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Research Article

What is Real about Cold Fusion and What Explanations are Plausible?

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Abstract

Experimental observations are now available to test rational theories and models about the cold fusion effect. Some of these informations are summarized and used to draw logical inferences about the requirements a plausible theory must satisfy. A model based on the role of super-clusters is proposed.

Keywords: Cluster, Cold fusion, Fusion, Nuclear reaction

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1. Introduction

The field of study commonly called cold fusion started in 1989 with the announcement by Profs. Fleischmann and Pons [1] of unusually large heat production in an electrolytic cell containing deuterium. At the time, the reported experimental results were too general to give much confidence in the claims for a fusion reaction between deuterons in palladium. Over the last 20 years, this situation has changed remarkably thanks to steady research in over eight countries. The question now is which part of this large data set can be believed and used to understand the mechanism that results in fusion and transmutation reactions.

To explain the anomalous results, a successful theory or model must be related to a unique physical and/or chemical environment because the nuclear reactions apparently cannot occur without this condition being present. Once this novel condition forms, a nuclear reaction can release its energy into the environment by several different processes. These can be proposed to including emission of energetic radiation. This radiation has been difficult to detect because most is absorbed before reaching a detector. Nevertheless, various nuclear products accumulate in the material and

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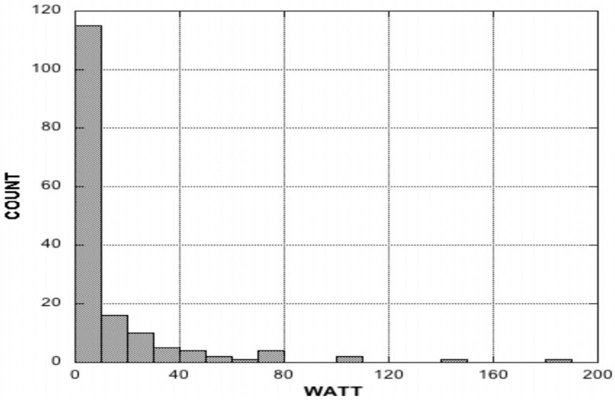

Figure 1. Histogram of power production using the electrolytic method.

these have been detected in significant amounts. Incremental transfer of energy directly to the surrounding atoms has also been suggested without emission of detectable radiation.

This is not a review or evaluation of proposed theories. Hopefully, the approach used in this paper will encourage theoreticians to evaluate their own ideas. In addition, this paper accepts the effect as being real and is not a critique or review of published work. A few well-documented studies are cited to provide a general understanding of the cold fusion effect. Each of these observations suggests several questions that must be addressed and logically connected by any theory. A mechanism is described that meets this requirement.

2. Discussion

Several indications of a novel process have been discovered. These have a range of acceptance and importance with heat generation being the most accepted and important. For this energy to result from a nuclear reaction, nuclear products must be found. At the present time, these products include, helium-4, tritium, transmutation products from various target elements, and energetic radiation. These are listed and discussed in the order of decreasing amount. So far, only helium production is quantitatively related to heat production. Other products, such as radiation may be present in amounts consistent with heat production but are difficult to detect due to their limited range in experimental conditions.

2.1. Heat

Energy production in excess of any known chemical reaction is the major indication of a novel nuclear reaction taking place. The number of successful efforts is too large to list here, but can be found in the book by Storms [2]. The histogram (Fig. 1) summarizes the amount of heat produced using the electrolytic method pioneered by Fleischmann and Pons. While many studies produced only a few watts of extra power, a significant number produced large and easily measured amounts of power. Furthermore, a single value is used from each paper even though many successful results are frequently described in the paper. “What kind of reaction can generate MJ of energy in a simple chemical system along with production of radiation and additional elements”? This question is addressed in a later section.

Where in a sample is this energy produced? McKubre et al. used the following equation to describe excess power (EP) obtained from wire cathodes in a Fleischmann–Pons electrolytic cell [3,4].

$$\mathrm{EP} = M(x - x_0)^2(i - i_0)\, \mathrm{d}x/\mathrm{d}t,$$

Table 1. Reactions resulting from fusion involving energetic deuterons.

