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Research Article

Cold Fusion Explained

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Abstract

This paper summarizes the experimental behavior on which the claim for cold fusion is based and provides a general description of how the proposed process works. New experimental results involving electron emission from the surface and the effect of applied electron current are also described. The nuclear process starts as the result of an unusual chemical condition during which many electrons and a few hydrogen nuclei can assemble at unique locations in a physical structure where they experience nuclear fusion. Although the proposed mechanism is not described in mathematical detail, significant features are identified and used as a model to guide future studies. This information is important because the fusion process promises to be a source of clean and inexhaustible energy and reveals a new kind of mechanism that can cause a variety of nuclear interactions.
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Keywords: cold fusion, LENR, CMNS, gap, nuclear mechanism, electron structure

1. INTRODUCTION

Thirty-five years ago, two professors from the University of Utah, Profs. Martin Fleischmann and Stanley Pons announced their discovery of a new kind of fusion [1]. The discovery promised to make a new source of pollution-free, inexpensive, and unending energy available, with water as the source of the nuclear fuel. People everywhere responded with enthusiasm when they recognized the promised benefit. However, the scientific influencers then discovered reasons to reject the claim because they could not replicate the behavior even after others were successful.

Furthermore, rejection was further justified because the behavior seemed impossible to explain using conventional understanding. The potential economic threat to conventional energy sources fueled the rejection. The response became so intense that Prof. Pons had to immigrate to France with his family, who continued to live as French citizens. As a citizen of the UK, Prof. Fleischmann returned to his country. Later, they set up a laboratory in France, where they expanded their discovery with support from a Japanese company. Although the work continued in other countries, it went underground in the US, where the work continued with support from private individuals who understood its importance.

Understanding the historical events is crucial as it lays the foundation for fully appreciating the present situation. To this end, Huizengakriv [2] provides the scientific reasons for the rejection, and Krivit [3] details how the rejection

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was executed. While this history may not hold scientific value, it has significantly influenced the investigation of the discovery and the prevailing beliefs about the claim even today. Therefore, it's important for the reader to acknowledge that the commonly held beliefs about the discovery may not be entirely accurate. This paper will succinctly summarize the current state of knowledge and provide an explanation for how the process might work.

The effect has been replicated hundreds of times in major laboratories and has been described in over a thousand papers. A peer-reviewed journal (https://jcmns.scholasticahq.com/) was created to allow the publication of papers that conventional journals would reject. The 38th volume is now available. Conferences have been held every few years in countries where studies are ongoing (https://en.wikipedia.org/wiki/International_Conference_on_Cold_Fusion). The 26th ICCF conference will be held in Japan in 2025. An Internet discussion group is available to debate various issues (LENR Forum, https://www.lenr-forum.com/forum/). Copies of the important papers can be obtained from an internet library (LENR-CANR.org). A website, Cold Fusion Now, provides a blog about the subject (https://coldfusionnow.org/blog/). The International Society of Condensed Matter Nuclear Science (https://iscmns.org/) guides the efforts. The discovery now has all the characteristics of an established field of science with easy access to an extensive library of information.

A skeptic might reasonably reject a single measurement or a collection of measurements after a common error has been identified. However, a collection of consistent behaviors made by many independent studies, as is the case here, is the kind of fundamental evidence on which all scientific ideas are judged. Various treatments are now known to affect the process in ways that eliminate error or any prosaic process as the reason for the behavior. Indeed, all of the requirements demanded by the skeptics and by general science have been met. The challenge now is to discover how the process works, which is the goal of this paper. This goal is accomplished by considering the full range of observed behaviors to which a single mechanism is applied regardless of the hydrogen isotope involved in the fusion process or the method used to initiate the reaction. The paper also includes suggestions as to how the proposed explanation can be tested and applied to produce useful power.

2. Observed Behaviors

Fusion can occur in a material through two different mechanisms. The first mechanism is called hot fusion because energy is applied. The second mechanism is called cold fusion because extra energy is not applied. Both mechanisms produce energy, but they involve different mechanisms, which results in different nuclear products.

2.1. Hot Fusion

In the case of hot fusion, the Coulomb barrier is overcome by using the kinetic energy of the nuclei as they encounter each other, usually in very hot plasma. The same nuclear reaction takes place in a material when it is bombarded by ions having kinetic energy, with the resulting nuclear product fragmenting by two different paths, as shown in Fig. 1. The paths have nearly equal probability even at the lowest applied energy. At the same time, the electrons present in the material add local screening that increases the very low fusion rate at the low applied energies. Nagel describes this process in detail [4].

Figure 2 compares the fusion rate in plasma to that produced when screening occurs in a material. When the effect of electron screening alone is plotted in Fig. 3, the graph gives the impression that the reaction probability is being increased to produce perhaps a valuable amount of energy, especially at a lower applied energy. This is not the case because the increase in electron screening does not offset the rapid reduction in fusion rate caused by the reduction in applied energy. At best, this behavior only shows that electron screening is possible in a chemical structure. However, this kind of screening does not apply to the cold fusion process because the mechanism is different. Hot fusion results from a chance encounter between nuclei and any electrons that happen to be located at the random site. In contrast,

$$^{2}H + {}^{2}H \rightarrow \begin{cases} {}^{3}H + p & E_p \sim 3.6\ MeV \quad E_t \sim 1.2\ MeV \\ {}^{3}He + n & E_n \sim 2.4\ MeV \quad E_\tau \sim 0.8\ MeV \\ {}^{4}He + \gamma & E_\gamma \sim 24\ MeV \end{cases}$$

Figure 1. The energy of the emissions resulting from hot fusion between deuterons as provided by Czerski [5] The emission of ^{4}He with a gamma ray has a very low probability and is never found to occur during cold fusion.

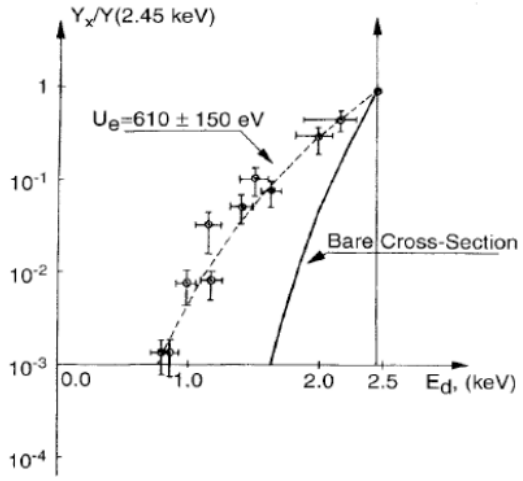

Figure 2. The result of the D+ bombardment of Ti with the indicated kinetic energy is compared to that produced by 2.45 KeV. The calculated rate obtained from the behavior in plasma is also shown as Bare Cross-Section [6]. A calculated value for the screening potential (U_e) is shown. The absolute fusion rate at this energy is near the detection limit, to which electron screening adds very little.

cold fusion requires the accumulation of nuclides and many electrons at the same site, a process that takes considerable time to occur, as described below.

2.2. Cold Fusion

Because fusion can occur without extra energy being applied, the designation “cold” is used. But immediately, we have several significant problems. First, the atoms of D in a material are too far apart to allow them to fuse. Without applied energy, a conventional mechanism would not bring them closer. Second, as shown below, the intact He^4 nucleus is produced rather than the fragments shown in Fig. 1. This creates a problem because the production of a single nuclear product would not allow the conservation of momentum when only this one nuclear product is emitted with the resulting nuclear energy. Third, the dissipation of a large amount of energy (23.85 MeV/He) would be expected to produce energetic radiation that should be detected outside the apparatus. This radiation is largely missing. These problems were used to justify the initial rejection. What has changed to cause the claim to be accepted? This paper will attempt to answer these questions, and its findings could have significant implications for our understanding of nuclear physics and energy production.

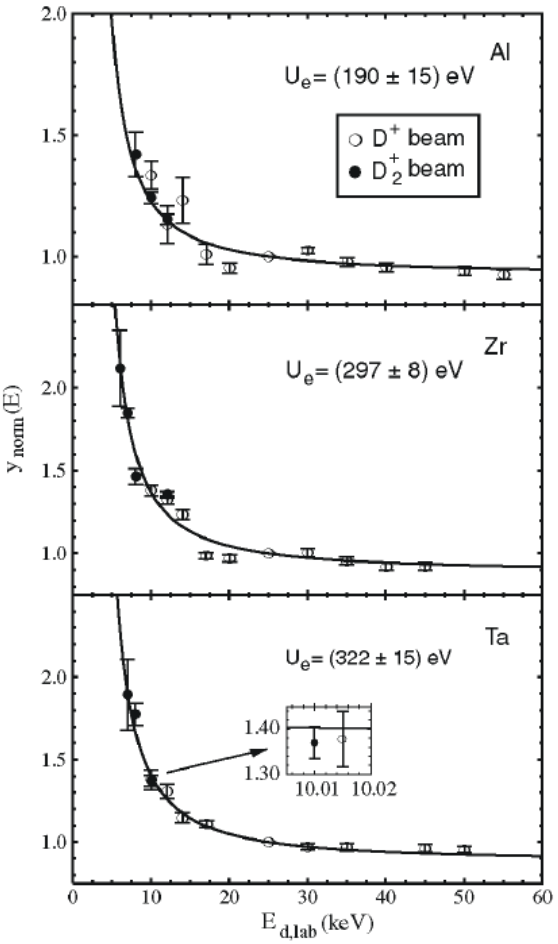

Figure 3. The fractional increase in the fusion rate that is caused by electron screening is compared to the rate produced in plasma as a function of applied energy. A value of 1.0 represents the absence of electron shielding. The value at the lowest measured applied energy is limited by the ability to detect the very small emission rate of nuclear products. The values of U_e represent the amount of electron shielding [5].

3. Energy Production

Unexpected heating power more significant than any plausible conventional source is the most often observed behavior. Although the amount of measured energy is small, because very small samples are studied, the amount of power per gm of material can, on rare occasions, be as large as that produced by the fuel in a fission reactor.

Figure 4 [3] shows a small example of successful energy-making efforts using electrolysis. The number of reported values is compared to the amount of power produced at room temperature by PdD samples having a similar small mass. Notice that most samples make a small amount of power, with only a few making significant power. Most samples of PdD make no detectable excess energy at all. This behavior reveals an uncontrolled operation of a rare condition that needs to be identified, which will be done later in the paper.

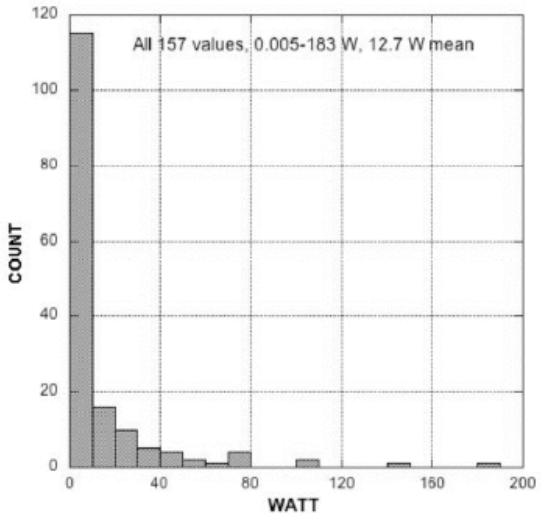

Figure 4. Histogram showing the number of reported values for the measured power at room temperature produced by similar samples containing PdD and exposed to electrolysis. Values are taken from Table 2, "The Science of Low Energy Nuclear Reaction" [7] published in 2007.

Even though this figure compares only a very small fraction of the total number of successful reports now available, this typical behavior continues to be observed. Now, as of 2025, over 500 papers have reported excess energy production from many different samples during which a similar behavior is observed, with more examples being reported as the method is mastered. We are no longer dealing with rare and difficult-to-cause behavior.

The shape of the histogram in Fig. 4 suggests a probability function could be used to describe the ability to produce the conditions required to support the fusion process. In another way, the shape suggests that no success is the most probable event, with a small amount of power being much more probable than a larger amount. Thus, chance enters the picture by determining how many proposed unique sites will form in a particular sample in which fusion can take place. The challenge is to increase the probability of forming the required site, thereby increasing the amount of nuclear power. We can be encouraged by a few samples from which a significant amount of power is produced. This increasing success suggests that effective methods are available to increase the power, as they are being gradually discovered and applied.

