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Research Article

A New and Improved Understanding of Cold Fusion Based on the Observed Behavior

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Abstract

Cold fusion requires two essential conditions for it to occur. First, a location in which the Coulomb barrier can be reduced must be created. This unique condition is called the nuclear active environment (NAE). Second, the nuclear fuel, which is any isotope of hydrogen, must diffuse from its usual location in the crystal structure and enter the NAE. Upon arrival in the NAE, the fuel is converted to a nuclear product by a very unusual nuclear process, which involves the electrons within the NAE reducing the Coulomb barrier and carrying away part of the nuclear energy as they are emitted with kinetic energy. Helium is the final nuclear product when deuterium is used. This paper describes how these requirements can be met without violating the rules governing a chemical environment while being consistent with the nuclear requirements. A model describing the process is provided using only the observed behaviors and their implications.
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1. Introduction

In 1989, Professors Fleischmann and Pons (F-P) [1] published a discovery that would eventually be identified as the fusion of deuterons within the palladium deuterium compound. After thousands of studies conducted in laboratories worldwide (LENR.org), the mechanism can now be described in simple terms. To fully understand this description, it is essential to first understand the more familiar **hot fusion** process to avoid mistaking this kind of fusion for the new kind, referred to as **cold fusion**.

Hot fusion was initially proposed as an explanation for the energy produced by stars when hydrogen is fused to form heavier elements. The nuclear reaction is relatively easy to induce; for example, striking a crystal of lithium deuteride (LiD) with a hammer will generate a burst of neutrons as the D nuclei fuse and the result fragments. However, to make the reaction frequent enough to generate useful power, temperatures in excess of millions of degrees are required. These high temperatures increase the chance of random encounters between two fuel nuclei, thereby increasing the probability that these encounters will result in fusion. This process has been applied on a large scale for the production of useful energy at a facility in France called ITER [2]. Many other large and small efforts are also underway in other countries.

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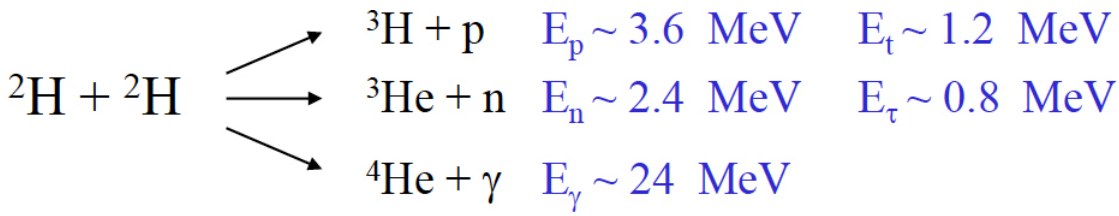

Figure 1. The energy of the emissions resulting from hot fusion between deuterons as provided by Czerski [3], [4]. The emission of ^{4}He with a very energetic gamma ray has a very low probability. These reactions are never observed when cold fusion occurs.

When deuterium (D) is used as the fuel, the hot fusion process results in the fragments of a helium nucleus, as shown in Fig. 1. The two fragmentation paths have nearly equal probability across all applied energies to produce a total of about 3.9 MeV/(D+D). This value is in contrast to 23.85 MeV/(D+D) produced by the cold fusion mechanism. The emission of neutrons is frequently used to measure the reaction rate of the hot fusion process. Neutrons are not emitted by the cold fusion mechanism.

The same reaction can also be initiated by bombarding a material containing D with D+ ions having energy sufficient to initiate the hot fusion mechanism. In this scenario, the reaction rate is enhanced by the surrounding electrons in the physical structure when the kinetic energy of the bombarding D+ ions is at the low end of the required energy [4], [5]. This effect is significant as it demonstrates that electrons within a structure can interact with a nuclear process. However, in spite of help from the electrons, the observed reaction rate becomes too small to detect when the applied energy is less than about 1000 eV. In contrast, cold fusion is easy to detect when no kinetic energy is applied. Although the increased reaction rate caused by the electrons in the lattice structure is small, it can be understood, fostering collaboration within the scientific community to study the process in more detail.

In contrast, cold fusion behaves entirely differently. In this case, the fusion reaction occurs spontaneously in various materials after they have undergone specific treatments, without the application of enough energy to cause hot fusion. Moreover, the nuclear product when D is used is the intact nucleus of helium-4 (He^4) that is measured as the gas. In other words, the conditions needed to trigger the fusion process, the resulting reaction rates, and nuclear product are entirely different between hot and cold fusion. These facts strongly support the conclusion that these two fusion reactions result from two entirely different and unrelated mechanisms with the electrons playing entirely different roles.

The understanding of cold fusion has been further complicated by the inability to agree on an effective explanation. This paper will attempt to clarify this confusion by describing a combination of simple and well-understood chemical processes that precede the spontaneous nuclear process. Nature is not creating this chemical environment in order to produce a nuclear reaction; instead, the nuclear reaction occurs simply because certain conditions just happen to enable a nuclear interaction at rare locations within the structure. The process cannot be initiated by a local concentration of energy because this would violate the Laws of Thermodynamics and cause chemical changes in the structure before nuclear interaction would result. The challenge is to identify and then create these conventional but rare conditions in large numbers.

The only mystery involves the nuclear process itself and the means by which it dissipates the resulting nuclear energy into the surrounding structure. Because the nuclear reaction is spontaneous after certain chemical conditions are created, knowledge about how the nuclear process works is not required to create a source of useful energy. Nevertheless, this knowledge is important because it reveals a new kind of nuclear-electron interaction with the advantage of producing useful energy without creating harmful nuclear products. A proposed description of the nuclear process is described in order to encourage a better replication and study of the mechanism.

2. Discussion

The cold fusion process can be described as the operation of three events. The first two are related to behaviors typical of a chemical process. The final event is related to the nuclear behavior. Each event is logically justified based on only the observed behavior. Neither part violates any rule of chemistry or physics although new rules may operate.