$$
\begin{aligned}
\mathrm{d}+\mathrm{d} &= {}^{3}\mathrm{He}\ (0.82\ \mathrm{MeV}) + \mathrm{n}\ (2.45\ \mathrm{MeV})\\
\mathrm{d}+\mathrm{t} &= \mathrm{n}\ (14.01\ \mathrm{MeV}) + {}^{4}\mathrm{He}\ (3.5\ \mathrm{MeV})\\
\mathrm{d}+\mathrm{d} &= \mathrm{p}\ (3.02\ \mathrm{MeV}) + \mathrm{t}\ (1.01\ \mathrm{MeV})\\
\mathrm{d}+\mathrm{p} &= {}^{3}\mathrm{He} + \mathrm{gamma}\ (5.5\ \mathrm{MeV})\\
\mathrm{d}+\mathrm{d} &= {}^{4}\mathrm{He} + \mathrm{gamma}\ (23.5\ \mathrm{MeV})
\end{aligned}
$$

where x_o is the critical average D/Pd of the bulk cathode, x the actual average composition, i the actual average current density, i_o the critical average I/cm^2, $\mathrm{d}x/\mathrm{d}t$ is the variation in composition. This equation can be expanded by

$M = nA$, where "A" is the number of nuclear active sites having 'n' efficiency.

The heat producing reaction favors locations where the deuteron concentration is greatest, which is affected to some degree by applied current density and rate of composition change. This location exists at the surface of the cathode in an electrolytic cell and on the surface of nanoparticles. The deuterium concentration becomes especially great on the surface of a cathode as the bulk composition approaches unity and on the surface of nanoparticles as they become smaller. In fact, the composition at the surface of a cathode has been measured [5,6] and the D/Pd ratio is found to be at least 1.5, which indicates the presence of another phase having a perfect-lattice D/Pd ratio greater than unity — perhaps as great as 2. [7] Abrupt changes in the temperature coefficient of resistivity at D/Pd = 1 also indicate the presence of another phase having a larger ideal lattice composition. [8,9] In addition to having a large D/Pd ratio, the surface of an electrolytic cathode contains lithium [10] and other advantageous impurities. Consequently, a theory based on β-PdD in bulk material is not addressing the true active environment, which is a complex alloy containing Li, Pd, D and other elements of unknown kind and amount, all with a very non-uniform distribution. Such surfaces also frequently contain significant oxygen because the stability of the Li-O bond prevents its reduction by hydrogen generated at the electrode.

2.2. Products of nuclear reactions

Although some anomalous energy is produced when ordinary hydrogen [11] or water [12] is used, the d–d fusion reaction has been and continues to be the center of attention. Many laboratories investigating cold fusion searched for products expected from hot fusion, but without success. For example, the expected neutrons are occasionally detected, but these are not associated with heat production either in time or in magnitude. Tritium is occasionally detected in small quantity, but again it is not associated with heat production.

A nuclear reaction between two nuclei must produce at least two products, which are required to carry away the energy and momentum. Fusion reactions involving deuterons are known to result in the paths listed in Table 1, with each producing the required two products. The first two reaction paths are found in equal amount when enough energy is applied to force two deuterium nuclei through the Coulomb barrier, i.e. hot fusion.

According to the third possible reaction path resulting in helium production, 23.5 MeV gamma radiation would be produced and easily detected. Failure to find this radiation supported considerable skepticism, but did not stop a search for helium at a few laboratories.

2.3. Helium

Helium has been detected on many occasions in cold fusion cells, in both the gas and the palladium cathode, and shown to have a relationship to the amount of heat measured. Two independent measurements are compared in Fig. 2. Many other studies show a clear correlation between heat and helium production, but without giving quantitative values. To properly understand these measurements, a few qualifications must be accepted. Normally, only the amount of He released into the gas stream is measured. McKubre et al. [13] and Matsunaka et al. [14] show that this quantity represents only part of the total amount of He produced since it omits any helium trapped in the solid Pd cathode. Although the amount trapped can be variable, depending on how deep into the surface helium forms, the round number value is about 50%. Both studies compared in Fig. 2 are consistent within expected uncertainty with the expected energy value after this 50% loss is applied. Taking all measurements into account and applying this potential loss of helium, Storms [2] proposed a value of 25±5 MeV for the energy produced by formation of each helium nucleus, which is consistent with the energy expected to result from d–d fusion.

Explanations have been suggested that involve addition of deuterons, protons, or neutrons to isotopes of lithium to generate helium. None of these reactions produce enough energy per He atom to be consistent with the measurements.

2.4. Tritium

Many examples of tritium production have been reported occasionally in electrolytic cells and during gas discharge [15,16] as reviewed by Storms [2]. Since tritium is seldom measured, it may be underreported. However, it is nevertheless rare. The amount found is always too small to generate detectable heat, but sufficient to demonstrate an unexpected nuclear process. When the neutron/tritium ratio is measured, it is always found to be very small — in the range between 10^{-9} and 10^{-6}. Consequently, tritium does not result from the normal hot fusion reaction.