The power is not produced uniformly throughout the material but only at certain locations. Szpak et al. [8], [9] observed this behavior by photographing an active surface using an IR camera. The bright spots in Fig. 5 show where the location was hotter than the surrounding material. These sites were found to wink off and on as the D fuel was slowly replaced after being converted to the nuclear product.

4. Material Issues

It's crucial to note that most materials won't support the fusion reaction, regardless of treatment. However, when the material preparation is meticulously done, cold fusion can be reliably achieved. This is not limited to palladium, as many other materials can also be engineered to support the fusion process. This growing success provides compelling

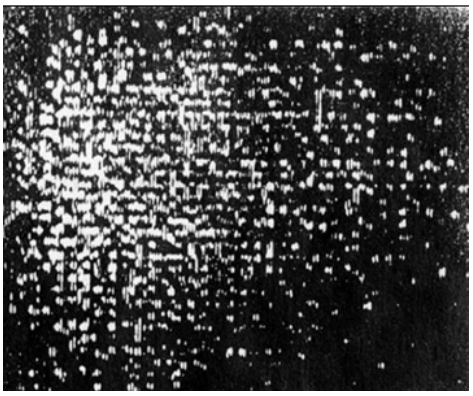

Figure 5. Picture of an active surface of Pd containing D taken using an IR camera as heat energy is produced [8].

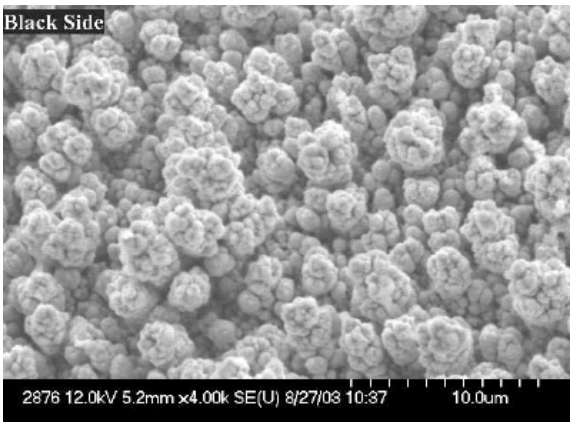

Figure 6. An example of a morphology that supports nuclear fusion. This deposit is made by electroplating Pd from $PdCl_2$+LiCl in D_2O [10].

evidence for the reality of the proposed fusion. The key challenge lies in consistently creating the active region in large concentration. This question will be further explored in the paper.

Figure 6 serves as an example of the intricate structure produced by a material frequently found to be nuclear active. This complexity is not always visible, especially when it occurs deep within the structure. It's important to understand that other types of active material can be expected to be equally complex.

The quest to identify the nuclear active environment (NAE) has led to various suggestions, including the role of nanoparticles, metal atom vacancies, grain boundaries, defects, or physical gaps. Identifying the correct NAE is crucial for designing a practical power source. This task is made more complex by the need to understand and apply both chemical properties and nuclear effects. While the fusion process can be produced for scientific study, especially when the material is heated, the rates are not yet practical for energy production.

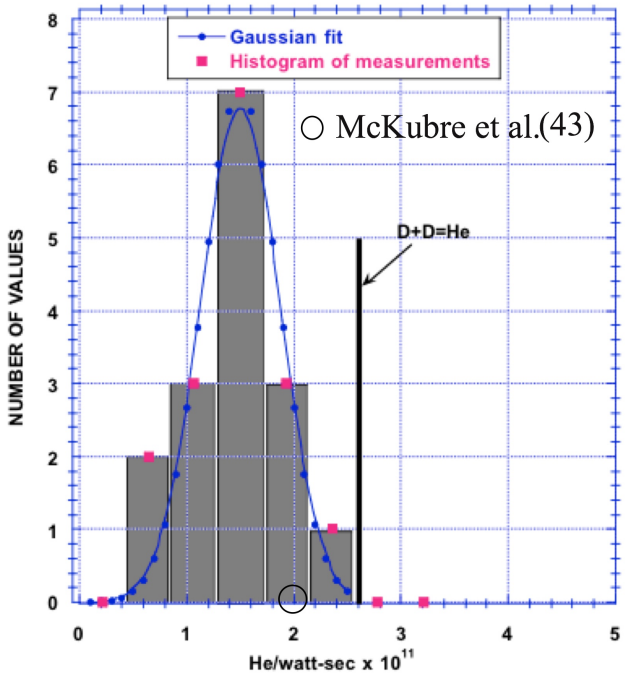

Figure 7. Histogram of 16 measurements by four independent studies showing the amount of helium divided by the amount of energy produced by electrochemical cells containing D_2O. A Gaussian error function is fit to the distribution of values. The ratio based on the mass change for the fusion reaction D+D=^{4}He is shown. The value obtained by McKubre et al. [11] resulted from a sample of charcoal on which a small amount of Pd was deposited. This sample was heated in D_2 gas near 243°C.

5. Nuclear Products

Nuclear reactions can be understood by identifying the resulting nuclear products and the energetic radiation as the nuclear energy is dissipated into the surrounding material. People have looked for and found these features to be part of the cold fusion process, as described below.

5.1. Helium

The expected ^{4}He was sought and found. Figure 7 compares the He/energy ratio for 17 measurements obtained by five independent studies. The collection shows a typical error distribution that can be compared to the ratio that is expected based on the mass change when helium forms by fusion of deuterium. This comparison shows that the average value for this ratio is consistent with about 50% of the produced He being missing and assumed to be in the PdD. But again, we have a problem because, based on direct measurements, helium produced in Pd cannot escape from the PdD under the conditions used during these studies.

The rate at which helium can diffuse out of palladium containing an isotope of hydrogen was measured in a controlled laboratory setting. Pd was reacted with tritium gas, after which the tritium was allowed to decay to produce increasing amounts of ^{3}He within the PdT structure. The rate at which the ^{3}He was found to leave the solid structure

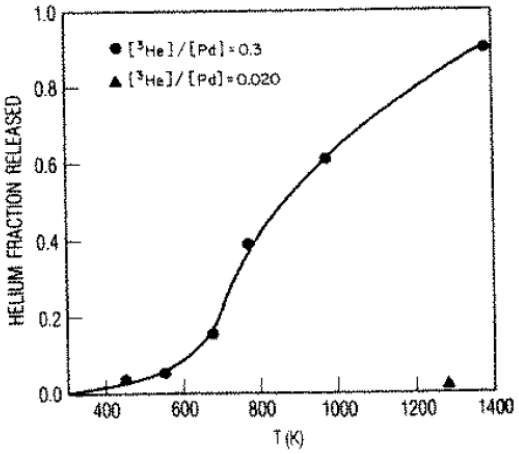

Figure 8. Fraction of helium released from PdT as a function of temperature for two different He/Pd ratios. From Abell et al. [12].

was then plotted as a function of applied temperature in Fig. 8 for two different He/Pd ratios. It's important to note that no He was extracted at 300K, indicating a threshold temperature for helium extraction.

Even the use of higher temperatures would not cause removal of the helium when the ratio was as low as 0.02. The average concentration of helium during a typical ^{4}He measurement shown in Fig. 7 would be near 10^{-11} He/Pd and the temperature would be near 300K. The claimed role of grain boundary diffusion during the studies of ^{4}He production, as is suggested as justification for the helium being able to diffuse out of the PdD, would apply equally to the slow loss of ^{3}He from PdT. Consequently, we would have no reason to expect any helium to be collected during the studies shown in Fig. 7, yet helium was collected. This contradiction is thoroughly examined later in the paper, providing a comprehensive understanding of the phenomenon.

5.2. Tritium

Tritium is also observed as a nuclear product, but not when the D is known to be free of H. Because the role of H contamination was not anticipated, and hence was not studied, this conclusion has to be based on the expected H contamination produced by how well the D was protected from being contaminated by H_2O in the environment during each study. For example, Bockris et al. had repeated success in making tritium presumably because their cells became contaminated with a measured amount of H_2O. After all, this contamination was expected because the cell was not sealed. An example is shown in Fig. 9 [13]–[15]. Tritium has been produced with improved success over the following years with hundreds of claims now being available.

Claytor et al. [16] produced tritium during the electric discharge of a gas containing different D/H ratios, as shown in Fig. 10. Success in producing tritium was improved when a small amount of D was present in the D_2+H_2 gas [17], [18].

On occasion, the T/n ratio was measured, as shown in Fig. 11. Although neutrons are correlated with tritium production, the amount is much smaller than when they are produced by hot fusion. This difference indicates that the tritium does not result from the hot fusion mechanism.

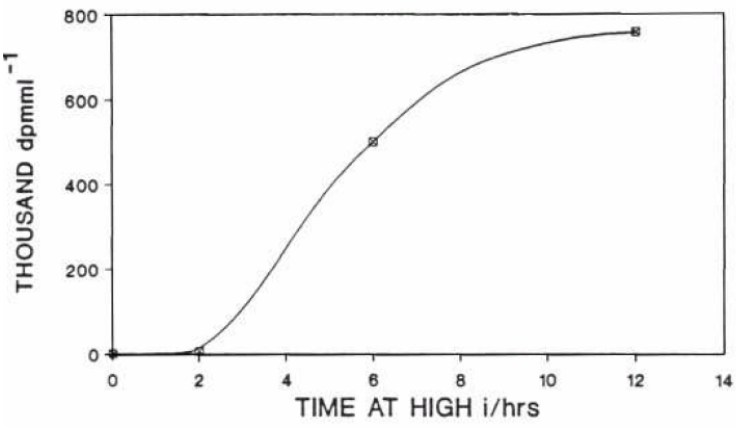

Figure 9. Example of tritium being made by the electrolysis of D_2O containing some H_2O. The designation "HIGH I" means a high current was applied to the electrolytic cell. The term $dpml^{-1}$ is the amount of the decay radiation measured during 1 min when emitted from 1 ml of liquid. The typical background radiation from D_2O is near 20 dpm/ml.

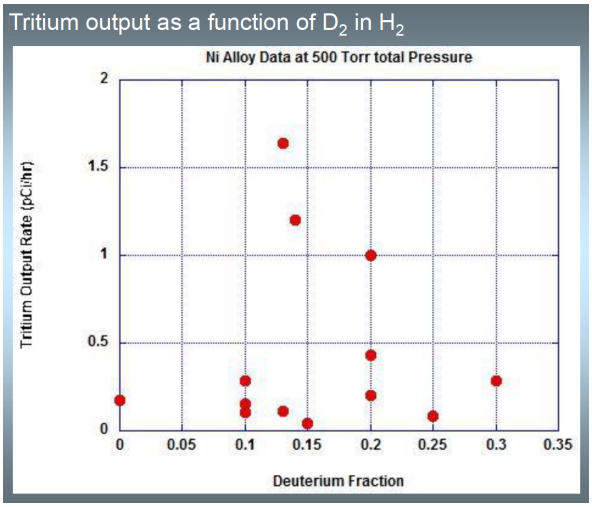

Figure 10. Effect of the fraction of D_2 in H_2 on the rate of tritium formation using low voltage gas discharge.

6. Radiation

Radiation produced by a nuclear event can reveal much information about the mechanism. However, this aspect of the fusion process is very complex because many different kinds of radiation result from several different sources, with only a tiny fraction of the radiation being able to leave the apparatus and be detected because it has too little energy to escape through the surrounding material. Although the different types are related, each is discussed separately.

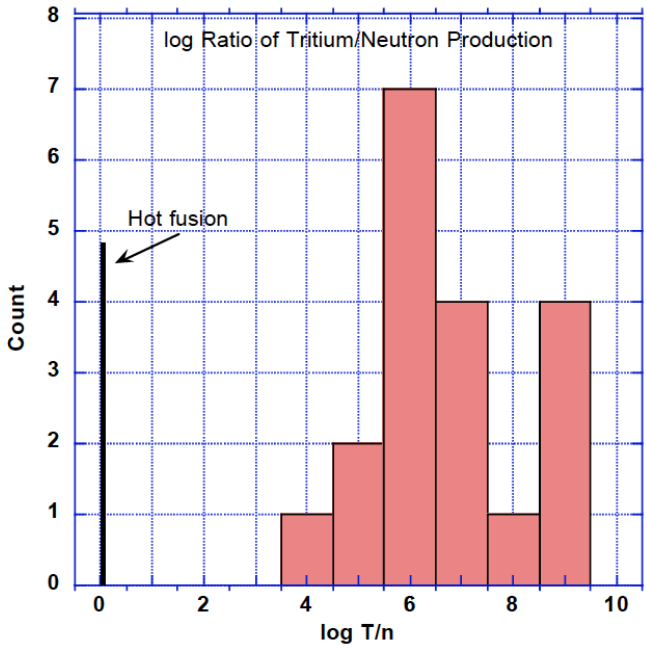

Figure 11. Histogram of published measurements of the log tritium/neutron ratio. The measured log T/n resulting from hot fusion is also plotted. The values are from Table 6 in "The Science of Low Energy Nuclear Reaction" [7].