The three events consist of:

1. *Creation of a special location in a solid material, in which cold fusion can occur, called the nuclear active environment (NAE).* Cold fusion cannot happen at any other location. The total number of NAE creates an upper limit to the total amount of fusion power produced by the material being studied. Large local concentrations can even cause local melting [6]. A large concentration throughout a structure can cause self-heating and eventual melting of the entire material [7].
2. *Transport of hydrogen fuel to these unique sites by diffusion from its normal location in the surrounding crystal structure.* The mechanism of transport involves common and well-understood processes. The rate of fuel transport controls the amount of power produced by a material containing a fixed number of NAE [8].
3. *Operation of a nuclear fusion reaction that occurs spontaneously and nearly instantaneously by a universal mechanism operating in the NAE regardless of the material, treatment, or hydrogen isotope.* Triggering is not required although other processes can increase the rate. If very high energy is applied, such as in the form of gamma rays, the cold fusion mechanism would not be the result. The lasers presently used do not have enough energy to initiate the hot fusion mechanism [9]–[11].

2.1. Event 1

The NAE consists of physical gaps or voids in the arrangement of atoms in a solid. These flaws are independent of the crystallographic structure and are very common in all materials. The only requirement is a critically small size, which is rarely formed. These gaps are not caused by or related to atom vacancies in the crystal structure. They can be created many different ways including by nano machining or nano etching, as described in the next section.

To state the obvious, this kind of flaw is a common and accepted part of all materials without the need to demonstrate its existence. Because they are created by random chance with a variable size, the number of suitable flaws is variable and rarely formed in significant numbers, thus accounting for the difficulty to cause the cold fusion process. The only mystery is how the gap can change the rules that govern electron interactions so as to reduce the Coulomb barrier between the fuel nuclei without affecting or conflicting with the chemical behavior. Remember, the fusion process takes place in a chemical environment to which the Laws of Thermodynamics apply. The amount of local energy available to any process operating on the atomic scale is limited to a fraction of an eV because a greater energy would interact with and destroy the chemical bonds holding the structure together before it reached a level required to cause nuclear interaction.

Figure 2 shows a cartoon describing the crystal arrangement and the proposed irregular conditions surrounding the NAE. The normal arrangement of the palladium (Pd) and hydrogen atoms is illustrated by the first cartoon. In this arrangement, large spheres represent the electrons surrounding the Pd nucleus, while smaller spheres indicate the possible positions of the hydrogen atoms. The electrons in this configuration are fully committed to forming a fcc structure and hence are not available to offset the Coulomb barrier between hydrogen atoms. In addition, the hydrogen nuclei are too far apart for their nuclear energy states to interact by a process that would not also affect the chemical properties. Therefore, a different electron and atom arrangement is necessary to achieve this goal. Nevertheless, this structure is the source of the fuel to the sites where fusion occurs. This means that for fusion to occur, the hydrogen nuclei must move from their normal locations to find and enter the NAE located some distance away, thus the role of the diffusion process.

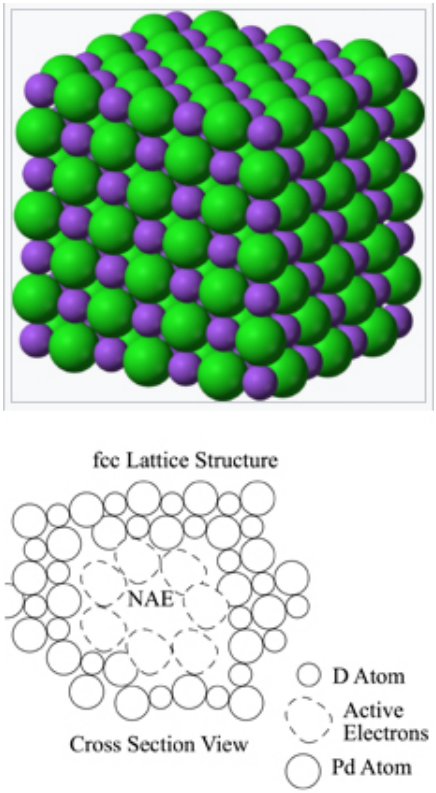

Figure 2. Cartoons showing the normal atom arrangement in a face centered cubic (fcc) structure (from Wikipedia) and the chaotic atom arrangement forming an idealized NAE. The NAE is a three-dimensional structure surrounded on all sides by electrons, some of which can support nuclear fusion when hydrogen nuclei (D, H, or T) enter the NAE [12].

The NAE can be described as an arrangement of the atom positions that create a gap surrounded by electrons so disorganized and chaotic that some of them are available to interact in unexpected ways with any hydrogen nuclei present in the NAE. The active electrons have energy states that do not involve the energy states of electrons normally associated with the Pd nucleus. These disorganized electrons are represented as the dashed circles in Fig. 2. When the region identified as the NAE is occupied by two hydrogen nuclei (D, H, or T), the uncommitted electrons can reduce the Coulomb barrier and facilitate fusion, which is described in a later section identified as EVENT 3.

The NAE structure can form in any solid material. The challenge is to find the most efficient method for its creation.

How can the NAE be formed within a material?

Examples of a few materials found to cause cold fusion are listed in Table 1. Although each material has been treated in different ways, the same active structure can be identified as being present as the NAE.

The challenge is to identify the common feature present in all these materials needed to support a fusion process. This goal is important because the ability to support fusion is frequently explained in several conflicting ways. Here the assumption is made that Nature would have only a single environment in which such an unusual and rare mechanism

Table 1. Processes that can increase the formation of the NAE The proposed location of the NAE in the material is identified.

1. Codeposit (CoD) of a metal (surface)
– Szpak [13]: Slow electrolytic deposit of Pd from $PdCl_2$ + LiCl or HCl in D_2O or H_2O.
2. Sintering of small particles (bulk)
– Arata [14]: Palladium black
3. Imbedded inert particles in Pd (bulk)
– Storms [15]: Particles of CaO or SiO_2 < 36 micron
4. Creation of porous material (bulk)
– Takahashi [16]: Oxidized Pd+Zr and other alloys
– Case [17], [18]: Charcoal + Pd particles
– Mizuno [19]: Stress induced gaps in Ni or Pd
– Imam et al. [20], [21]: Stress induced gaps in Pd-B alloy
– Iwamura et al. [22], [23] Stress induced gaps between layers of CaO and Pd
– Biberian et al. [24] Hydrotalcites precursors
5. Accidental formation (surface)
Damage caused by low-voltage gas discharge [25], [26]
Damage caused by super wave [27]
Damage caused by extended electrolysis
Damage caused by ultra sound [28], [29]
Damage caused by mechanically created cavitations [30]
6. Nano-machining (surface)

could occur. To this end, each item in Table 1 is discussed below in sequence to identify the location of the NAE and how this condition can be created on purpose.