Bockris [17] reported interruption of tritium production when the electrolytic cell was shaken, suggesting the source is dendrites on the cathode surface that are removed by agitation. These later reformed to continue production. Surface examination showed deposits of copper from wires within the cell. Claytor et al. [16] have been increasingly successful in producing tritium using pulsed DC discharge between alloys of palladium in deuterium gas. This process is very sensitive to the composition of the alloy and also generates dendrites.

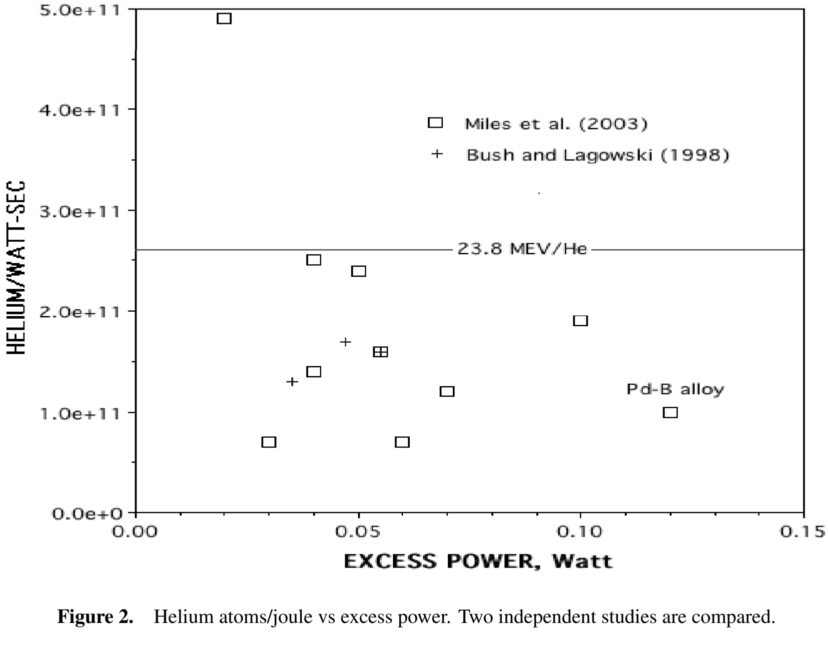

Figure 2. Helium atoms/joule vs excess power. Two independent studies are compared.

Table 2. Observed transmutation reactions reported by Iwamura et al.

$d + d = {}^3He$ (0.82 MeV) + n (2.45 MeV)
Ba + 6d = Sm + ?, Q = 67.6 MeV
Sr + 4d = Mo + ?, Q = 53.4 MeV
Cs + 2d = La + ?, Q = ∼24 MeV
Cs + 4d = Pr + ?, Q = 50.5 MeV

Tritium is unique because it is one of the very rare radioactive elements produced by the process. A useful theory must account for its occasional presence.

2.5. Transmutation

Isotopes and elements not present in the initial environment are reported. [2] While the elements or isotopes may have been present initially as contamination, this argument cannot be applied successfully to all such claims. Two studies stand out in showing that clusters of deuterons might be involved in such transmutation reactions. Iwamura et al. [18–22], in a series of papers, claimed to detect the reactions shown in Table 3. Clusters containing as many as six deuterons are found to enter the nucleus as a unit. However, several aspects of this work require explanation. As shown in Fig. 3, the target nuclei are deposited on a 400 Åthick surface layer of palladium that lies on a layer of CaO, a presumed catalyst. How does the cluster get from the catalyst to the target and why do the clusters not react with the intervening palladium? How is the significant energy communicated to the environment? Clearly, something must be emitted that is not detected, as indicated by the question mark in Table 3.

The second study involves the work of Miley et al. [25,26]. His experiments employ SIMS, AES, EDX and NAA for analysis. The work is based on the use of thin films of nickel and/or palladium deposited on an inert substrate, with a small amount of platinum as an impurity from the anode and perhaps a little sulfur as an impurity from the electrolyte because the electrolyte contained Li_2SO_4 in H_2O. Elemental analysis was made before and after electrolytic action. Although it is safe to assume some of the detected elements resulted either from contamination, migration to the surface from within the sample, or from error in analysis, the general pattern appears to be real. The study showed a region of atoms having high concentration from about mass 106 (Pd) to mass 130; from mass 195 (Pt) to mass 210; and from about mass 25 (S?) to mass 32. The region around nickel (58) shows elements on both the high mass and the low mass sides of this potential target element. Transmutation requires addition of something to the target, which leaves elements on the low-mass side unexplained. Addition of neutrons, protons or deuterons to Pd is explored next as a potential explanation.