6.1. Ions

The nuclear fusion product is always emitted as ions with significant kinetic energy. Because ions have a minimal range in a material, they cannot be detected outside of the apparatus. Consequently, the silicon barrier detector (SBD) is an effective tool for detecting ions and measuring their energy within the apparatus.

Karabut et al [19] (KK) measured the ion spectrum inside the apparatus when gas discharge occurred in D_2. An SBD was used to determine the ion energy, and the presence of energetic ions was confirmed using CR-39 plastic, on which the ions formed surface pits. [20] The energy spectrum consists of many separate peaks with nearly equal separation, as plotted in Fig. 12. Most energy is in the range between 1 MeV and 6 MeV, with a change in behavior at a greater energy. The log of the relative intensity of each peak shows a linear relationship to the energy, as shown in Fig. 13.

Occasionally, this radiation continued even after the gas discharge was turned off, revealing a sustained fusion process. Therefore, the apparent emission did not result from electrical "noise" produced by the discharge. They assumed this radiation resulted from alpha emission because ^{4}He was detected in the Pd cathode after the study. Some tritium and a small neutron flux were also detected in the gas during the discharge.

Eight years later, Storms and Scanlan [21] (SS) measured the ion spectrum over a smaller range of energy (Fig. 14), again produced by low-voltage gas discharge while using a silicon barrier detector. This time, absorbers were inserted between the source and the detector to reveal the true nature of the ions and to demonstrate that they were not the result of "noise" created by the electric discharge. Pulses caused by electronic noise would not be changed by the insertion of such thin absorbers. They also reported that both D_2 or H_2 produced very similar spectra and determined the nature of

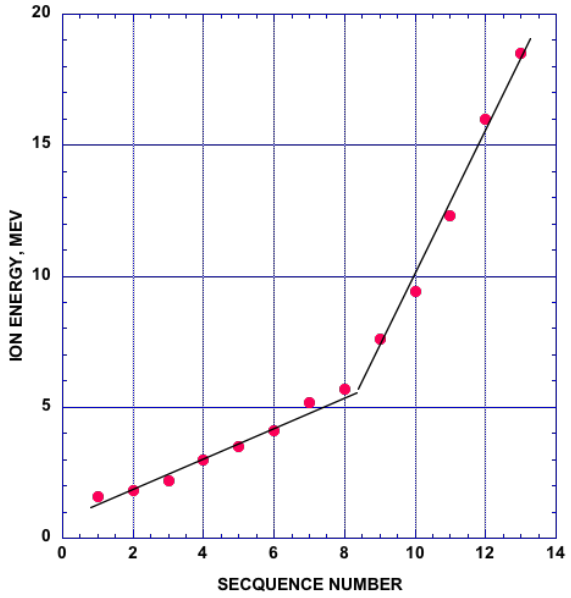

Figure 12. Ion energy vs number in sequence reported by KK.

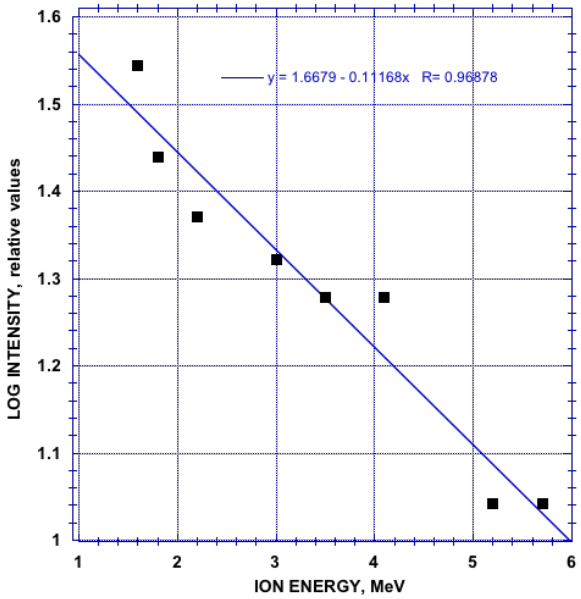

Figure 13. Log of the relative intensity of ion emission vs energy reported by KK for energy below 6 MeV.

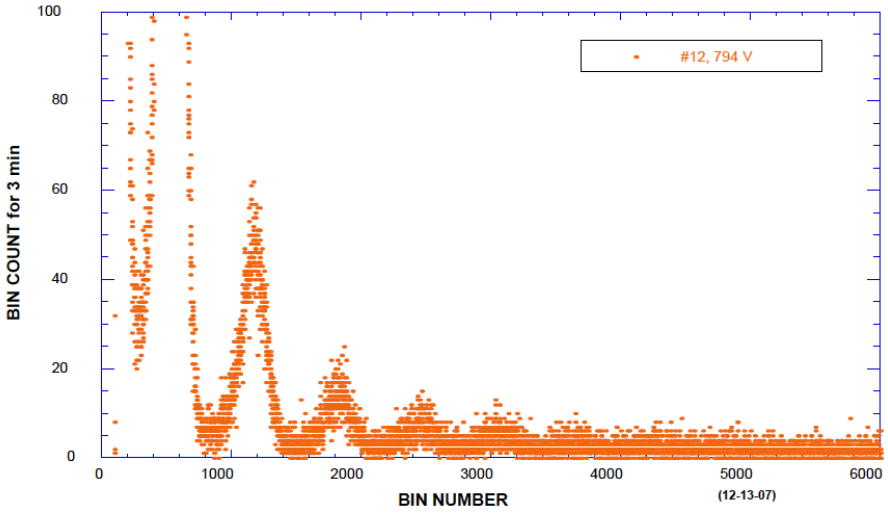

Figure 14. A typical spectrum is produced during gas discharge when either H_2 or D_2 is used. The bin number was calibrated using the alpha emitted from Po^{210}. The counts at BIN number less than 200 are caused by "noise" created by the electrical discharge (MeV=0.000657 *BIN).

the ions by measuring 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. The emissions were shown to be consistent with the ions of a hydrogen isotope, not helium! However, at the time the work was done, the emission of ^{4}H, which is consistent with the observed behavior, was not considered.

As shown in Fig 15, these two independent studies show the same basic behavior. This basic agreement is important, with the small difference being explained by the ions detected by KK and SS having a different amount of measured energy because they had passed through a different amount of material. Nevertheless, both studies show a series of peaks having a range of energy, with nearly the same amount of energy separation between each peak. KK found this constant separation to be larger (0.617 MeV) than the value reported by SS (0.417 MeV) perhaps because the ions measured by KK experienced less energy loss as a result of passing through less material. This behavior is not typical of a conventional nuclear process. The mystery is deepened by the ion energy having no clear relationship to the total amount of energy released by the fusion reaction (23.85 MeV/^{4}He). An explanation is suggested in a later section.

The intensity of each peak also shows a regular relationship in both studies when plotted as log intensity vs energy (Fig. 16), with the difference in slope being consistent with the ions measured by SS having passed through a greater amount of material.

The very similar behavior of both H_2 and D_2 reported by SS is a surprise. This behavior suggests that the same nuclear product can result from both reactants. However, this behavior does not eliminate other nuclear products from being produced simultaneously. These other emissions would be undetected if their energy did not fall within the range of the SBD. An explanation is explored in a later section.

Ion emission from electrolytic cells has also been studied by many people [22]–[24] using CR-39 to detect their presence and energy. The resulting spots produced in the CR-39 plastic were believed to be caused by ^{4}He emission. However, given the studies of KK and SS, these spots could instead have resulted from ^{4}H emission with a wide range

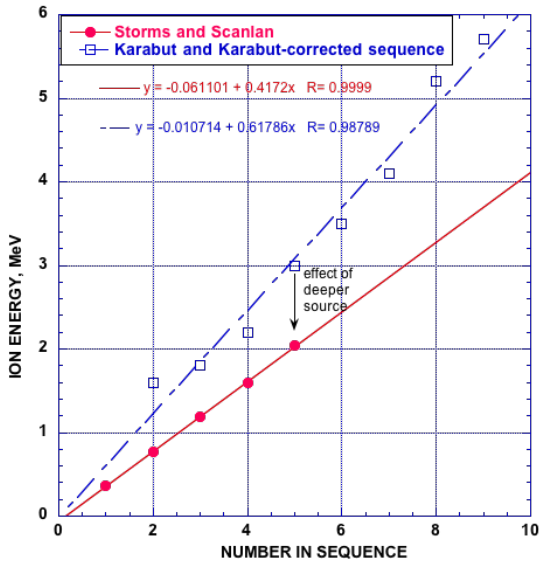

Figure 15. The relationship between the sequence in the spectrum and the ion energy. The values are obtained from Figs. 12 and 14. The arrow shows the effect on the measured energy caused by passage through an absorbing material. The sequence number for the KK values is changed because the first peak in their series was not identified by KK. The extrapolation to near zero shows that all peaks in each series have been identified.

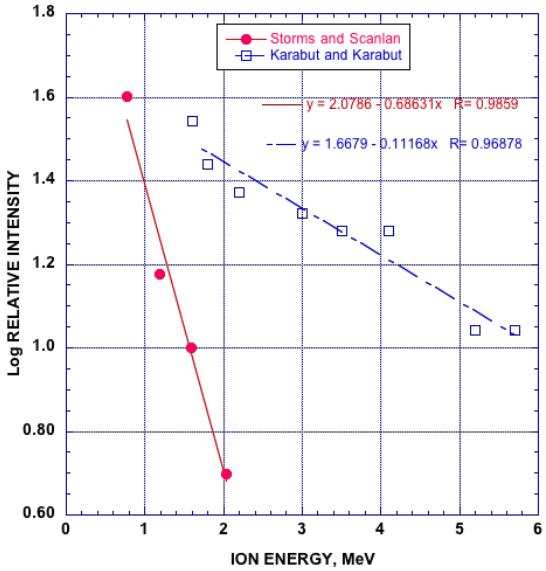

Figure 16. The relationship between log intensity and ion energy. Because the intensity is based on a relative value, only the difference in slope is significant. The values for SS are obtained from Fig. 14.

of energy and intensity. This possibility, which challenges the existing understanding, necessitates a reevaluation of these studies.

The emitted ^{4}H ions have sufficient energy to cause transmutation and hot fusion reactions, from which unexpected radiation might result. This possibility is discussed later in the paper.

It is crucial to pause and delve deeper into this behavior because the implications are more significant than commonly perceived. When the deuterons fuse, 23.85 MeV/^{4}He is released, which must be dissipated while momentum is conserved. The emitted nuclear product has only a fraction of this energy, leading to the question: Where is the missing energy? The conservation of momentum necessitates the simultaneous emission of two particles, raising the question: Where is the other particle? The dissipation of energy as discrete energies separated by an equal amount is a unique behavior that demands attention. These implications, far from being trivial, add to the growing list of questions that an explanation must address. This paper provides partial answers to these significant implications.

6.2. Electrons

Electrons are normally emitted as decay products when a neutron changes into a proton within the nucleus. This process is called beta decay. Tritium is a beta emitter. In the case of cold fusion, electrons seem to play several different roles. The first role involves their effect when a current is passed through the material, thereby causing an increase in power production. The second role involves their observed emission when fusion is occurring. This behavior implies that electrons are emitted along with the observed ions, thereby carrying some nuclear energy and momentum. These implications can be tested.

Recently, Gordon and Whitehouse (G-W) [25] made a groundbreaking discovery. They measured a strong electron current being emitted from a deposit of Pd exposed to D_2 or from a deposit of Fe exposed to H_2. This emission is not the result of beta emission due to its lack of a half-life. Instead, a steady current of energetic electrons is emitted from a material known to produce cold fusion. This finding could be the final piece of the puzzle, leading to a new understanding of how nuclear energy is dissipated and how momentum is conserved during cold fusion.

