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Role of cluster formation in the LENR process

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Abstract

Presence and absence of expected radiation, occurrence of nuclear reactions having only one apparent product, and transmutation reactions involving addition of more than one deuteron all indicate involvement of large clusters of deuterons in the LENR process. These clusters are proposed to hide their Coulomb barrier and to react with isolated deuterons to produce fusion and to react with larger nuclei to produce transmutation. Members of the cluster not directly involved in the nuclear reaction might be scattered by the released energy, thereby allowing momentum to be conserved and the resulting energy to produce particles having energy too small to be easily detected or to cause easily detectable secondary reactions. Justification of this model is discussed. This proposed model is consistent with most observations, but raises additional questions about the nature of such super-clusters and other ways the energy may be communicated directly to the lattice that will be addressed in future papers.

1. Introduction

Many attempts have been published in an attempt to explain how fusion and transmutation are possible at or near ambient conditions in solid materials. A successful theory must show how the Coulomb barrier is lowered and how the resulting energy is dissipated into the environment. This dissipation process can be imagined to take two forms: emission of energetic radiation or dissipation of energy directly into the environment. If radiation carries the energy, the amount detected should be consistent with the amount of heat produced. Some radiation has been detected but not enough to account for the energy being generated as heat. Consequently, either several processes dissipate the energy or most emitted radiation is absorbed before it reaches the detector. In addition, the energy of emitted particles must be too low to produce secondary reactions that should be easy to detect. This paper will explore one possible mechanism for production of energetic particles fitting these requirements.

The cold fusion process can release a large amount of energy from very energetic nuclear reactions. This aspect of the phenomenon has been demonstrated by too many studies, as reviewed by Storms,[1] to cite here and needs to be accepted as an important characteristic of cold fusion. Conventional nuclear reactions release energy either promptly as radiation, consisting of energetic particles and/or gamma emission, or slowly as radioactive decay. The only known example of direct coupling of nuclear energy to an atomic lattice is the Mossbauer Effect. However, the energy involved in this process is much smaller than that produced by the nuclear reactions associated with cold fusion, which makes this mechanism hard to relate to the cold fusion process. If radiation has sufficient energy, secondary reactions will be detected, which can reveal more information about the process. Absence of such secondary radiation limits the possible energy of the primary energetic particle. Nevertheless, a variety of particle and X-ray energies are reported, which demonstrate that not all energy is being directly deposited in the lattice. In addition, a model must explain the observed complex collection of emission energies and types of detected radiation.

Most models focus on the periodic structure that exists in solid PdD as being the location of the nuclear active environment (NAE). In contrast, this proposal draws attention to the surface of nanoparticles where large clusters of deuterium are thought to form. These clusters are proposed to be involved in the initiation of the fusion and transmutation reactions as well as allowing at least some energy to be released into the environment as energetic particles without producing easily detectable radiation. Logic requires the clusters to contain many more deuterons than has been considered in the past, so called super-clusters.

Although the cluster concept is not new, the full extent of their involvement, their proposed large size, and the location of their formation have not been published before. This paper shows the logical connection between this concept and observed behavior.

2. Discussion

Table 1 summarizes some of the possible fusion reactions. In each case, two products are formed and observed to result when high energy is applied. Two products allow momentum to be conserved while depositing the energy into the environment. If only one product is observed, a different type of reaction must be proposed to achieve the same result.

Table 1. Reactions resulting from fusion involving deuterons.

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

For example, many studies have shown that helium results when extra heat is produced.[1] Because the expected gamma of 23.5 MeV is absent, the reaction cannot occur as written in Table 1. A more complex process must take place. Takahashi[2, 3] proposed that four deuterons came together as a cluster to form two helium nuclei each of which carry away 23.8 MeV and the necessary momentum. Such a reaction conflicts with the absence of significant neutron radiation resulting from the well-known (α, n) reaction, mainly involving lithium, that such high-energy alpha will initiate. Consequently, a small cluster, the members of which completely fuse, is not consistent with observation, even if a plausible process, such as formation of a Bose-Einstein Condensate [4], could create the cluster. While many models have been proposed to avoid some of these issues, each has limitations that encourage a new approach.