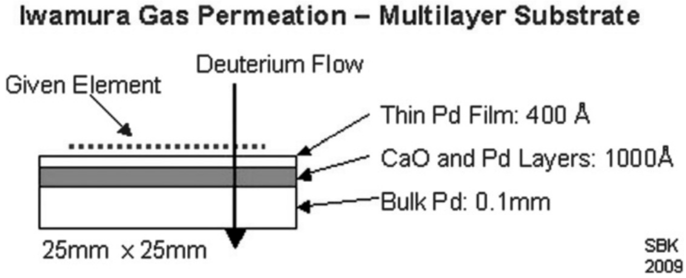

Figure 3. Simplified cross-section representation of the Iwamura experiment. Figure provided by Steve Krivit [23,24].

Figure 4 shows the position of the stable isotopes near palladium with respect to their atomic number and atomic weight. If neutrons were added to palladium, the resulting isotopes would follow a horizontal line on the figure and eventually produce beta emitters. These have half-lives that decrease from minutes to milliseconds as more neutrons are added. To produce the observed elements near mass 130, a series of decays from parent to daughter would have to take place over a significant length of time as each isotope decayed to another radioactive isotope with gradually increasing atomic number. In addition, the expected radioactivity is rarely detected even though this would be an easy measurement. Therefore, it is possible to conclude that transmutation does not result from neutron addition from any source.

If protons were added to palladium, the resulting isotopes would follow a line parallel to the one shown on the figure labeled protons. The mass of the heaviest stable isotope is 114 before unstable isotopes are produced, which are not high enough to explain the full range reported.

Only addition of deuterons, as indicated by the line labeled "add deuteron", result in the full range of observed stable isotopes. This same process can be applied to nickel, platinum and sulfur to give the same conclusion in spite of the fact that water containing the normal amount of deuterium was used. Apparently, only deuterons, regardless of having a relatively low concentration in normal water, produce active deuteron clusters.

In the case of elements having a mass less than nickel, these cannot result from a reaction with deuterons or any other particle. These elements might result from fission of nuclei after addition of deuterons to palladium, as has been suggested by other authors. Apparently, release of additional energy to form the very stable nuclei at and near iron allows fission to take place. The consequence of this proposed process is summarized in Table 5. Since no radioactive isotopes have been found to result from transmutation, it is safe to assume only stable isotopes are formed by the fission process, shown in bold. Except for Ag, stable isotopes result only by the addition of an even number of deuterons up to 10. No stable isotopes are formed by larger additions. However, a few unstable isotopes, shown in italic, can release additional energy by splitting into the elements listed at the bottom of the table. In other words, stable isotopes remain whole and certain unstable (radioactive) isotopes might fission while conserving total mass and total atomic number. The quantity of each transmutation or fission product is determined by the abundance of the target isotope and unknown selection rules.

Although this approach does not prove elements near iron result from fission, it does show that such a process is consistent with the atomic numbers and weights resulting after deuteron addition to palladium. One of many examples of experimental evidence for this process is shown in Fig. 5, based on an electrolytic study by Mizuno [27,28] who used

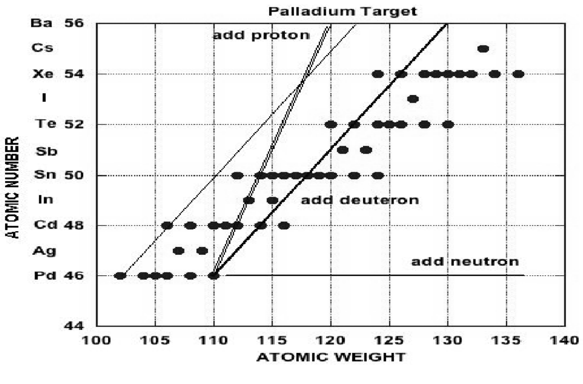

Figure 4. Stable elements as a function of atomic weight and atomic number near palladium. Lines show the result of adding neutrons, protons, or deuterons to palladium.

Table 3. Summary of isotopes made by adding deuterons to palladium.

Element	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La	Ce
Atomic number	46	47	48	49	50	51	52	53	54	55	56	57	58
#D	0	1	2	3	4	5	6	7	8	9	10	11	12
Atomic weight	102	104	**106**	*108*	*110*	*112*	*114*	*116*	*118*	*120*	*122*	*124*	*126*
	104	106	108	110	112	114	116	118	120	122	124	126	128
	105	107	109	111	113	115	117	119	121	123	125	127	129
	106	108	110	112	114	116	118	120	122	124	126	128	130
	108	110	112	114	116	118	120	122	124	126	128	130	132
	110	122	114	116	118	120	122	124	126	128	130	132	134
Fission elements			Ti+ Co	2 Mn Ti+Ni	Fe+Mn	2 Fe	Fe+Co	2 Co	Ni+Co	2 Ni	Ni+Cu	2Cu	

#D is the number deuterons added.