1. The so-called CoD method uses a very small electrolytic current to deposit a very porous and poorly bonded collection of particles on the surface of the cathode. Although the method is a reliable source of fusion power, the resulting small amount of power is suitable only for research. The nanosized pores in the particles are proposed to be the NAE.
2. When small particles of Pd sinter into a solid mass, small gaps form throughout the bulk material where the particles did not have the correct crystal alignment required to form a uniform structure. These gaps can have a size required to support fusion when the initial particles are sufficiently small. Any method that involves very small particles will form such gaps, which eliminates the surface of the particles as the unique nuclear active location.
3. When small particles of an inert material, such as CaO or SiO_2, are present in Pd, gaps will form around the particles when the metal expands as it reacts with hydrogen. The gap can have the required size when the particle is sufficiently small. This process is proposed to explain the success Fleischmann and Pons had when using Pd supplied by Johnson Matthey plc. In this case, the small particles of CaO are proposed to result from the method used to reduce the dissolved oxygen content in the Pd melt.
4. Porous material having a random collection of flaws with a suitable small size can be created many different ways. One method of special note is the use of coconut charcoal to which small particles of Pd have been added. Being made from a natural product, the charcoal contains many different structures with flaws of many different sizes. Ordinary charcoal containing the same type of Pd particles was not found to be nuclear active,

Table 2. Processes that can increase the rate at which the fuel can reach the NAE.

1. Increased temperature [8], [24]
2. Electromigration and the Gorsky Effect (Gorsky Effect) [33]– [35] + magnetic field
3. Laser radiation [9], [36]
4. Gross diffusion caused by a concentration or pressure gradient [37], [38]
5. Concentration of fuel in the lattice (D(H)/Pd ratio) when the concentration of NAE is large at low temperatures [39], [40].

thereby eliminating the Pd as the site of the NAE. Apparently in this case, the Pd is needed only to split the surrounding D_2 gas molecule to make D ions available to the NAE in the charcoal. The unique impurities in the natural charcoal probably created the required small gaps.
Stress between two materials that expand by different amounts can create the required NAE structure. In this case, the differential expansion results when the material reacts with hydrogen [31].

5. Various treatments can produce surface damage containing some NAE [30], [32]. These methods tend to be unreliable because they are very sensitive to the controlling variables and experience repeated destruction and creation at uncontrolled rates. Nevertheless, the various processes have supported many useful studies.
6. Gaps of suitable size can be created in a surface region by methods available to the integrated circuit industry. This approach could be used to make the NAE in large numbers with reproducibility.

These examples support the conclusion that the universal NAE can be produced many different ways in many different materials. The only challenge is to create it in high concentration with reliability. The material and methods need to be considered only with this goal in mind. The most effective method would be their creation by nanomachining. This method would allow a high concentration of NAE to be manufactured in any material, with very little material being required, thereby removing the justification of using a cheaper metal less effective than palladium.

2.2. Event 2

After some NAE has formed, the fuel located in the lattice structure or in the surrounding gas must move to the NAE by a conventional process, with a successful encounter being controlled by random chance. Processes known to increase the ability of hydrogen to move in a structure are summarized in Table 2.

The expected ability of increased temperature to enhance the fusion rate was recognized by Fleischmann and Pons [41] and others [42]–[44], but this effect was not properly exploited at the time. Consequently, most studies that were intended to demonstrate the fusion process were conducted at room temperature, which rarely allowed for a detectable fusion rate, given the low sensitivity of the calorimeters being used at the time. For example, notice in Figure 3 that no excess power is detected at room temperature during this study, yet power is clearly produced when the temperature is increased. This behavior has been frequently observed. Ironically, the many failures that were used to reject the claim for cold fusion might have been reduced if the temperature had been increased. Storms [8] demonstrated that the effect of temperature on fusion power is related to the normal diffusion process, as both processes share similar activation energy.

Applying a voltage, along with the resulting current, can increase the diffusion rate of ions through a lattice structure. This phenomenon was termed the “Coehn effect” by Fleischmann [35] when deuterium (D) was caused to move to the negative region when a voltage was applied to PdD. When observed in other materials, it is known as electromigration. The integrated circuit industry has studied this mechanism because it impacts on the longevity of computer circuits.

The effects of temperature and electromigration were explored using a sample of palladium (Pd) that was activated by a deposit of CoD palladium. This sample was placed in deuterium (D_2) gas, which could be heated while a direct