Creation of isotopes and elements not present in the initial environment by addition of deuterons to the nucleus of certain elements has been frequently reported.[1] While some elements or isotopes might have been present as contamination, this argument has not been applied successfully to all the observed reactions. Two studies stand out in showing the role of clusters in such transmutation reactions. For the first, Iwamura et al. [5-9] in a series of papers claimed to detect the reactions shown in Table 2. Clusters containing as many as 6 deuterons are required to enter the nucleus as a unit. However, a problem remains to explain how the significant energy released by the process is communicated to the environment. Clearly, something must be emitted that is not detected, as indicated by the question mark.

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

Ba + 6d = Sm + ?, Q=67.6 MeV
Cs + 4d = Pr + ?, Q = 50.5 MeV
Sr + 4d = Mo + ?, Q= 53.4 MeV
Cs + 2d = La + ?, Q = ~24 MeV

The second study involves the work of Miley et al.[10, 11]. His results, based on use of SIMS, AES, EDX and NAA for analysis, is summarized in Fig. 1[2]. The work is based on the use of thin films of nickel and/or palladium with a small amount of platinum as an impurity from the anode and perhaps a little sulfur as an impurity from the electrolyte, which contained Li_2SO_4 in H_2O. Elemental analysis was made before and after electrolytic action. The general pattern shows the following: regions of atoms having high concentration are found 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

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[1] This work has been previously evaluated 1. Storms, E.K., *The science of low energy nuclear reaction*. 2007, Singapore: World Scientific. 312. and is too extensive to cite here.

[2] Although of poor quality, this is the only representation of the summary that is available.

the low mass sides. The question is, “What process can explain these general observations”? Transmutation requires a target nucleus to which something is added. The possible addition of neutrons, protons or deuterons to Pd is explored next.

Figure 2 shows the position of the stable isotopes near palladium with respect to their atomic number and atomic weight. If neutrons are 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 the upper limit of the Miley data, 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 radioactivity is not detected even though this would be an easy measurement. Therefore, 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 for protons.

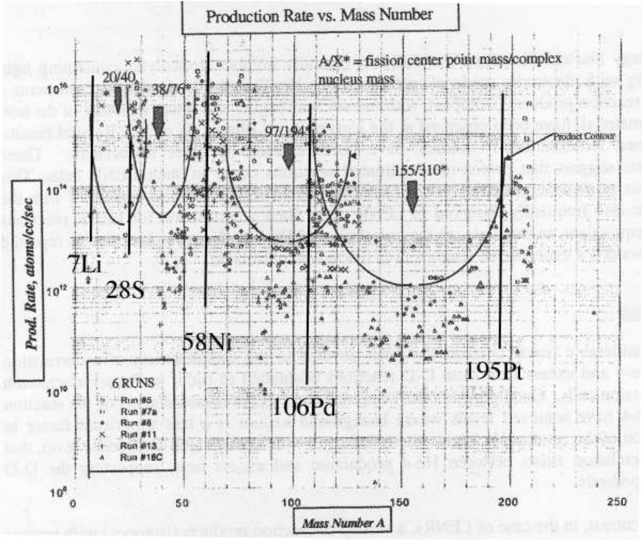

Fig. 1 - Log rate of production vs mass number of elements produced in thin films by electrolysis in H_2O + Li_2SO_4.

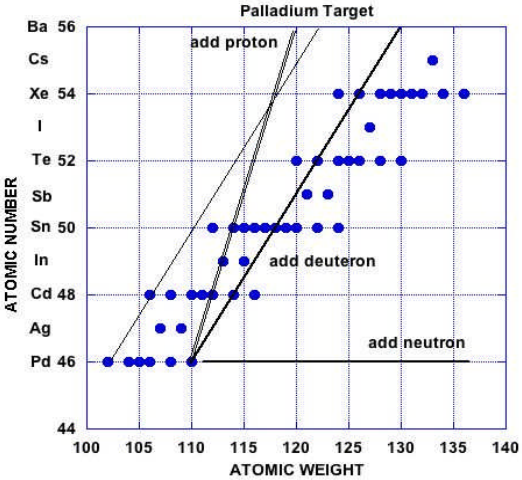

Fig. 2 - Stable elements as a function of atomic weight and atomic number near palladium.