Bold indicates stable isotopes.

Italic indicates radioactive and produces stable isotopes after fission.

Normal indicates radioactive and produces radioactive isotopes after fission.

a Pd cathode, Pt anode, and an electrolyte containing D_2O. These elements are located within a few tens of microns of the surface and hide a substantial portion of the underlying palladium.

2.6. Energetic radiation

Nuclear reactions are expected to produce radiation that can be used to determine the nature of the reaction. For many years, failure to detect expected radiation was a reason for skepticism and frustration. At the very least, X-ray radiation should be detected from the slowing-down process of energetic particle emission and gamma radiation. Both should be detectable well away from the source using simple detectors such as film or Geiger-Mueller counters. Such radiation has been reported occasionally, although its magnitude is much smaller than required to explain heat or transmutation products.

Charged particles have a much shorter range and must be sought very close to the source. Until CR-39 was used, detection was not possible in electrolytic cells although such radiation was found during gas discharge using other kinds of detectors. The apparent absence of such radiation encouraged people to propose mechanisms that did not require energetic emissions. The characteristics of detected radiation must now be examined carefully to determine whether

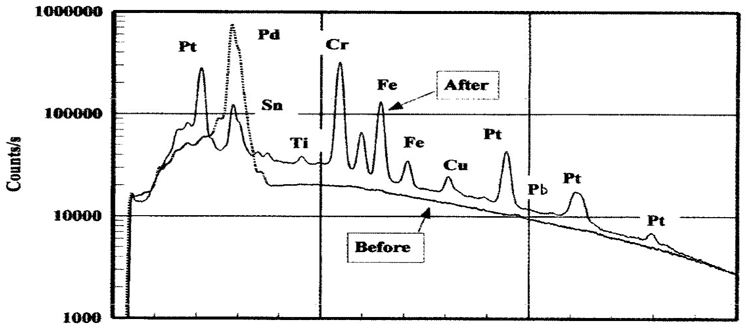

Figure 5. EDX examination of a palladium cathode before and after electrolysis [27].

these mechanisms are necessary and to discover exactly how the nuclear energy is dissipated. Because different energy is applied and different detectors are used, radiation from electrolysis and gas discharge are discussed separately.

2.6.1. *X-ray emission during electrolysis*

Electrolysis involves so little energy that emission of X-radiation from processes other than nuclear is unexpected, yet such radiation has been reported many times. This provides one more clear indication of a nuclear reaction being the source of the anomalous energy.

The X-ray emission from electrolytic cathodes using dental X-ray film revealed a point source that appeared to be well focused [29]. When X-ray energy is measured, the results are consistent with K-α radiation from elements present on the surface along with some Bremsstrahlung [30–32]. The radiation flux correlates with the amount of heat being produced [33,34]. However, the measured flux is very low, no doubt caused by absorption in the cell wall as calculated by Violante et al. [35]. Bursts of radiation reveal the erratic nature of the process, a fact that is not visible in the heat measurement because the large time constant typical of calorimeters smoothes the process. A process that can eject an electron from a K-α state, which for Pd requires about 19 keV, must be considered

2.6.2. *Particle emission during electrolysis*

After many failed attempts, particles of various kinds having a range of energies are found during electrolysis using D_2O. Because their range is very short, detection requires placing CR-39 very close to the cathode. Passage of energetic particles modifies the plastic, producing a pit when some plastic is dissolved away by subsequent application of concentrated NaOH. The energy and type of radiation can be estimated from the size and shape of the pit.

Mosier-Boss et al. [36] found pits on pieces of CR-39 after exposure to radiation from cathodes made from three different metals. Each was subjected to electrolysis in $D_2O + LiCl + PdCl_2$ in the same cell while Pd was deposited on each metal surface. The front side of the CR-39 shows the effect of what are identified as alpha particles with energy near 1 MeV and pits on the backside are produced by radiation identified as neutrons. The silver cathode (Ag), which readily absorbs neutrons, did not generate radiation that is able to penetrate to the backside.