To explore this possibility, the relationship between electron emission and heat production was studied using an active material and a calorimeter described in a previous paper [26]. A piece of Pd was activated by applying a layer of Pd using the codeposition method [18] (CoD) in the manner used by G-W. A picture of a typical surface applied this way is shown in Fig. 6. This material was placed in D_2 gas with a surrounding Pt electrode used to collect the emitted electrons. This collector-emitter assembly is shown in Figure 17. This assembly is sealed inside a quartz cell that can be heated using resistance wire wrapped around its outside. The electron current passing between the electrodes is measured as a voltage created across a resistor having a value of 0.1 Mohm.

The material was heated in D_2 gas over a temperature range, as shown in Fig. 18. Excess power and electron current are both increased by increasing the temperature, suggesting a common cause.

These measurements are more complex than a simple analysis would suggest. For example, electrons can escape from the sample only when the fusion reaction occurs near its surface, while the heat energy can escape regardless of where it is produced. With many different chemical environments being present, the temperature could influence these locations differently. In addition, some currents could result when the emitted electrons create ions in the D_2 gas. Also, thermionic emission could add some current when the temperature is above a critical value. For the sake of the following study, the current measured at temperatures below 350° C is proposed to result only from those electrons emitted by a nuclear process that were able to leave the surface with an unknown amount of reduction in their original energy.

Next, an effort was made to determine the energy distribution of the emitted current. The measurement was made by applying a voltage between the sample and the collector while the cell was held at 298° C. The sample was given the indicated negative potential relative to the collector, as shown in Fig. 19. This potential would encourage all emitted

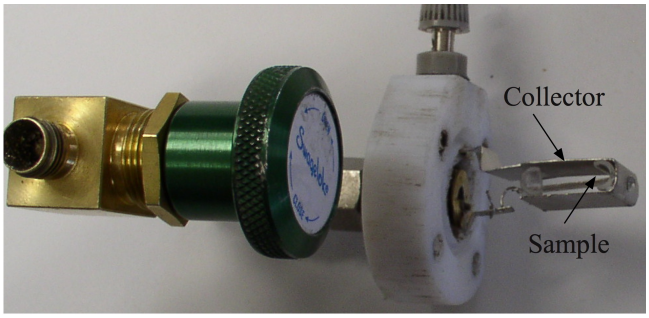

Figure 17. Photograph of the sample-collector assembly. The assembly is placed in a quartz glass cell that is heated by resistance wire wrapped around the outside. The internal temperature is measured using an RTD located near the sample. The cell can be evaluated and filled with D_2. The cell is placed in a Seebeck calorimeter that can measure the excess power with a random error of ± 0.005 W.

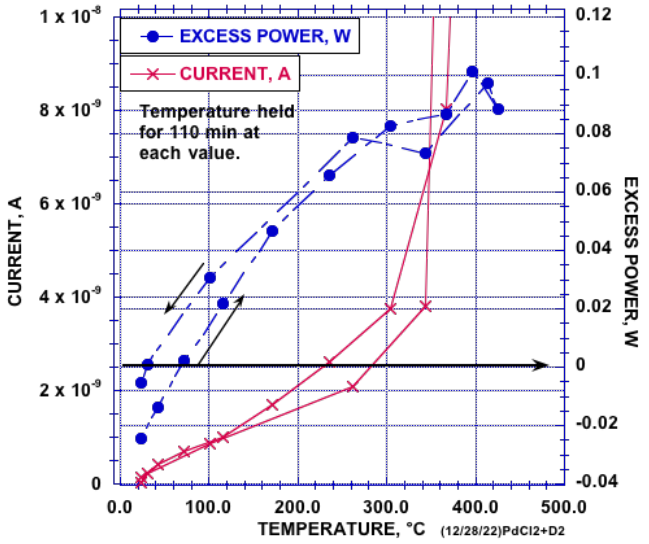

Figure 18. Excess power and emitted electron current are measured as a function of temperature when co-deposited Pd is heated in D_2 gas. An external potential was not applied between the two electrodes. The arrows indicate the sequence of the measurements. The excess power was measured before the current was measured. The current was then measured when the temperature was increased and then decreased. The temperature is measured inside the cell near the sample.

electrons, regardless of their energy, to leave the surface and be collected as a current that was measured as a voltage across a resistor in series with the source of the applied voltage. Any ions in the gas would add to this current with a value that would change as the potential became less negative. The lack of a change in current (Fig. 19) as the voltage is decreased to zero indicates that gas ionization is not a significant current source.

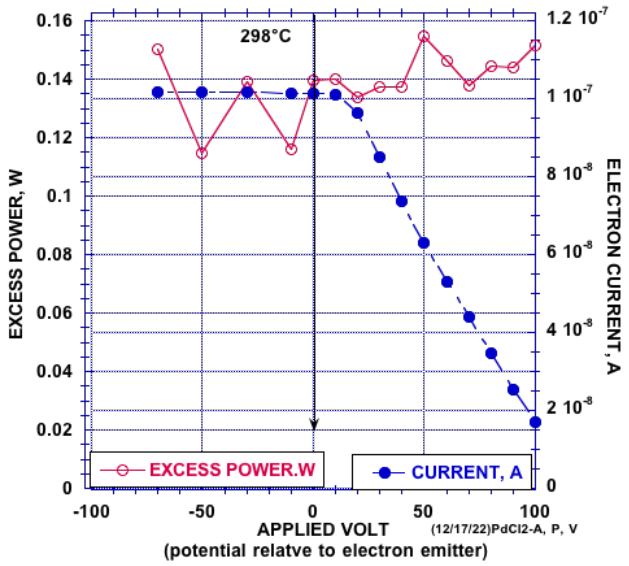

Figure 19. Electron current and the excess power at a temperature of 298° C when the voltage between the emitter and collector is changed. The potential is shown relative to the sample, thereby causing the electrons to be emitted with additional kinetic energy from the sample when the indicated voltage is negative.

On the other hand, when the sample voltage is positive relative to the collector, electrons would be returned to the sample when the applied potential is equal to or greater than their energy. The reduction in the emitted current (Fig. 19) as the sample voltage is made more positive reveals that the emitted electrons have a range of energy, most of which falls below 100 V. However, this energy may not be the actual energy of the electrons being emitted from the nuclear process itself because the collected electrons might have traveled through enough material to cause a reduction in their energy by an unknown amount. Later measurements show that the energy of the emitted electrons can occasionally exceed 100 V. This energy cannot result from a conventional source, such as a chemical reaction because chemical reactions generate electrons with only a few eV of energy.

In addition, the power reported by Gordon and Whitehouse [15] represents only the power dissipated when the current is passed through a load. This power does not represent the total power carried by the emitted electrons because most of their kinetic energy would have been dissipated as heat when stopped in the electron collector. So, we once again have a question to answer, "Why are so many energetic electrons produced with so much energy?"

Figure 20 shows how the current changes with time as the applied voltage increases. After each voltage increase, the current decreases at a rate that depends on the amount of applied voltage. When 100 V was applied continuously, the amount of emitted current rapidly increased with a corresponding slight increase in excess power. A similar increase might have happened after a smaller voltage had been applied if the voltage had been maintained for longer. This behavior reveals another unexpected clue that is discussed in a later section.

Based on the measured power combined with the expected He/energy ratio (Fig. 7), the maximum number of fusion events during this study is 3.9×10^{10} fusion/sec. The measured current shows that electrons manage to escape at a maximum rate of 6.2×10^{11} electrons/sec, which is the lower limit to the total number of electrons being released from the nuclear events. If we assume at least 1/2 of the emitted electrons cannot be measured because they are emitted

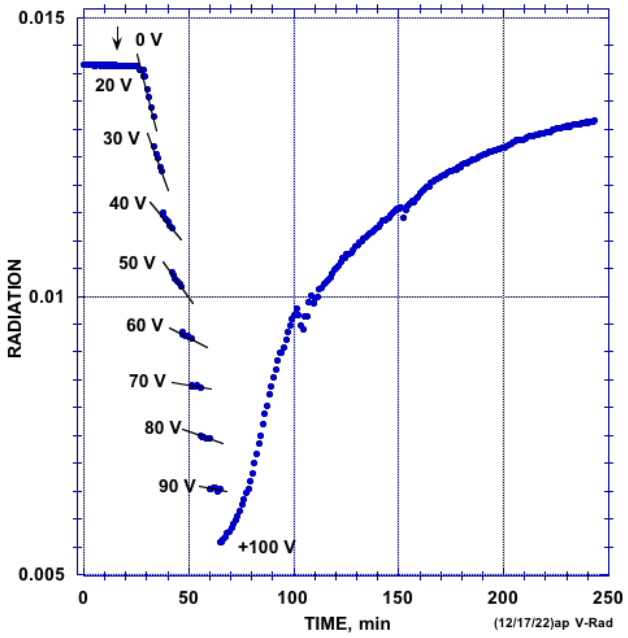

Figure 20. Effect of time on the voltage measured across a series resistor when the voltage across the cell is changed as shown in Fig. 19. The ordinate designated as radiation represents a relative value for the electron current.

toward the interior of the sample, the ratio of the (number of electrons)/(number of fusion events) is 32. This ratio is important because it shows that more electrons are emitted than the number of fusion events. If these electrons resulted from the fusion process, why are so many more emitted compared to the number of fusion events? An answer is provided below.

6.3. Photons

Karabut et al. used photographic film to record highly focused beams of photons being emitted from the cathode during gas discharge in D_2. In addition, they [27] measured the photon energy and found the radiation to have laser-like behavior with an energy consistent with a nuclear source as well as having energy typical of X-rays. Some of this radiation was even found to result from radioactive decay that occurred over many hours. Some of the implications of this behavior are discussed by Hagelstein [28].

The pattern of the photon emission was similar when either 0.5 mm of aluminum or 2 mm of lead were placed between the cathode and the photographic plate, an example of which is shown in Fig. 21. Apparently, photons having a wide range of energy are emitted as tightly focused beams in random directions with different intensities. More detail is provided by Karabut et al. [29] in another paper. The implication of this behavior is complex and important, as discussed in another section.

Szpak et al. [30] also used photographic film to detect photon radiation that appeared to be emitted from a single well-defined source, but in this case when an electrolytic cell was used. It's important to notice that photon radiation having a similar unusual behavior is produced when different conditions are used, suggesting a common mechanism.

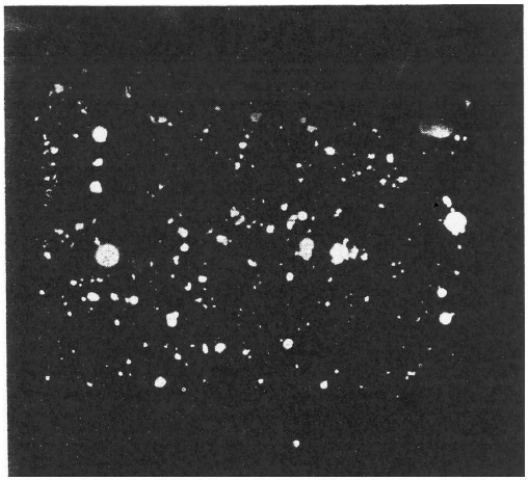

Figure 21. Spots are produced on photographic film by photons that pass through 0.5 mm of aluminum. A similar pattern is produced when 2 mm of Pb is used, which indicates the radiation has a wide range of energy.

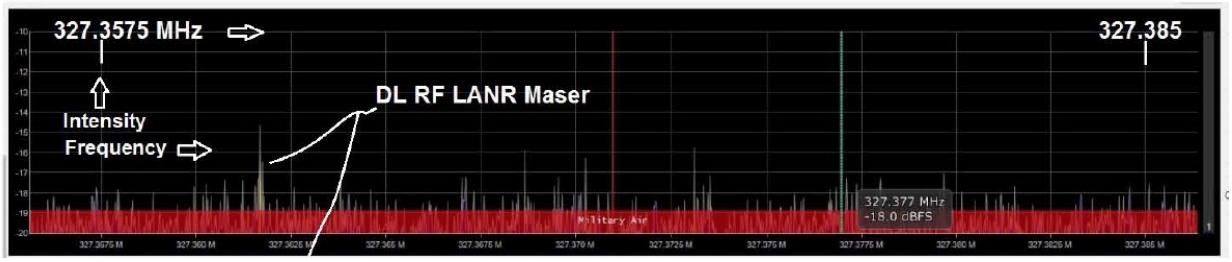

Figure 22. Emission of 327.37 MHz Hyperfine Maser-type radiation emitted when cold fusion occurs in PdD-ZrO_2 [31]

Because people would not expect to see highly focused beams of radiation to result from a nuclear process, methods able to detect such radiation have not been used by most previous studies, thereby missing this unusual behavior. This oversight is important because the unique behavior has the potential to reveal the mechanism by which the nuclear energy is released, as described next.