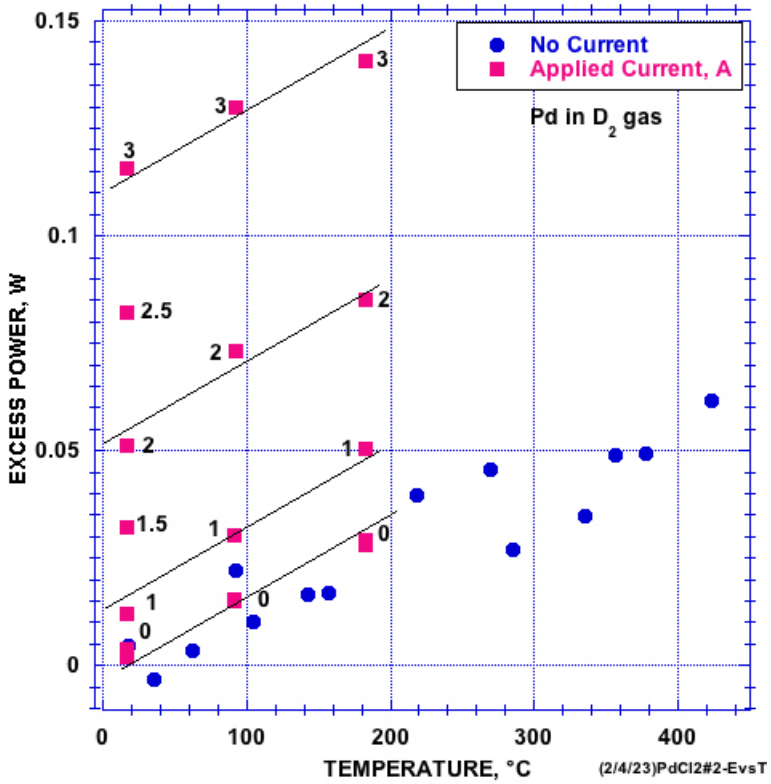

Figure 3. Effect of applied current is shown in units of ampere(A). The values for "no current" were obtained first followed by the values designated as "applied current". The current at a constant temperature was measured and then the temperature was increased and held for 100 min until the temperature became constant.

current (DC) was passed through its length. The D_2 pressure created a D/Pd ratio of approximately 0.7 at room temperature, with a reduction in the D/Pd ratio as the temperature is increased. Measurements were taken while both the applied current and temperature were varied. Each data point, shown in Fig. 3, was obtained after maintaining constant conditions for 100 minutes, allowing the Seebeck calorimeter [45], [46] to reach a steady state.

The temperature effect was studied first, after which a current was applied while measuring the resulting excess energy. The power added to the calorimeter by the current was measured and subtracted from the measured power. However, the added power was trivial due to the PdD having a very small resistance of 0.026 ohm.

It is notable that the applied current produced a significantly greater increase in the fusion rate compared to the increase caused by temperature alone, as expected. When the amount of excess power is plotted as a function of current at room temperature, the results shown in Fig. 4 exhibit consistent behavior that can be fit by a quadratic equation. This behavior was independent of time and remained unchanged even when the current direction was reversed, indicating that the effect was not caused by the increased concentration of deuterium at the cathode, which involves a very slow change in D concentration. The good fit to a quadratic equation suggests the amount of power applied by the current might be measured incorrectly. This possibility needs to be explored by future studies.

The ability of D+ ions to locate and occupy a NAE site also can be enhanced by a flux of D resulting from a concentration gradient or a pressure difference across the thickness of a material because the resulting flux would cause the fuel to encounter the NAE with greater probability.

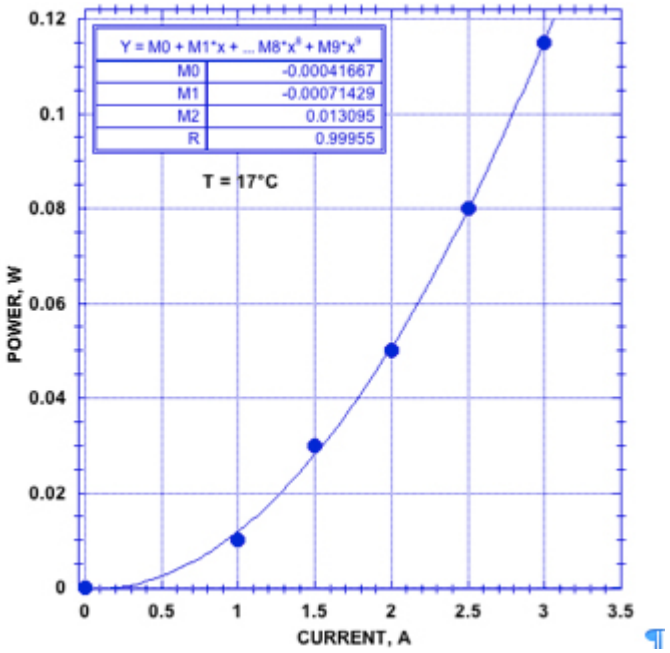

Figure 4. Excess power as a function of applied current at 17°C. Notice that no power is detected in the absence of applied current at 17° C.

The application of laser radiation will also increase the reaction rate, possibly due to a local increase in temperature or enhanced diffusion caused by phonon activity. Other, unknown processes might operate.

Additionally, the application of a magnetic field is expected to improve the efficiency of ion diffusion, as the ions are guided along a more complex path created by the lines of magnetic force, thereby increasing the probability of encountering the NAE.

Many researchers believe a large concentration of the fuel in the lattice structure is required to achieve a useful rate of fusion. Apparently, a high concentration is only effective when the concentration of NAE is large at low temperatures. When the concentration is small, the fuel concentration has very little effect. A previous paper shows the effect of the D/Pd ratio with greater clarity [47].

In summary, the amount of power generated by a material can be increased and controlled using demonstrated methods that align with established chemical behavior. These methods are all consistent with an increased ability for the fuel to move from its normal location to find and then enter the special site that supports the fusion process. The most effective method is electromigration, which causes an immediate change in the amount of fusion power. This rapid response would allow for effective fast control to match the load change on an industrial energy generator.

2.3. Event 3

The true mystery of cold fusion involves the nature of the fusion process itself. Nevertheless, nothing about this mechanism needs to be known to design an effective source of energy because the nuclear process happens spontaneously after the fuel has assembled in the NAE. Therefore, a useful generator of power only requires the NAE to be created with a high concentration in a suitable material.

For the sake of a complete discussion, the proposed nuclear mechanism is summarized in Table 3.

Table 3. Summary of the proposed events occurring during the fusion process.

1. The Coulomb barrier is overcome by a concentrated assembly of electrons in the NAE without kinetic energy being applied.
2. When deuterons fuse, the mass energy is emitted as energetic ^{4}H ion radiation and energetic electrons. Helium is the final nuclear product when ^{4}H decays by beta emission. Neutrons are not emitted. Deuterium results as the nuclear product when H+H fuse. Tritium results as the nuclear product when H+D fuse. Neutrons and helium result when D+T fuse. These products result because an electron is captured in the nuclear product before the mass-energy is released as kinetic energy. The energy required to add the extra electron is supplied by the energy released by the fusion reaction.
3. The momentum is conserved during each nuclear product emission by the emission of many electrons in suitable directions.
4. The process is spontaneous in the required environment identified as the NAE.
5. Secondary nuclear reactions with energetic emission, including neutrons, are produced by local hot fusion and transmutation reactions. These result when the energetic emission created by cold fusion encounters a stationary nucleus within the lattice.
These events are described in more detail by Storms [48] and in a future paper.

