordon, H.J. Whitehouse, Lattice Energy Converter, *JCMNS* 35 (2022) 30–48.
- [36] Z.M. Dong, C.L. Liang, B. Liu, Q.-M. Wei, J. Tian, S.X. Zheng, J.Z. Yu, X.Z. Li, Studies on Anomalous Phenomena of D/Pd Systems using a Gas-loading Process – A Stride Towards Neutrino Detection, *J. Cond. Matter Nucl. Sci.* 4 (2011) 119–31.
- [37] A.B. Karabut, Y.R. Kucherov, I.B. Savvatimova, Nuclear product ratio for glow discharge in deuterium, *Phys. Lett. A* 170 (1992) 265–72.
- [38] E.K. Storms, B. Scanlan, Detection of radiation from LENR, in: D.L. Nagel, M.E. Melich (Eds), *14th International Conference on Condensed Matter Nuclear Science*, www.LENR.org, Washington, DC, 2008, pp. 263–87.
- [39] A.B. Karabut, E.A. Karabut, P.L. Hagelstein, Spectral and temporal characteristics of X-ray emission from metal electrodes in a high-current glow discharge, *J. Cond. Matter Nucl. Sci.* 6 (2012) 217–40.
- [40] A.B. Karabut, E.A. Karabut, Research into spectra of X-ray emission from solid cathode medium during and after high current glow discharge operation, in: D.L. Nagel, M.E. Melich (Eds), *14th International Conference on Condensed Matter Nuclear Science*, www.LENR-CANR.org, Washington DC, 2008, pp. 362–7.
- [41] A. Karabut, Research into powerful solid X-ray laser (wave length is 0. 8–1.2 nm) with excitation of high current glow discharge ions, *11th International Conf. on Emerging Nuclear Energy Syst.*, Albuquerque, NM, 2002, pp. 374.
- [42] A. Meulenberg, J.L. Paillet, Nature of the Deep-Dirac Levels, *JCMNS* 19 (2016) 192–201.
- [43] E. Storms, The Nature of the Fusion Reaction in Palladium and Nickel, *ICCF-23*, Xiamen, China, 2021.
- [44] E. Storms, Anomalous Energy Produced by PdD, *J. Cond. Matter. Nucl. Sci.* 20 (2016) 81–99.