Optical photons are also emitted with laser-like characteristics. [27], [29] This behavior is not typical of a "normal" nuclear process.

6.4. RF Radiation

Swartz [31] reports detecting RF radiation having an energy near the D ionization line at 327.385 MHz with maser-like characteristics (Fig. 22). This radiation could result when the kinetic energy emitted from the fusion reaction is dissipated into the surrounding lattice structure from a coherent source.

Elements		Assumed Reactions
Cs	4d	$^{133}_{55}Cs \xrightarrow{4d(2\alpha)} {}^{141}_{59}\mathrm{Pr}$
Ba	6d	$^{138}_{56}Ba \xrightarrow{6d(3\alpha)} {}^{150}_{62}Sm$, $^{137}_{56}Ba \xrightarrow{6d(3\alpha)} {}^{149}_{62}Sm$
W	4d or 2d	$^{182}_{74}W \xrightarrow{4d(2\alpha)} {}^{190}_{78}Pt$? $^{186}_{74}W \xrightarrow{2d(\alpha)} {}^{190}_{76}Os$?

Figure 23. Examples of the fusion products being added to another nucleus [32].

6.5. Transmutation

Elements located in the material near the sites of the fusion reaction can experience changes in their nuclear structure as a result of fusion products being added or by the target nucleus being caused to fission into two parts.

Iwamura et al. [32] added various elements to the nuclear active region that were then found to have acquired different numbers of D nuclei in their nucleus after fusion involving deuterium had occurred, as summarized in Fig. 23. Presumably, the nuclear product resulting from one or more fusion reactions has sufficient energy to overcome the large Coulomb barrier and enter the target nucleus. Given that ^{4}H is assumed to be the initial energetic particle, how are the observed transmutation products produced? The answer to this question requires additional studies.

Miley et al. [33] carefully analyzed a material that had experienced the fusion process and observed the results shown in Fig 24. The regions designated C and D show the result of one or more fusion products being added to the target nucleus, in this case the target being either Pd or Pt, with the Pt being at a very low concentration in the material. Regions A and B reveal evidence for the fragmentation of the transmutation product. Many other people have reported seeing similar behavior, as explained by Storms [34].

From these few examples, you can see that the transmutation process is complex, with products that can result from the addition of one or more fusion products after which fission of the target nucleus can occur on occasion. Ongoing studies in many laboratories are finding additional complexity in the transmutation process. Radioactive decay of the transmuted product has been seen on occasion. Further implications are explored by Storms [34].

7. Changes in the Environment

The rate at which the nuclear products and radiation can be produced is determined by how rapidly the hydrogen nuclei and electrons can form the required assembly. This rate can be changed by those conditions that can affect the accessibility of the nuclei and electrons to the NAE. These conditions are found to include the temperature, the D/Pd ratio, a current passing through the material, a magnetic field, and the application of laser radiation.

7.1. Role of Temperature

Many studies have shown the effect of increased temperature. However, the temperature is too small to directly influence a nuclear reaction. Instead, the temperature affects a chemical process that limits the rate of the nuclear reaction. This realization has encouraged a search for this limiting process.

Most early studies were made at temperatures near 20°C even though F-P [35], [36] noted that the power could be increased by increasing the temperature. They correctly called this the “positive feedback effect”. Unfortunately, this description limited the understanding of how temperature affected the power.

As shown in Fig. 25 [26], temperature has the same effect when a measurement is made in either the electrolytic cell or in D_2 gas using the same sample. In addition, as can be seen when the current in the electrolytic cell is turned

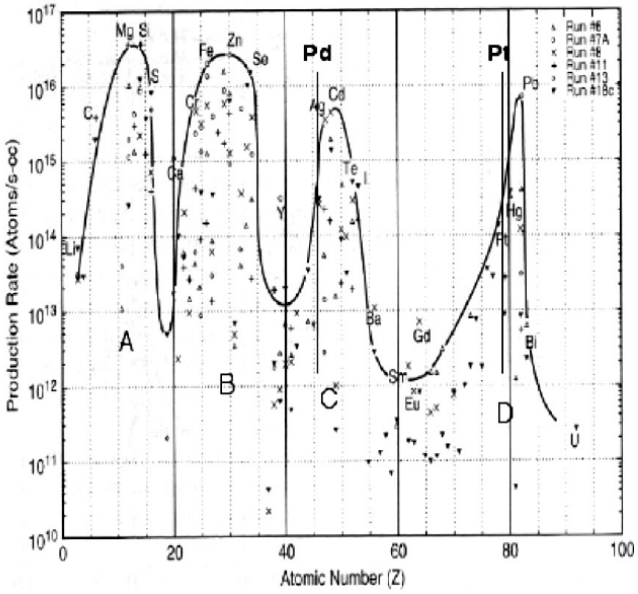

Figure 24. Examples of fusion products being added to Pd or Pt along with the occasional fission of the target nucleus. [33] The figure is from Storms [34].

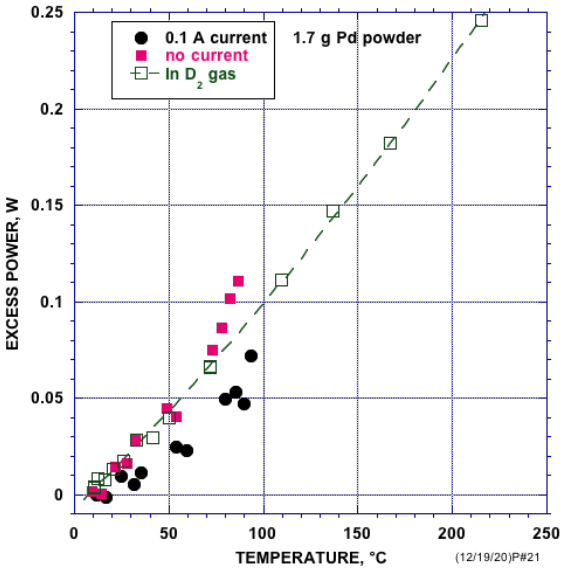

Figure 25. Excess power is a function of temperature when a sample of pressed Pd powder weighing 1.7 g is heated in an electrolytic cell containing D_2O +LiOD or when it is heated with a variable pressure of D_2 gas. Production of power at higher temperatures continued even after the current to the sample was stopped in the electrolytic cell resulting in a loss of D. Note that no detectable power was found at the lowest temperature.

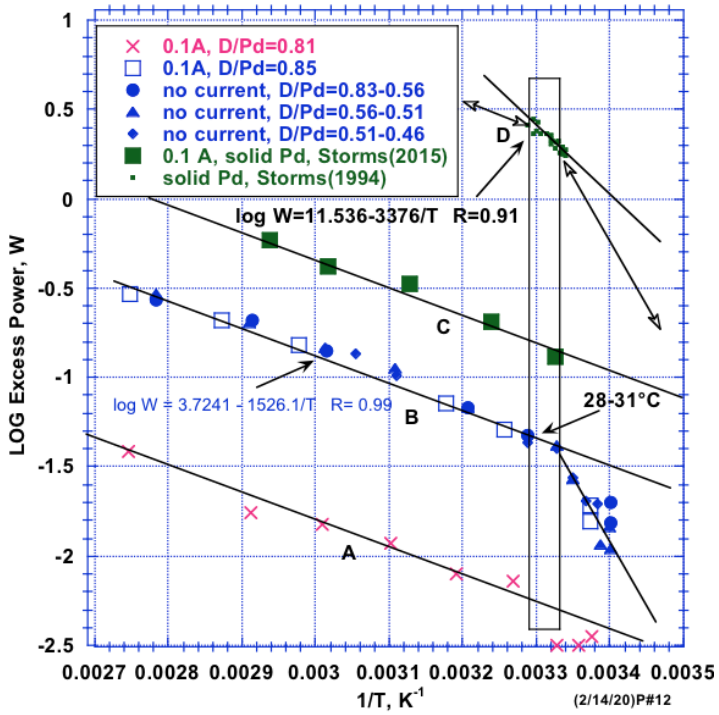

Figure 26. Comparison between the behaviors of different samples of solid and pressed powdered Pd when heated in an electrolytic cell. The designations A, B, C, and D designate independent measurements. The lines drawn through each measurement are parallel, showing that each has the same activation energy. [26], [40]. The study labeled "D" fell in a transition temperature region between two different values for the activation energy, noted as Storms(1994) [41]on the figure.

off, thereby causing a loss of D from the sample, the effect of temperature is not changed by the resulting change in the D/Pd ratio.

In chemistry, the slope of log power vs 1/T is identified as the activation energy for a process that limits the reaction rate. This value represents the energy required to overcome an energy barrier to the final event. Because the activation energy for the cold fusion process is similar to the activation energy for the diffusion of D in PdD, it is fair to suggest that the diffusion of D controls power production under certain conditions [37]. In other words, heat production appears to be related to the ability of the D or H to access the nuclear active sites by chemical diffusion, both during the initial formation of the nuclear assembly and when the hydrogen nuclei are replaced after they have been converted to the nuclear product. Therefore, temperature is an important rate-limiting variable.

An example of this behavior is shown in Fig. 26, where the activation energy for the process occurring in an electrolytic cell is shown to be independent of the amount of power being produced. The activation energy and the amount of power are also independent of the D/Pd ratio, as shown previously in Fig. 25.

Access of nuclei to the active site can also be increased by having a flux of D atoms pass through the nuclear active region, as demonstrated by McKubre et al. [38]. A few studies have even used this method to produce power by causing a flux of D to pass through Pd metal at a constant temperature [39].

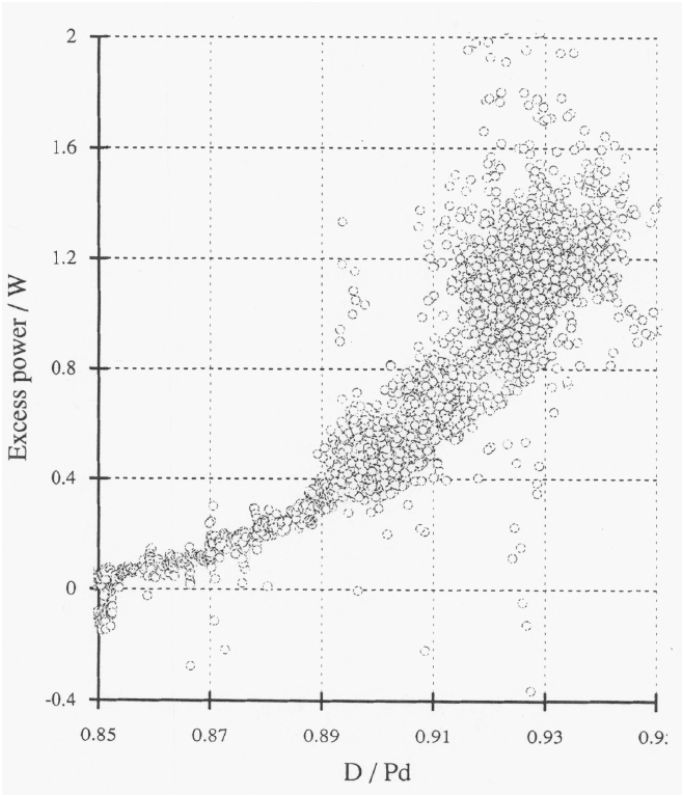

Figure 27. Effect of D/Pd ratio on power production when an active batch of Pd wire was reacted in an electrolytic cell near 20° C. McKubre et al [44].

Based on years of experience, samples that produce no excess energy at a low temperature frequently produce energy when heated. Perhaps cold fusion may be easier to produce than the many failed measurements at room temperature suggest.

7.2. Effect of D/Pd Ratio

A change in the D/Pd ratio has many effects, only two of which are noted here as important. The bond energy between the D or H atoms decreases as the D(H)/Pd ratio is increased [42]. This makes the D or H more energetically available to form another structure outside of the crystal, such as the assembly required to support the fusion process. In addition, the crystal expands as D or H is added. This expansion can cause gaps to form around embedded particles, as is described in a later section. When the increased availability of D is considered, it's important to realize that a million times less D is required to make the same amount of power as would result from a chemical reaction. Consequently, very little D would be required in the lattice structure to support a reaction rate from which significant power could be obtained. How can this expectation be reconciled with the observed behavior?