These events cause ^{4}He gas and heat energy to be detected when deuterium is used. The measurements are summarized in Figure 5 as a histogram showing values of He/energy from seventeen measurements by four separate studies using electrolysis at 20° C. Notice that these values combine to show a variation typically produced by random errors as shown by the good fit by the Gaussian equation. It's important to realize that this ratio involves two independent measurements that could have resulted in a very large spread in the values as the consequence of random errors, yet it does not.

When the average is compared to the amount of He/energy calculated using $E=mc^2$, with m being the mass change, about 50% of the expected helium seems to be missing. This missing helium appears be trapped within the Pd metal because when efforts are made to remove this gas, the total amount of helium collected is very close to the expected value. The measured heat-energy could be too large as the result of any transmutation reactions that would result from the fusion reaction. Some energy might also be missing as an antineutrino is emitted by the proposed beta decay of ^{4}H. The ratio plotted in Fig. 5 needs to be studied with greater precision for the process to be fully understood.

One additional value was obtained from a sample of coconut charcoal containing small particles of Pd that was heated in D_2 at about 250° C [49]. This value agrees very well with the values (Fig. 5) obtained using electrolysis, demonstrating that electrolysis is not required to cause the fusion reaction.

Notice that when two D's combine to form helium, no nucleons are left over. Therefore, the observed neutron radiation cannot result from this reaction.

A Serious Problem

Now we come to the true mystery of the process. Apparently, only one nuclear product is emitted. Consequently, momentum cannot be conserved when nuclear energy is released into the environment as kinetic energy of the nuclear product. This problem can be better understood by considering that all nuclear reactions require the emission of two different masses in opposite directions with equal momentum along with the energy resulting from the nuclear process. This requirement is as important to nuclear processes as the Law of Thermodynamics is to chemistry.

The apparent failure of cold fusion to comply with the conservation of momentum has led people to propose new mechanisms never before observed in Nature [51]. Some people suggest that cold fusion is actually a variation of hot fusion that occurs at low energy. In this scenario, momentum is conserved by the fragmentation of the helium nucleus, as illustrated in Figure 1. The apparent detection of helium gas, summarized in Figure 5, is even seen by some as an artifact resulting from poor measurements. Others propose that the detected helium gas is real, and that energy is communicated to the surrounding material through phonon interactions, resonance processes, or other unique mechanisms. At one time, I proposed the slow serial emission of photons [48] as a mechanism to avoid

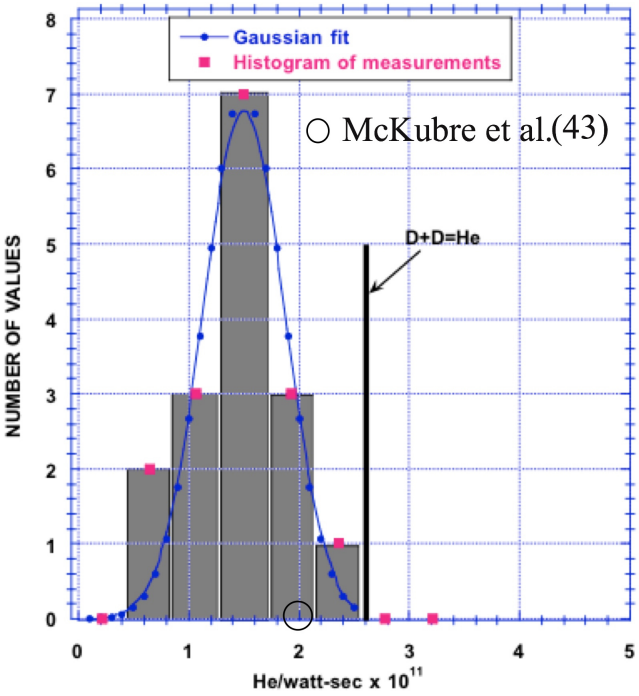

Figure 5. Histogram of measured He/energy values compared to the ratio obtained using the mass change when the fusion reaction D+D=He occurs [50] [48]. The vertical line represents 23.85 MeV/He.

the conundrum. These conflicting explanations have created confusion and uncertainty within the field, delaying the practical application of this mechanism as a source of useful energy.

This model proposes that momentum is conserved and energy is communicated to the surrounding material by the emission of electrons along with the nuclear product. This process is illustrated using the cartoon shown in Figure 6. The logic begins with the fact that the Coulomb barrier between two nuclei must be reduced to allow their nuclear energy states to interact, which is a basic requirement of any fusion process. This reduction is proposed to occur in the NAE, where electrons are available to facilitate this interaction. These electrons are represented by the green structure at the top of the figure. They are not associated in a conventional way with the nuclei of the Pd atoms. Their presence causes the two nuclei, represented as red circles, to move closer together. Eventually, they come close enough for their nuclear energy states to interact by means of the strong force. Since electrons are involved in this process, they are available to become part of the newly combined nuclear energy state, as shown by the purple structure. This structure embodies the true mystery of the process.

However, this combined structure contains a large amount of excess energy that must be released for the stable nuclear product to form. Because the structure contains many electrons, these electrons are emitted in opposite directions, thereby conserving momentum and releasing kinetic energy equal to the mass change into the surrounding material as heat energy. One electron is proposed to remain in the emitted nuclear product. The electron emission can take different paths as summarized by the last three reactions. These paths are discussed in the following section.

What evidence supports this description? The first evidence for energetic electron emission was provided by Gordon and Whitehouse [52], [53]. They called this process a Lattice Energy Converter (LEC) and proposed it as a source of useful electrical energy. Several replications followed [54].