Lipson et al. [37] constructed an electrolytic cell with a cathode made by oxidizing Pd and plating one side with gold. This was reacted with deuterium using the electrolytic method and placed next to a silicon barrier detector while under vacuum. The energy of particles emitted during removal of deuterium is shown in Fig. 6. Notice most particles have energy near 0.7 MeV, with a rapid drop in number at higher values. Lower energies may be present, depending on where the lower detection-limit was set. Some of the peaks near 8 MeV might be caused by radon. Although the particles were identified as alpha, this conclusion is questionable, which also raises doubts about the assigned energy. Nevertheless, the emitted particles appear to have a range of energy with most having low energy. Based on the small flux, apparently only a very small part of the sample was active.

In contrast to evidence for conventional particles having relatively low energy, Oriani and Fisher [38,39] used CR-39 to detect particles able to cause secondary reactions well outside of the apparatus. These are detected within the electrolytic cell as well as up to 8 cm from the cathode after having passed through the electrolyte and glass. As suggested by Kowalski [40], these might be energetic neutral particles emitted from an unconventional source.

2.6.3. *Particle emission during gas discharge*

Particles emitted from the cathode during and after low-voltage gas discharge in D2 have been detected using a silicon barrier detector (SBD), from which energy can be determined after the kind of particle is identified using absorbers. Energy is reduced by an amount proportional to the absorber mass-density that depends on the kind of particle being

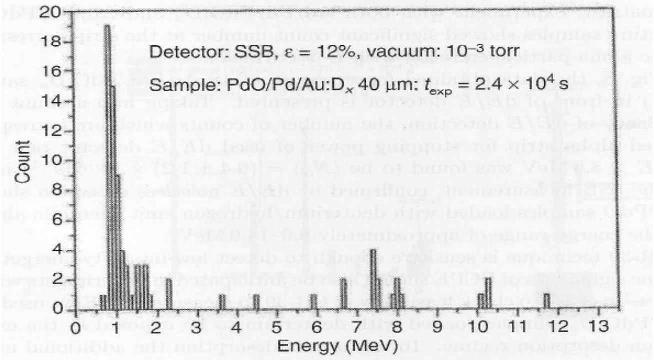

Figure 6. Particles emitted from PdD as deuterium is removed [37].

detected. Alphas are easy to identify this way but protons and deuterons are more difficult to differentiate from each other because they have similar absorption characteristics.

Karabut et al. [41] produced a discharge in D2 using a Pd cathode and less than 500 V. Immediately after the discharge was stopped, the spectrum shown in Fig. 7 was recorded using a silicon barrier detector. The radiation at 3.5 MeV was identified as alpha using absorbers. Presumably, this radiation resulted from a nuclear reaction as the deuterium content slowly decreased from the rate produced by the discharge.

Too much electrical noise prevented the spectrum from being recorded during discharge. This delayed reaction, so called life-after-death, was explored by Savvatimova [42] by measuring the total current produced by emitted ions and by observing exposure of X-ray film. Evidence for strange radiation having extraordinary penetrating power was also found, similar to reports by Oriani and Fisher [43], Matsumoto [44], and Lochak and Urutskoev [45].

Storms and Scanlan [46] (Fig. 8) observed an energetic particle spectrum during discharge in D_2 at 794 V using a silicon barrier detector. The particles were tentatively identified as deuterons and distinguished from electrical noise using absorbers. The lowest energy that could be measured was about 0.5 MeV, with decreasing numbers of particles with greater energy, similar to the behavior found by Karabut et al. [41]. The question is, “What process produces this type of energy spectrum”?

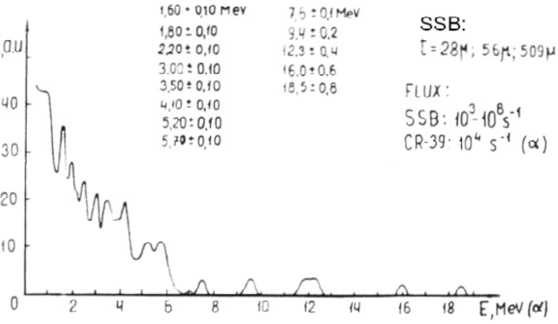

Figure 7. Energy of particles emitted immediately after discharge in D2 was stopped [41].

3. General Requirements of Theory

A comprehensive theory has been slow to develop because several ad hoc assumptions are required to explain the "impossible" behaviors. Now that the field has a large body of experimental data, a rational basis exists to reject or accept many proposed theories. This understanding is summarized below.

The nuclear reactions occur where deuterium concentration is the greatest, which includes the surface of electrolyzing cathodes and the surface of nanoparticles of certain metals and alloys. These environments have very little relationship to the properties of b-PdD, which have been used as the basis for many mechanisms. In addition, the nuclear-active environment (NAE) has additional unknown features that are rare to form. These facts need to be applied to a proposed theory.