McKubre et al. (Fig. 27) found an increase in the D/Pd ratio caused the amount of power to increase when he used a special batch of Pd, a unique form of Palladium with specific properties or characteristics that make it suitable for

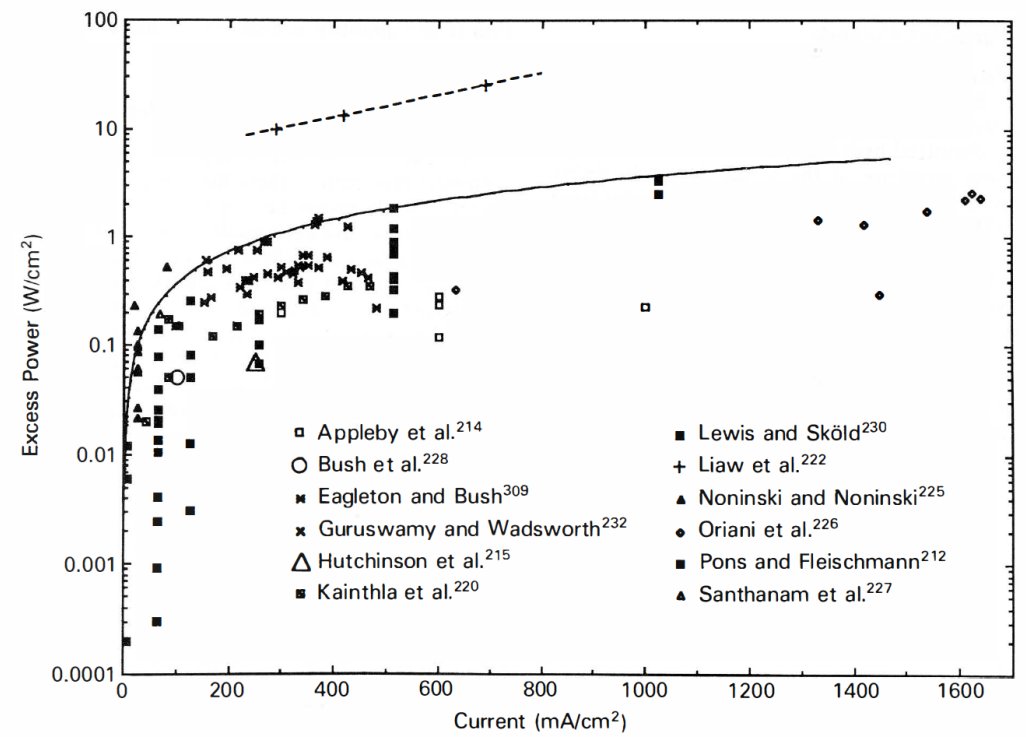

Figure 28. Comparison between excess power and the electrolytic current. The values obtained by Liaw et al. were obtained near 350° C using a molten KCl+LiCl electrolyte. The references can be found in the review by Storms [45].

the experiment. A similar behavior was reported by Kamimura et al. [43]. In both cases, the measurements were made near 20° C.

Notice in Fig. 27 that essentially no power was produced when the D/Pd ratio was less than D/Pd=0.85 at 20° C. However, excess power would be expected if the lower compositions had been heated. Perhaps the D/Pd ratio only has an effect when the measurements are made at a relatively low temperature.

The temperature and D/Pd ratio appear to increase the rate of a process already underway that only needs the power to be increased above the detection limit for the process to be made visible. The temperature has a greater effect on the rate than does the D/Pd ratio. Consequently, the temperature can overwhelm the effect of the D concentration at higher temperatures, thereby causing the D content to have no noticeable effect. The D/Pd ratio is also proposed to increase the number of nuclear active sites, thereby increasing the amount of power. This issue is discussed in greater detail later in the paper.

7.3. Role of Current Passing Through the Material

Figure 28 compares many power production measurements using an electrolytic cell when the electrolytic current is increased. Because the current would cause an increase in both the cathode temperature and D/Pd ratio, other possible effects of the current were ignored. However, the effect of current became more interesting when the current was passed through PdD in D_2 gas.

Figure 29. Sample of Pd coated with electrodeposited Pd and cut to allow the passage of a current through the metal. The cross-section through which the current passes is about 1 mm x 3 mm. The Pd weighs 2.5 g. Only a small fraction of the current passed through the active surface.

Tanzella et al. describe using a pulsed current to stimulate the heat-producing process in a complex solid structure [46]–[48]. This process is described by a patent [49] that reveals a significant area of research in energy production and materials science. The patent proposes that the pulsed current causes free neutron formation followed by the formation of ^{4}H. Ignored is the need to add 0.78 MeV of energy as mass to the resulting neutron, thus creating uncertainty about the value of the theory.

Celani et al. [50] applied pulsed current to an electrolytic cell that caused the excess power to increase. They later used DC to heat Constantan wires after they were bent into complex shapes [51]. Additional excess power was produced when a pulsed current was added. The method was justified by a proposed increase in the local concentration of D caused by electromigration.

Staker [52] caused DC to pass through a wire of Pd while it was electrolyzed in a conventional electrolytic cell. He found that this current would increase the amount of excess power. Unfortunately, he explained this behavior using a proposed phase change for which no evidence exists [53].

Tanaka and Himeno [54] propose that spontaneous and applied electron currents could increase the fusion rate by increasing the tunneling process.

These explanations may require a reexamination, as is done later in the paper. Nevertheless, despite the conflicting explanations, an applied current clearly has an important effect on the amount of fusion power.

Encouraged by these findings, a study of this effect is described here. A piece of solid Pd was plated with Pd to produce local islands of a complex structure, as described by Gordon and Whitehouse (G-W) [25]. Figure 29 illustrates how the Pd was cut to allow the current to access most of the material. The sample was placed in a cell containing D_2 gas at about 0.5 atm and heated, as shown in Fig. 30. The small amount of power added by the current was subtracted from the power produced by the sample. This extra power was too small to cause a significant temperature change. In each case, DC power passing through a resistance wire surrounding the cell is used to increase the temperature.

It is crucial to note that the effect of applied current is substantial with an increased effect as the current is increased, as shown in Fig. 31. This variable has the potential not only to significantly increase the amount of power but could

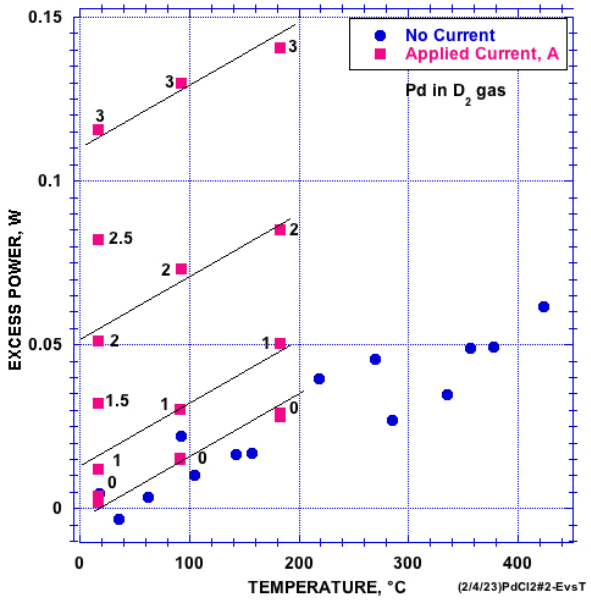

Figure 30. Effect of a steady DC passing through PdD at various temperatures in D_2 gas. The amount of applied current is shown in units of ampere(A). The values for "no current" were obtained first followed by the values designated as "applied current". The current at a constant temperature was measured and then the temperature was increased and held for 100 min until the temperature became constant.

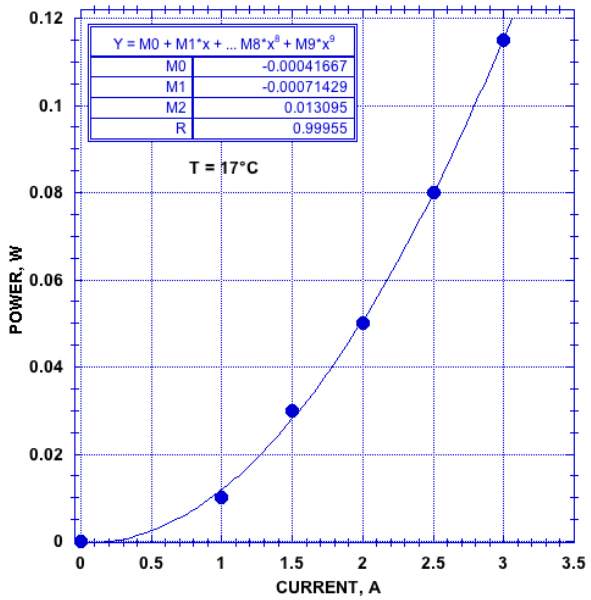

Figure 31. Excess power as a function of applied current at 17°C. Notice that no power is detected in the absence of applied current at 17° C.

also be used to provide a rapid response to a variable load when this source of energy is applied. Moreover, this variable is independent of temperature, and the effect of applied temperature is independent of the current. In other words, the effect of these two variables results from two different and independent processes, with applied current having the more significant effect. The resistance also could be used to calculate the average D/Pd ratio using the equation provided by McKubre and Tanzella [55].

A current reversal after the study caused no change in excess power. In addition, the current caused an immediate response. This behavior suggests that the concentration change caused by electromigration did not significantly affect excess power because electromigration is a slow process. This preliminary study must be repeated to determine the effects of a magnetic field, pulsed DC or AC, and current density. The reason why current significantly affects power is explained in a later section. These findings have significant implications for understanding power generation in solid structures and should be further investigated to advance our knowledge in this field.

7.4. Role of Laser Radiation

The application of laser radiation to a material can have many effects, including causing an increase in the local temperature, making electrons more available, and stimulating the phonon energy states. Which of these effects influence the fusion reaction is still being debated.

Notably, Letts and Cravens [56], [57] discovered that PdD coated with Au produced extra energy when exposed to 669 nm laser radiation, suggesting a potential breakthrough in our understanding of laser-material interactions. Storms [58] replicated the claim and demonstrated that laser radiation does not initiate the nuclear process but increases the reaction rate for a process already underway. This work also demonstrated that the Au coating was not necessary to produce excess energy when a different sample of Pd was studied.

Later, Letts et al. [59], [60] applied two lasers having variable frequencies. Several beat frequencies were produced that they claim increased the amount of power. This result has been used by Hagelstein [61] to support his phonon model. However, this study failed to see the single-frequency effect observed during their previous studies. In addition, the attempted replication of this work by Guffey et al. [62] failed to produce the claimed effect. Other people have applied lasers with various frequencies that were able to amplify the amount of power without the need to apply a beat frequency or a layer of gold, an example of which is reported by Tian et al. [63]. Consequently, the role of a special frequency, as claimed by Hagelstein and Letts, remains a topic of ongoing research and debate.

Laser radiation is found to produce antistokes [64] and Maser [31] radiation. This radiation could be the result of changes in the chemical structure produced by the fusion reaction or be emitted directly from the nuclear process itself. Importantly, this behavior suggests a coherent process may occur during the fusion reaction, a finding that could have significant implications for our understanding of nuclear processes. More will be said about this idea in another section.

8. Proposed Explanation

A few puzzle pieces are identified in the previous sections, so now is the time to fit them together. The challenge is to explain all of the observed behavior by the operation of a single mechanism. In addition, this mechanism has to account for the missing energy in the emitted ions and how the nuclear energy is emitted while momentum is conserved. The mechanism must also be consistent with the chemical environment in which the nuclear process operates and with all other observed behaviors. The process can be best explained as operating in stages.

8.1. Stages

Four separate events occur in sequence, consisting of several chemical events followed by several nuclear reactions. Each event is described as if it were an isolated mechanism with the nuclear event being an unexpected consequence of a novel chemical arrangement involving electrons and hydrogen nuclei.