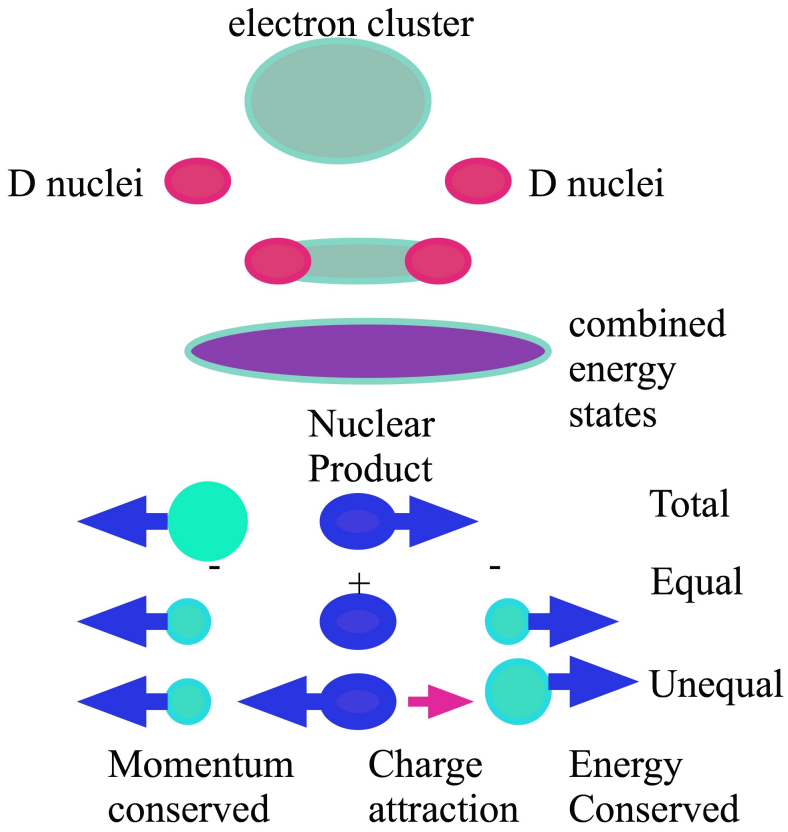

Figure 6. Cartoons showing the sequence of events occurring during the cold fusion process. The final cartoons show three possible ways the energy can be dissipated into the surrounding structure by the emission of the nuclear product and electrons.

A measurement of electron emission done by the author is described next. The sample is palladium (Pd) coated with palladium using the CoD method (see Table 1). This was exposed to deuterium gas (D_2) at a pressure that would place the PdD in the two-phase region (α+β) at room temperature. The current was measured without an external voltage applied between the Pd emitter and the platinum (Pt) collector. Figure 7 shows the effect of temperature on both the excess power, measured using a Seebeck calorimeter, and the emitted current, which was measured as a voltage across a resistor connected between the emitter and collector. Both the fusion power and the emitted current increase as the temperature is increased, suggesting a common source. However, the reason for the rapid increase in current at temperatures above 350° C is unknown.

The number of electrons emitted by each fusion reaction was calculated. This value is obtained using the measured amount of power to calculate the fusion rate at 298° C. The collected current is obtained from Fig. 8 without voltage being applied. The resulting value of electron/fusion is doubled because at least ½ of the electrons would to be emitted away from the collector. The resulting value of 30 electrons/fusion would be a lower limit for the actual value, as some electrons would be stopped before reaching the collection electrode. This value supports the proposed emission of electrons as the carriers of momentum and nuclear energy.

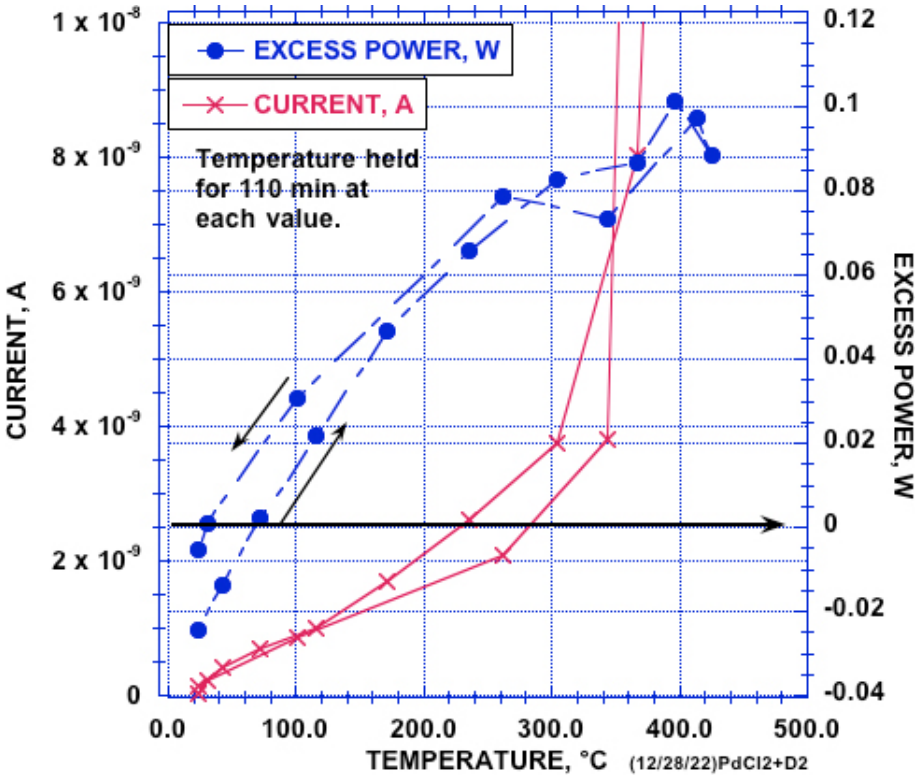

Figure 7. Comparison between excess power and electron emission current from α-PdD + β-PdD in D_2 as a function of temperature.

Next, a voltage was applied between the collector and emitter. When this voltage was positive (Fig. 8), all electrons with energy less than the applied voltage would be returned to the emitter, resulting in a reduction of the measured current. The figure shows that the emitted electrons had a range of energies exceeding 100 eV. This energy level is too high to have resulted from a chemical process or from differences in work function. It is proposed that this energy reflects what remains after the electrons emitted from the fusion reaction have passed through the palladium on their way to the surface of the sample. Notice that the excess power increased as electrons were returned to the surface by the applied voltage.