The major heat producing reaction is unconventional fusion between deuterons to produce helium-4, which can occur at rates in excess of 10^{12} He/second as bursts. Helium results in preference to the other products because a mechanism is available in a solid to dissipate the resulting energy and achieve a product having the lowest energy. In contrast, the only mechanism available in plasma to create helium requires emission of gamma radiation, which is rare. Consequently, the other less-energetic paths are taken in plasma because they can use energetic particles to dissipate energy, as summarized in Table 1.

Other possible but rare reactions involve additions of multiple deuterons to nuclei of various elements in the NAE, i.e. transmutation and production of tritium. Formation of radioactive elements other than tritium is rare but not impossible. Neutrons do not play a role in these reactions, neither as reactants nor as products. Protons have a limited role and deuterons are the main reactant.

Energy is released from these reactions by energetic particles without gamma emission. The energy of these particles is smaller than expected to result from the proposed source reaction and is too small to allow detection except very close to the source. Some energy might be absorbed directly into the lattice, but this process has no direct evidence and might have no importance once all of the particle emissions have been identified. Some of the particles have strange properties, making identification even more difficult.

Regardless of the reaction, the resulting particle energy can produce secondary reactions, resulting in neutron and/or gamma emission, if their energy is above critical values. Failure to detect significant amounts of such radiation indicates existence of a mechanism that can reduce the energy below these values. Measurements show that the observed particle energy is well below the energy released by a fusion or transmutation reaction. This realization places emphasis on

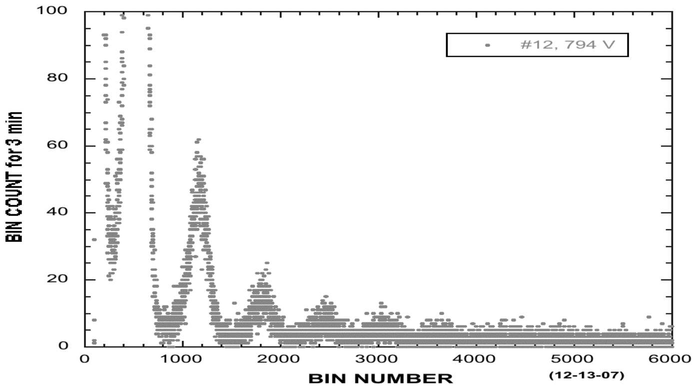

Figure 8. Spectrum of particles emitted during DC discharge at 794V in D_2 [46].

the low-end of the energy range as location of important particle energy and indicates the need for a process that can reduce energy to these low values.

A plausible theory must also be consistent with general scientific understanding. To get over a barrier, energy must be concentrated to a level equal to the barrier height. If the concept of tunneling is used, the energy must be high enough to produce the observed reaction rate. Accelerating the nuclei, as used to produce hot fusion, can achieve this result, but with some unintended consequences within the lattice. The atomic structure will not tolerate local high-energy without it being absorbed by various processes before it can reach levels required to affect nuclear interactions. Consequently, concentration of local energy is not possible. Instead, an exothermic reaction must occur for the process to be spontaneous and must be localized on a group of deuterons, called the active structure (AS) located within the NAE. This cluster allows multiple deuterons to enter a nucleus at the same time and cause the observed transmutation. This assumed process leads to several logical consequences. As energy is lost from the AS, electrons in the AS become more stable, hence increasingly less affected by the presence of a nearby nuclear charge. This allows them to remain fixed in locations, orbits, or energy levels that can hide the combined nuclear charge of the AS. Once this total charge is sufficiently hidden, the AS can approach and enter another nucleus, whether this is a deuteron or a heavier element. In other words, a two-step process is required. The first step involves incremental loss of energy until a special structure is sufficiently stable to overcome a Coulomb barrier. This process gives off energy that accelerates the reaction without requiring additional energy from the environment. Once this structure forms, a nuclear reaction occurs as the second step with a large release of energy that further accelerates the process. What type of mechanism might be consistent with these requirements?

4. Summary of Proposed Mechanism

The model is based on the assumption that a change must take place in a material for the nuclear reactions to be initiated. In other words, the required conditions are not present in normal material. This change must be identified along with all the consequences. This requirement is addressed as follows:

Two basic questions, in addition to the requirements noted above, need to be addressed by any theory. These are, "How can multiple deuterons enter a nucleus with high atomic number and how is the energy resulting from this reaction dissipated into the environment"? One possible answer is the involvement of deuterium clusters in both processes. While involvement of small clusters has been suggested in the past by several authors [47,48], this model solves a couple of problems by proposing the clusters have a large number of members, called in this paper "super-clusters" having a size that is described by the number of deuterons present, so-called number-size. However, the proposed size is less than clusters having 306 members as proposed by Miley. This concept is applied first to the transmutation reaction and then to fusion.