Because these events do not occur informally throughout the material but only at specific, unique sites, the nuclear reactants must accumulate at each site due to a relatively slow chemical process. The nuclear events occur only after this assembly is complete, followed by an unknown but very short delay as the nuclear energy states rearrange and dissipate their excess energy as the kinetic energy of emitted particles.

In addition to fusion, the nuclear process can result in secondary nuclear reactions, identified as transmutation reactions, as the fusion product adds to the surrounding nuclei. Hot fusion reactions can also occur when the energetic fusion product interacts with the surrounding hydrogen nuclei. These rare reactions might produce radiation and various decay products that can be mistaken to result directly from the fusion reaction itself, thereby adding complexity and confusion. Storms and Scanlan [29] and other people have reported seeing radiation that might have resulted from such sources. Although these secondary nuclear reactions are not discussed here, the occasional emission of neutrons and energetic photons needs to be evaluated with these other possible reactions in mind.

8.2. Nuclear-Active-Environment (NAE)

Cold fusion is proposed to require a new structure in which a nuclear process can take place without applied energy. The environment in which this assembly can form is rare. Nevertheless, the nuclear process will not happen unless this environment is available.

The unique location in which the nuclear reaction takes place is called the nuclear active environment (NAE). The number of such locations in a material determines the maximum amount of nuclear power produced. When the fusion sites are present in a local concentration too high, local melting can result [30]. Because most materials do not contain any NAE, most materials, including Pd, will not support cold fusion, as frequently demonstrated. The challenge is to identify the NAE and then find ways to create more of it.

Someone has suggested every location in PdD as the NAE, including the crystal structure itself, the D or Pd atom vacancies, various defects in the atom arrangement, and grain boundaries. The surface of small particles and small physical gaps are also proposed as possible sites. The correct identification of the NAE is critical to creating the required environment so that cold fusion can be adequately studied and eventually used as a practical source of energy. Therefore, a critical evaluation of the suggested sites is required.

When evaluating the suitability of a site, it's important to realize that simply having two D(H) occupy the exact location at the same time is insufficient for fusion to occur. A very unusual and complex structure involving electrons must also be present to reduce the Coulomb barrier. Furthermore, this structure must not conflict with the chemical conditions present at the site. These requirements greatly restrict the nature of the required sites. For example, sites within the lattice structure, such as vacancies, defects, or tetrahedral locations would violate this requirement because they are created by the rules governing the formation of the fcc structure. This important consideration is challenging for people who do not understand the nature of chemical interaction to accept. I hope I can be forgiven for repeating the reasons in many different ways. Palladium will be used as an example, but the comments apply equally to all materials with a crystal structure.

The tetrahedral site in a fcc structure fails because each has the same chemical properties and, hence is chemically identical to all other tetrahedral sites that exist in every sample of Pd. If the NAE could form in one site, it would form in all other sites with equal probability, thereby making the fusion process very common for all samples of PdD, which is not the case. In any case, such sites do not contain an electron structure suitable to reduce the Coulomb barrier.

Vacancy occupation fails for the same reason. Two kinds of vacancies exist in PdD(H). The first kind forms where atoms are missing in the D(H) sublattice, which results in the observed wide range of D(H)/Pd ratios as a variable number of crystal sites are randomly filled by D+ or H+ ions. Each site contains only one D(H), with more than a single occupancy being briefly caused only by the chance occupation as the result of normal self-diffusion. If this chance occupancy resulted in cold fusion, the effect would be expected to be much more common and occur in every Pd sample regardless of its treatment.

Metal atom vacancies can occasionally occur in the Pd sublattice but are rarely formed under the conditions used to cause cold fusion. These vacancies are eliminated as the NAE because if the atom arrangement required for fusion to occur were chemically stable in a vacancy, the vacancy would not be a vacancy. Instead, all identical vacancies would contain this stable structure as part of the regular atom arrangement, creating a different atom arrangement without vacancies. In addition, the NAE would be ubiquitous throughout the entire lattice structure, which is not the case. In addition, the claim by Staker [53] that vacancy tubes are present in PdD is very weak because, if they exist at all, the application of high pressure is required, which is not used when cold fusion occurs. Also, because these tubes would have the same chemical properties as a Pd atom vacancy, their occupancy would suffer the same limitation. Indeed, evidence suggests that the atoms in PdD and PdH only have a standard fcc structure under the conditions used to study cold fusion.

These limitations leave cracks or gaps formed as the accidental result of stress relief or changes in volume at specific locations. Because gaps are always present in material while cold fusion rarely occurs, the required conditions must rarely form in the gaps. This behavior suggests the gap must have a critical width and/or a critical chemical property that is seldom present.

Experience reveals that the conditions required to form NAE can be present in Pd when manufactured. This condition is even maintained throughout the material regardless of its subsequent treatment. As a result, when a piece of Pd supports cold fusion, most parts of the batch from which it came are also active even after the material is given a different physical form, such as a wire. The opposite is also true. Dead samples result from batches in which most samples are dead. Also, very pure Pd is found not to support cold fusion. Instead, certain impurities appear to be important. This overall behavior significantly limits the nature of the NAE when Pd is used. Other active materials, of which many are known, would be expected to have similar characteristics. The challenge is to find the universal characteristic that can be created in all materials. This problem is addressed in a paper soon to be published in JCMNS. A copy is available at www.LENR.org.

8.3. Nuclear-Active-Structure (NAS)

The actual arrangement of atoms and electrons that experience fusion is called the nuclear active structure (NAS). Fusion of the NAS takes place as the nuclear energy states rearrange in collaboration with the surrounding electrons. Eventually, the structure can appear to "explode" as the resulting mass change is converted to kinetic energy, with the nuclear product going in one direction and a collection of electrons being expelled in the opposite direction. The NAS can reform in the same NAE as the hydrogen nuclei and electrons reassembled. The process is revealed as hot spots that wink off and on in the video provided by Szpak et al. [9]. The measured power results from the sum of the energy made by this chaotic and random process operating at a relatively small number of isolated locations in the active material. The greater the number of NAE in the material, the more power would be produced. Successful amplification of this energy source would require treatments that increase the number of NAE and the rate at which the NAS reforms in each NAE after their destruction by the fusion event.

Because this electron assembly shields the Coulomb barrier between the hydrogen nuclei, it would, by necessity, become part of the combined nuclear energy states of the hydrogen nuclei. As a result, all of these electrons would be available to dissipate the energy and momentum. This idea will be discussed in the following sections.

We have now reached the heart of this problem. We are confronted by the possibility of a nuclear process that has never before been seen nor suggested. This nuclear process is proposed to involve the direct interaction between electrons in a chemical structure and the nuclear energy states of hydrogen nuclei such that these electrons can dissipate part of the nuclear energy resulting from the formation of the nuclear product. This process is possible without causing chemical effects that would have revealed this process to chemists over the years. We can now explore the implications of the behaviors shown in Figs. 7 and 15.

8.4. The Reason Why ^{4}He can be Detected

Based on the data summarized in Fig. 7, ^{4}He is the main nuclear product from which the measured energy results. Nevertheless, measurements show that helium made in PdD cannot leave the material at the temperature used to make the measurements. This problem has been addressed by assuming fusion occurs only near the surface of the PdD, allowing at least 1/2 of the helium atoms to exit quickly. This assumption may not be correct based on transmutation products being found throughout the material.

Furthermore, Storms and Scanlan [21] showed that helium is not emitted directly from the nuclear event. Instead, an isotope of hydrogen is emitted. Now, the reason why the helium can be detected outside of the PdD structure can be understood. Because the first nuclear product is ^{4}H, being an isotope of hydrogen, it would diffuse rapidly to a surface along with the D in the PdD structure. After exiting the material, it would experience normal beta decay to produce the detected ^{4}He. The amount of ^{4}H that could escape would depend on the size of the sample, the diffusion rate of this isotope in the material, the half-life, and how long after the fusion process started before the collection process started. This delay results because the measured loss rate would not equal the production rate until the concentration of ^{4}H has reached a critical value in the PdD. Because the length of this delay is uncontrolled during the reported measurements, a variable amount of the ^{4}H is retained in the Pd. Any ^{4}He formed by beta decay would be forever trapped in the Pd. This assumption provides a method to estimate the half-life of the ^{4}H as being on the order of minutes.

Before this proposed process could be accepted, the decay mechanism of this hydrogen isotope needs to be reexamined.

8.5. Decay Mode of ^{4}H

Hydrogen-4 is the only hydrogen isotope with the potential to decay into ^{4}He. However, this isotope is said to decay rapidly by neutron emission when it is formed with high energy [65]. Because this conclusion is used to reject the claim made here, the decay characteristics of ^{4}H need to be discussed with the possibility that the decay mode might change when the isotope is made at low energy by cold fusion. This paper is not designed to evaluate the existence of ^{4}H, which has been done elsewhere. Nevertheless, some ideas worthy of future examination are suggested as follows.

The ^{4}H nucleus is claimed to form briefly when liquid deuterium is bombarded by ^{3}H+ ions having an energy of 57.5 MeV [43]. Emissions of energetic p, n, and ^{3}H are observed. The ^{4}H is proposed to form when the deuteron transfers a neutron to the ^{3}H, causing an energetic p to be emitted. The resulting ^{4}H then quickly sheds a neutron, causing the remaining ^{3}H and neutron to be emitted in opposite directions. I suggest that the observations on which the creation of ^{4}H is based can also be explained by the fragmentation of a deuteron into p and n without the formation of ^{4}H.

8.6. The Consequence of ^{4}H Formation

As noted in the previous description, the presence of electrons in the NAS is proposed to reduce the Coulomb barrier. After the electrons have been assembled around the hydrogen nuclei, they would interact with each other and the

Table 1. Proposed reactants, nuclear products, and energy for each reaction produced by cold fusion [34].

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

nuclear energy states of the hydrogen nuclei. This interaction would result in an overlap of the energy states by which the energy states associated with electrons could be combined with the energy states of the two hydrogen. Apparently, this mixture of energy states is limited to only one electron being captured. The consequence would create the nuclear products listed in Table 1. Unlike the problem with how Godes [66] explains the formation of ^{4}H, this explanation has the neutron being formed as part of the fusion reaction, which supplies the required mass-energy. Consequently, this single mechanism can produce all of the other known fusion products without the need for an additional mechanism.

In this way, tritium formation is explained by the fusion between H and D and a captured electron. A similar reaction between two H and an electron would result in an energetic deuteron. In each case, other electrons would be emitted with enough energy to conserve momentum, and the ions would be emitted as a series of energies with the same separation, similar to the behavior shown in Fig. 15, but with, perhaps, a different amount of separation. In summary, the overall process appears to convert one hydrogen isotope into another due to fusion involving electron screening, electron capture, and electron emission. This behavior is not beta decay or reverse beta decay. Instead, this process is proposed as a new kind of nuclear reaction.

All of these initial nuclear products are accompanied by the emission of many electrons.

The research described here leads to some intriguing testable predictions. For instance, when only H is caused to fuse without D being initially present in the NAE, the amount of tritium (^{3}H) would slowly increase as the initial nuclear product (D) accumulates in the material and fuses with H. As the D concentration further increases, the D+D reaction would produce ^{4}H and its decay product ^{4}He. Consequently, the same nuclear emission would be detected when either pure H or pure D were used, as was observed by Storms and Scanlan [21] The amount of ^{4}He and the amount of energy produced by this complex collection of reactions would be less than that produced by pure D+e+D, yet would still be significant, with the amount of ^{4}He and energy slowly increasing as more D forms. At the same time, accumulating tritium would fuse with H to produce ^{4}H or with D to produce the observed neutron emission. The T/n ratio would depend on the D/H ratio, which would change as the fusion process continued. In addition, transmutation products would accumulate to produce a rich stew of elements and isotopes with their own decay modes. It's important to note that the use of H-free deuterium would never result in tritium production. This prediction would be important because it shows how to avoid the production of tritium, a dangerous nuclear product, when the fusion reaction is used to make large amounts of power.

As we delve deeper into the research, two more questions emerge, each holding the key to unlocking further understanding. How is the momentum conserved and where is the fusion energy that is missing from the emitted ^{4}H, according to the measurements of KK and SS? These questions are crucial in our quest for comprehensive knowledge in the field of nuclear physics and fusion energy.