Even more interesting, the amount of emitted current was sensitive to how long the voltage was applied (Fig. 9). This effect is especially obvious after a steady value of 100 eV was applied. This enhancement of the emitted current and, presumably, the fusion rate is proposed to result from electromigration, which was increased in the surface due to an additional returned electron current in that region. Clearly, these behaviors warrant further exploration, as they reveal important information about the process.

In addition to the emission of electrons, the emitted nuclear product exhibits very unusual behavior. Figure 10 shows the energy distribution of the detected emissions produced by gas discharge in D_2 gas using Pd as the cathode, as reported in extensive studies conducted by Karabut et al. in Russia [55]. A replication of this experiment was performed by Storms and Scanlan (SS) [56] using a modern silicon barrier detector (SBD), which resulted in the spectrum shown in Figure 11. These two studies produce similar behavior when compared in Figure 12, demonstrating

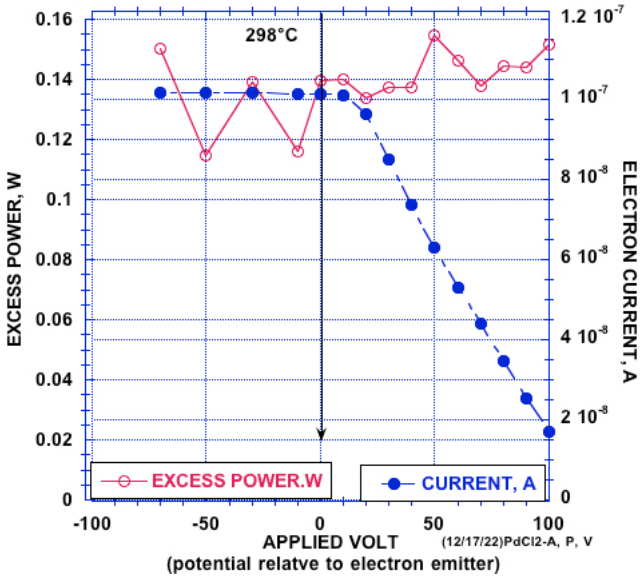

Figure 8. Effect of a voltage applied between the emitter and collector on the electron current at 298° C emitted from α+β PdD in D_2 gas. The excess power is also shown.

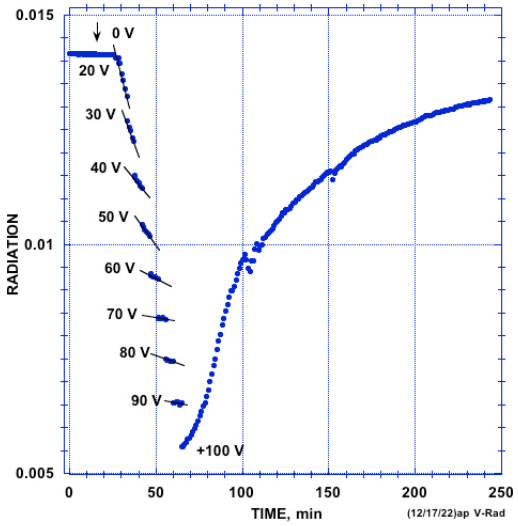

Figure 9. Effect of time on the measured current shown in Fig. 8, plotted as arbitrary units identified as Radiation. The voltages applied between the emitter and the collector for each measurement shown in Fig. 8 are identified.

agreement not only in values but also in the slope as a function of the sequence number. In addition, both data sets extrapolate to near zero energy at point #0. The small difference between the two results can be attributed to the emitted ions having to travel through different amounts of material before reaching the respective SBD.

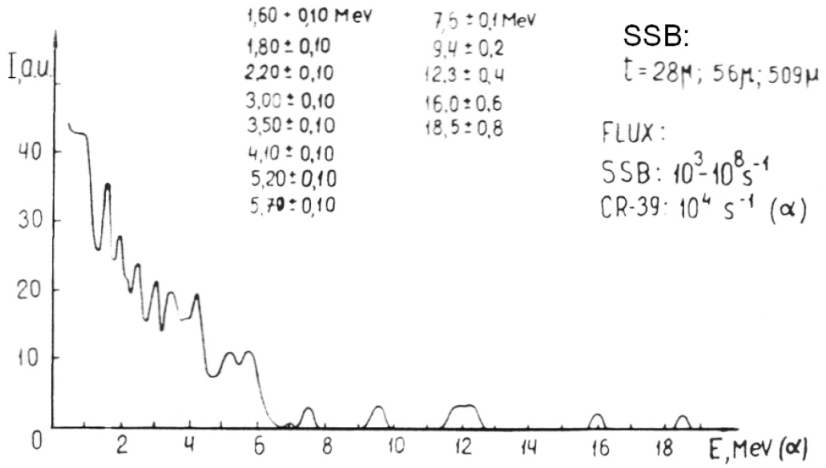

Figure 10. Energy measured using a silicon barrier detector for ions emitted from Pd by gas discharge in D_2 [55] KK.

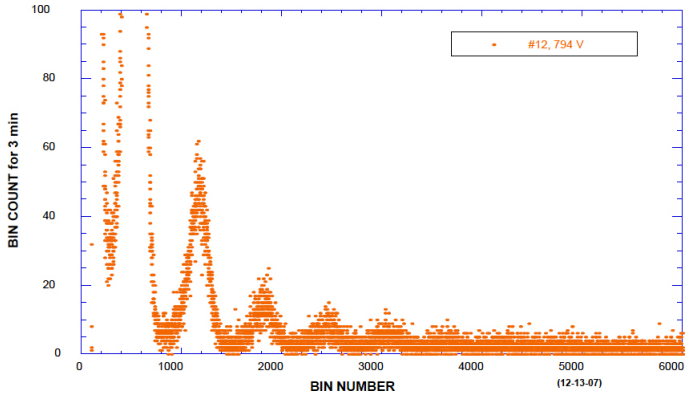

Figure 11. Energy measured using a silicon barrier detector for ions emitted from Pd by gas discharge in D_2 + H_2 [56] SS.