Up to 10 deuterons apparently can enter a nucleus. For this to happen as a single event, all must be at the same place at the same time. For all members of the cluster to enter at the same time, they also must be located close together compared to nuclear dimensions and their nuclear charge must be hidden from the target nuclei. These requirements imply existence of an unusual bonding state that can form within a group of deuterons. The nature of this state will not be discussed here, but will be a subject for future papers.

Clusters of deuterons are proposed to form by an exothermic reaction requiring a catalyst or template. Once the basic structure of the cluster has formed on the surface of this special material, it detaches and diffuses in random directions within the solid lattice. Initially, this seed structure cannot cause fusion or transmutation because it has not released enough energy. Energy is released in small units as each deuteron is added, causing the effective nuclear charge of the assembly to be increasingly hidden. For example, in the Iwamura study, cluster seeds form on the surface of the CaO and these diffused through 400 Åof Pd to the surface where target nuclei have been deposited. During the trip, the seeds grow in number-size as they encounter an increasing concentration of deuterons streaming in the opposite direction.

A transmutation reaction is only possible after the number-size has increased enough to hide the nuclear charge of the assembly and to reduce the physical size comparable to that of the target nucleus. Presumably, in the Iwamura study, clusters do not become active until they reach the deposited targets, where reaction with the deposited targets as well as with the much more numerous palladium nuclei become possible. A similar process might occur in studies [49–56] during which deuterium is simply allowed to diffuse through palladium, which produces a small amount of heat and transmutation products.

This special material is rare so that cold fusion occurs infrequently and only when and where the material is present. The observed delay in starting power production is proposed to be caused by slow formation of this material and slow growth of clusters to a reactive number-size. The rate of cluster growth is influenced by the concentrations of AS and deuterons. Therefore, nuclear reactions will have the highest rate where deuteron concentration is greatest. This concentration determines how fast cluster size increases and the probability of an active cluster finding a deuteron with which to fuse one of its members.

The AS is slow to form because it is a complex combination of certain atoms that seldom result in the require structure. Several different combinations of several different elements are probably active, all in the form of nanoparticles. Consequently, the NAE is located on the surface of nanoparticles that are formed on a surface or present after having been placed in the apparatus fully formed. Naturally, not all such particles are active. As a result, the amount of power produced by a cell is highly variable, as is observed. Power output will also be highly variable over short and long times, as observed, because active clusters will be destroyed by energy release and new ones will have to form by a random process. The challenge is to identity nature of the active nanoparticle and to make these in large amounts. Only then can the effect be made reproducible and a source of significant power.

Once a cluster reacts with a target nucleus, how is the considerable energy dissipated? If the cluster has more members than can be fully absorbed by the target, the extra members are proposed to carry away the energy. The number of extra members would have to be large enough so that the energy of each emitted deuteron is too small to cause significant secondary reactions. Furthermore, a transmutation reaction would have to be impossible before this large number had been achieved to prevent this requirement from being violated. Therefore, the nuclear charge must be increasingly hidden as the number-size increases and a critical number, determined by the charge on the target nuclei, must be reached before reaction is possible.

The probability of a fusion reaction between a cluster and a deuteron is expected to increase as number-size increases, resulting in competition between further increase in number-size and the fusion reaction. Therefore, fusion will have a higher rate than does transmutation and compete with transmutation by removing clusters that might grow enough members to cause transmutation. However, even a fusion reaction will require the cluster to be large enough to avoid secondary reactions. Because a random range of number-sizes are expected to react, the energy of emitted deuterons is expect to have a range of values, from ones that are difficult to detect to a few that are energetic enough to produce secondary reactions, similar to the spectrum of particle energy shown in Figs. 6–8. This range is expected to be sensitive to conditions and applied energy, which might explain the observed wide range of reported energies for detected particles. Also, some of the emitted particles might be neutral or be a fragment of the original cluster, which would complicate identification and measurement of energy. A cluster fragment, if it retains the unique bonding characteristics, might not be stopped easily by matter and could explain the behavior of reported “strange” radiation.

The proposed model is still very incomplete and ignores many observations. Nevertheless, the logic suggests a new way to look at the problem that might be helpful in development of more complete models.

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