8.7. Implications of the Proposed Electron Emission

The search for the mechanism by which the released nuclear energy is dissipated has resulted in many suggestions. For the sake of discussion, let's assume this energy is dissipated by the emission of electrons such as are detected as an electron current in the LEC [25]. After all, if an assembly of electrons were required to shield the Coulomb barrier,

these electrons would be expected to share the energy state of the combining nuclei. Hence, they would be available to dissipate this energy as an emission of electrons. The implications of this assumption are profound, potentially reshaping our understanding of nuclear energy dissipation.

By combining the conservation of momentum equation with the known kinetic energy of the ^{4}H and the total energy released by fusion, the number of electrons being emitted and their energy can be calculated. The following equations describe the conditions required when momentum is conserved by the emission of ^{4}H in one direction and all of the electrons involved in the creation of the ^{4}H in the opposite direction. These equations would apply equally well if ^{4}He were assumed to be the nuclear product. Consequently, it is important to realize that the behavior described below does not depend on the formation of ^{4}H. Use of the mass of helium with the measured energy in the following equations would result in the same basic behavior.

$$A*Me*Ve = Mh*Vh$$

where A is the number of electrons being emitted for each ^{4}H emitted, Me is the mass of an electron, Ve is the average velocity of the emitted electrons, Mh is the mass of ^{4}H, and Vh is the velocity of the ^{4}H being emitted in the opposite direction to the electrons.

$$Ke = 1/2*A*Me * Ve^2 = \text{total kinetic energy of the emitted electrons} = (23.85\text{-}Kh) \times 10^6 \text{ eV}$$

The total energy released by the formation of ^{4}H would be slightly less than the amount measured after ^{4}He forms because some energy is contained in the ^{4}H that is released later by beta emission with an antineutrino. Because this energy is assumed to be small compared to the total energy released by the fusion reaction, the measured values for the ^{4}H energy are used. These values are the lower limit because some energy is lost as the ions pass through the material to the detector. The values used here (Fig. 15) are obtained from the equation used to fit the KK data because these energies seem closer to the initial energy than the values SS reported. These considerations would not significantly affect the essential characteristics of how the electron energy and their number would behave.

$$Kh = 1/2*Mh * Vh^2 = \text{kinetic energy of } ^4\text{H (Values obtained from Fig. 15.)}$$
$$Mh = \text{mass of } ^4\text{H} = \text{mass He} + \text{mass e} = 4.002603 + 0.000548 = 4.003251 \text{ amu}$$

This mass is the lower limit because a small amount of mass is lost as energy when the electron and antineutrino are emitted as ^{4}He, which is created by beta decay of ^{4}H.

These equations can be reduced to:

$A = (4.003251*Kh)/(0.000548*(23.85\text{-}Kh))$ = total number of electrons emitted with each ^{4}H that has a measured kinetic energy of Kh.

$(23.85\text{-}Kh)\cdot 10^6/A$ = energy of each emitted electron.

Fig. 32 plots the calculated values for the kinetic energy of each electron and the number of electrons (A) emitted from each fusion reaction. Because the nuclear product is emitted with a discrete flux and energy, the electrons are also emitted with a similar characteristic but in the opposite direction.

As can be seen in Figs. 13 and 16, the lowest energy of the emitted ^{4}H has the largest flux compared to the other ion emissions. Fig. 32 shows that, at the same time, the more energetic the electrons, the fewer the number. In addition, while an equal amount of kinetic energy separates each peak of the ^{4}H emissions, each peak of the electron emission is also separated by an equal number of emitted electrons. This extraordinary behavior has several implications.

For the momentum to be conserved, all of the emitted electrons must travel in the same direction but opposite to the corresponding ^{4}H emission. This means these electrons must form tightly focused beams. This requirement suggests the gap (NAE) from which all of the detected ions originate is not symmetrical but may have a preferred direction to its shape. This behavior also suggests a coherent relationship between the energy of the emitted electrons.

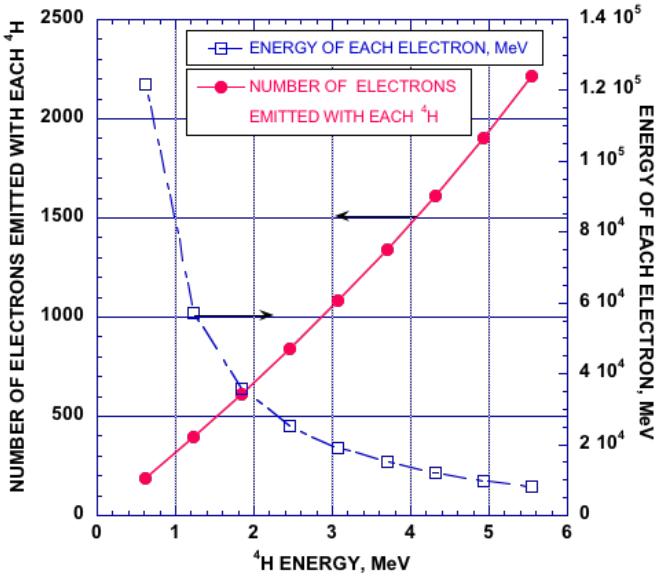

Figure 32. The number of electrons and their energy that are emitted with each ^{4}H to dissipate the fusion energy while momentum is conserved. The values are obtained using the least squares equation shown in Fig. 15 to obtain values for each energy peak of ^{4}H observed by KK.

Because each peak of ^{4}H is separated from its neighbor by the same number of emitted electrons (∼220) and by the same amount of kinetic energy (∼0.62 MeV), this suggests that a regular array of energy levels exists in the assembly in which fusion takes place.

These electrons are proposed to generate the observed photon radiation as Bremsstrahlung (https://en.wikipedia.org/wiki/Bremsstrahlung). The description of this process provided by Swartz and Verner [67] does not apply. Instead, beams of electrons are emitted from each NAE. The energy of these coherent electron beams would be converted to coherent beams of X-ray and optical radiation as they pass through the surrounding material. These photons would travel in the same direction as the electron beams and could result in the photon beams having random directions but with a very narrow focus, as shown in Fig. 21. Because the electrons have a wide range of energy, as shown in Fig. 32, the resulting photons would also show a wide range of energy, as is observed. [6], [29], [68], [69] Nevertheless, the energy of the phonons would tend to peak at a characteristic energy as the result of a complex relationship between the number of electrons having each energy, with the high-energy electrons producing more photons with greater energy.

A theoretical description of such electron structures is provided by Wikipedia (https://en.wikipedia.org/wiki/Wigner_crystal).

The calculated electron spectrum is plotted in Fig. 33 where the relative intensity is plotted as a function of election energy when emitted with the corresponding ^{4}H. This spectrum results by dividing the intensity of the electrons emitted with each ^{4}H ion, as plotted in Fig. 32, by the total of all the electrons emitted from all of the emitted ^{4}H within the measured range. The result is a hypothetical and idealized electron spectrum. The average energy of the emitted electrons is near 0.03 MeV with most of the electrons having energy between 0.01 and 0.02 MeV.

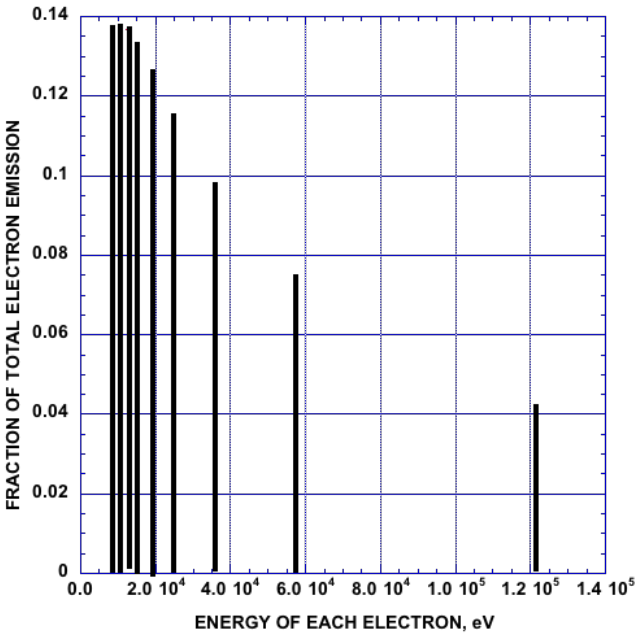

Figure 33. The calculated spectrum of the election energy resulting from the D+e+D reaction before the emitted electrons have passed through any material. The fraction of the total electron emission flux is shown for each ^{4}H peak with energy below 6 MeV, as reported by KK. This spectrum of electron emissions is expected to occur at the same time the ^{4}H ions are emitted but in the opposite direction.

8.8. Implications of the Electron Behavior

The gap structure is proposed to contain a high concentration of electrons that are part of the electron structure in the crystal lattice but exists in a concentrated arrangement because the crystal structure is highly distorted at this location. These electrons are proposed to cause fusion after two nuclei of the fuel manage to diffuse and assemble at the same location within the NAE. The slow step involves the rate at which the fuel can move from its locations in the crystal structure. This process is increased when the temperature increases, but it is increased by applied current as the result of electromigration, which significantly increases the diffusion rate. Although temperature and applied current change the diffusion rate, their effects on this process are independent.

A magnetic field would be expected to increase the current's effect because the path length would increase as the ions follow the magnetic lines of force, thereby increasing the probability of encountering a NAS. However, if the paths did not intersect a NAS, nothing would happen. Success would require the field's orientation be changed until the random ion current intersects as many sites as possible.

This current would also cause D or H ions in the material to move and slowly concentrate near the negative polarity as the result of electromigration, identified frequently as the Coehn Effect, [33] thereby further increasing the availability of nuclei at this location but reducing the concentration of D at other locations. The result of this process is expected to be small because D concentrates at a slow rate, and the effect of an increased D/Pd ratio is small at higher temperatures.

8.9. Unanswered Questions

Although many questions can be answered about the process, several important ones remain. Incredibly challenging is why nuclear energy is dissipated by the emission of ions with a series of discrete energies. Also, why can the electrons in the assembly be emitted all in the same direction opposite to the ion emission with a series of discrete energies? Because these questions result only from the observed behavior and the need to conserve momentum, they cannot be ignored as speculation. Instead, we must acknowledge that an extraordinary and unknown process can occur in a chemical structure with the production of observable nuclear products and radiation. These questions point to an entirely new nuclear process never before observed.

8.10. Predictions

This collection of behaviors allows several testable predictions. These predictions can be used to verify the explanation and guide future studies.

1. The use of D that does not contain H will not produce tritium.
2. The use of pure H that does not contain extra D will eventually produce tritium at an increasing rate as the amount of D increases due to the initial fusion of H to form D. The small neutron flux will also increase as the concentration of tritium increases. A suitable mixture of D and H will produce tritium fastest. The rate will also depend on the material in which the NAE is located.
3. Either D or H will produce nuclear energy, with H producing less power than D when the same number of NAE is present.
4. The amount of power will depend on how fast the D or H can reach the NAE, with the diffusion rate of H or D within the material being a controlling variable.
5. The use of either D or H will produce the emission of ^{4}H and the subsequent formation of ^{4}He, its decay product, by fast beta decay. The use of H will produce a smaller but variable ^{4}He/energy ratio compared to D.
6. An electron current caused to pass through the NAE will increase the fusion rate. A magnetic field of suitable direction and intensity can also increase this rate.
7. A flux of hydrogen isotopes passing through the NAE will increase the fusion rate. This flux can be increased by increasing the temperature or by increasing the concentration gradient of the D or H.
8. Either D or H will produce a flux of emitted electrons, but in different amounts and with different energies.
9. A practical energy generator can be constructed by nano-machining a conducive metal to produce suitable gaps, which can be exposed to a source of deuterium, to an electric current, a continuously variable magnetic field, and increased temperature as a way to control the amount of power.
10. Most nuclear energy is dissipated by a large number of electrons, each of which has only a small fraction of the total and is coherently related to the other emitted electrons.
11. The fusion process involves a series of equally separated energy states that decay with a short half-life to release its energy as the kinetic energy of many electrons and a nuclear product, each of which is radiated in opposite directions.
12. The products produced by the hot fusion mechanism will be occasionally observed, especially when the D concentration is large.
13. Transmutation products will form at the sites of the fusion reaction, with the nuclear product determined by the atom being transmuted and the hydrogen isotope that fuses.
14. The energetic electrons resulting from the beta decay of ^{4}H can be detected when measurements are made inside the apparatus. Because an antineutrino is also emitted, the electron energy will have a range of values. This energy is proposed to be greater than the energy of each electron being emitted directly from the fusion reaction.

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