The proposed explanation predicts that the same kind of emission with the same energy characteristics would result from cold fusion occurring in any material containing deuterium, not just Pd. In addition, because fusion between H+H+e is proposed to produce deuterium, this nuclear product is predicted to fuse with another D to produce this emission behavior even in the absence of D_2 in the gas, although at a lower rate. These predictions need to be tested.

The study by SS also revealed that the emission had characteristics of an isotope of hydrogen rather than helium when it passed through absorbers of various thicknesses. This observation provides further support for ^{4}H being emitted. The energy of 0.76 MeV required to form the extra neutron in the ^{4}H nucleus is subtracted from the fusion energy. This subtracted energy is eventually added to the measured heat energy when the ^{4}H decays to form ^{4}He by beta decay. Of course, some of this energy would be lost as the result of antineutrino emission, which would shift the measured He/energy plotted in Fig. 5 to slightly larger values. This possibility adds importance to measuring the He in both the gas and the PdD.

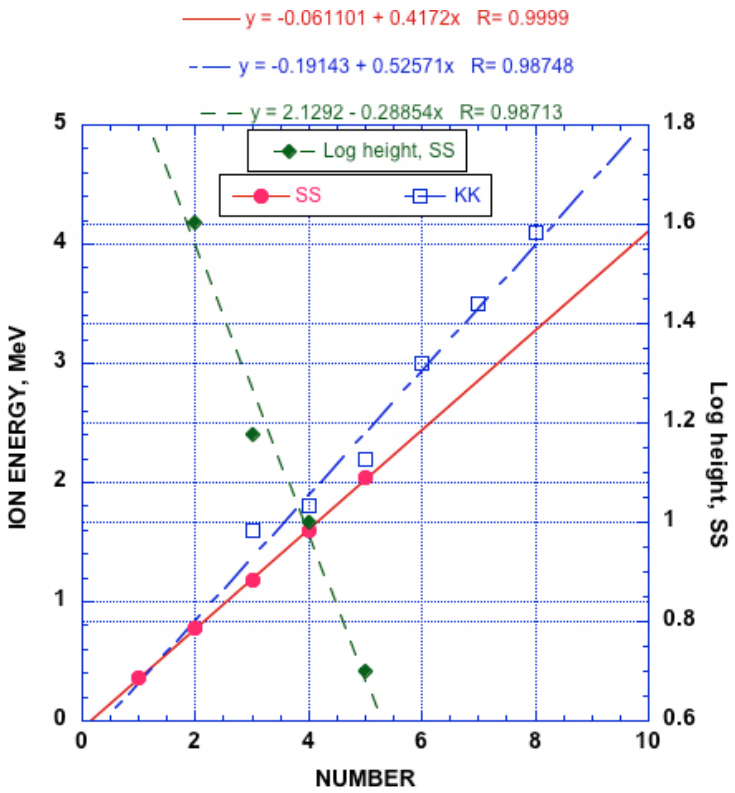

Figure 12. Comparison between the data sets in Figures 10 and 11. The log ion intensity is obtained from the data in Fig. 11. The first value in Fig. 10 is assumed to be point #3 in the sequence with the previous values being hidden in the noise.

It's important to note that the only way for the energy of an emitted particle to change is for its velocity to change. The regular change in the emitted energy of ^{4}H indicates that the square of its velocity changes in equal steps, with an increased velocity leading to a decreased probability of emission. The challenge is to understand the mechanism that causes this behavior. Perhaps it's more than coincidence that the energy difference between each adjacent peak is nearly equal to the mass-energy of an electron.

This information allows for a logical explanation that combines the observed behavior of the emitted electrons with the measured energy of the nuclear product. The lower part of Figure 6 describes this process as a cartoon. Several possible behaviors can be suggested. The nuclear product and electrons can each be emitted in opposite directions, ensuring that the momentum of the many electrons equals the momentum of the nuclear product when the total combined energy of both emissions equals the required 23.85 MeV/He. The consequence of this behavior was examined in a previous paper [57]. While the behavior of the electrons can be calculated using this description, the series of emitted energies exhibited by the nuclear product remains unexplained.

Instead, an equal number of electrons can be emitted in opposite directions so that the electrons alone conserve momentum and carry all of the kinetic energy. Under these conditions, the nuclear product would remain stationary, increasing the likelihood of it being trapped in the material. Extrapolation of the log intensity to point #0 (Fig. 12) shows that about 50% of the fusion products would be expected to have no kinetic energy.

Table 4. Summary of the storms model.

1. A special condition called the nuclear active environment (NAE), consisting of a void having a special small size, must be formed in large numbers by suitable treatments. (Table 1)
2. The material must be exposed to an isotope of hydrogen, preferably deuterium as the fuel.
3. The fuel must be caused to move more rapidly from its normal locations in the material and assemble in the NAE. (Table 2)
4. The Coulomb barrier is reduced by a large local assembly of electrons in the NAE. (Table 3)
5. The fusion of D results in the formation of ^{4}H that decays to ^{4}He by beta emission.
6. The nuclear energy is dissipated into the surrounding material by the emission of energetic electrons among with the ^{4}H, which rapidly decays by beta emission to form ^{4}He.
7. Neutron emission and transmutation occur as secondary reactions as a result of the energetic fusion products encountering a stationary nucleus in the surrounding structure.
WARNING:
1. The NAE is expected to have a limited lifetime as the NAE becomes saturated with the nuclear products.
2. The use of H_2 is not recommended because it is expected to produce tritium while making much less energy/fusion reaction compared to D, which does not make tritium.

These several possibilities are too complex to explain here. Consequently, further understanding will have to await future studies. For the present, the process can be seen as complex with several process operating to satisfy the conditions required to dissipate the nuclear energy.

3. Future Plans

Future plans should focus on creating the NAE with increased reliability. The methods identified in Table 1 provide examples of how this might be accomplished. As the method to make NAE is mastered, the treatments listed in Table 2 can be used to control the amount of power generated as heat energy. Proper design then can be used to harvest enough electrical energy from the emitted electrons to make useful electrical power directly, as envisioned by Gordon and Whitehouse. This model provides a clear path to accomplish these goals.

4. Summary

Table 4 provides a summary of the events that lead to fusion.

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