Radioactive isotopes are produced above mass 114, which is not high enough to explain the full range of reported data. Only addition of deuterons results 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 normal water being in the electrolyte. Apparently, deuterons, regardless of their concentration, produce active clusters and most transmutation. In the case of elements having a mass lower 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 several authors. Because the resulting nuclei are at and near iron, additional energy can be released by formation of these very stable nuclei. Consequently, a certain fraction of nuclei resulting from addition of deuterons to Pd split into two parts during the transmutation process and may account for the frequent reported presence of iron on the palladium cathode of electrolytic cells. These two studies, as well as many others, suggest a role for clusters containing at least 8 deuterons in the transmutation process. Where are these clusters formed?

The only universal feature found in all successful cold fusion experiments are nanoparticles. These form slowly on the surface of electrolytic cathodes, they form as a result of gas discharge, and they are known to be active when certain such materials are exposed to deuterium gas.[12, 13] Consequently, a feature associated with such a structure can be assumed to initiate all of the observed cold fusion reactions.

The difficulty in producing cold fusion indicates a special condition is required before the nuclear reaction can occur, presumably after nanoparticles are formed. This special condition is hard to create, occurs only in small and variable amounts, and presently is produced largely by accidental conditions within the apparatus. Where is this special condition located?

McKubre et al. used the following equation to describe excess power (EP) obtained from wire cathodes in a Fleischmann-Pons cell. [14, 15]

$$EP = M*(x-x_o)^2*(i-i_o)*\square x/\square t,$$

where x_o= critical average D/Pd of the bulk cathode, i_o= critical average I/cm^2

We can expand this equation by adding the equation:

$$M = n * [nae],$$ where [nae] is the amount of NAE having ‘n’ efficiency.

Consequently, the heat producing reaction favors locations where the deuterium concentration is greatest. This location exists at the surface of the cathode in an electrolytic cell and on the surface of nanoparticles.[16-18] 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. This analysis reveals the bulk composition is only important because it affects the surface composition where the nuclear reactions actually occur.

3. Conclusion

The goal of this paper is to show a logical connection between selected observations and a proposed mechanism involving energetic particle emission and super-clusters without describing exactly how the mechanism works. In addition, the proposed mechanism is not likely to be the only one operating. The nature of the proposed super-cluster and its manner of formation will be subjects of future papers.

A mechanism must dispose of energy resulting from a nuclear reaction in a manner consistent with observation and known laws of nature. The same mechanism is expected to operate regardless of the energy source, whether it is fusion or transmutation. The absence of detectable gamma radiation when helium is produced means the energy is either being directly absorbed by the lattice[19-21] or particles are being emitted by an unconventional process and these are absorbed before most can reach a detector. The fact that some particles do reach a detector[22-24] puts greater emphasis on the role of energetic particles and the need to find the unusual mechanism for their creation. Indeed, the nature of these particles and the mechanism of their formation is the unique challenge facing any theory of cold fusion. One solution to this challenge involves clusters, but in a way that has not been suggested before.

Clusters of deuterons are clearly involved in transmutation reactions. Apparently, a variety of new elements are made based on the number of deuterons in an active clusters and availability of suitable targets. Various rules must determine how many d can enter at the same time to avoid producing radioactive products, which are rarely found. We next assume the same mechanism is operating to cause fusion between deuterons.

The fusion rate will depend on the number of active clusters and the concentration of deuteron targets. Consequently, the fusion rate will be more sensitive to the deuterium concentration than is transmutation. Because clusters are made from deuterium and form where the deuterium concentration is greatest, fusion as expected to occur close to where clusters form. Transmutation, on the other hand, is expected to occur at a distance from the site of cluster formation, as has been observed.

For any nuclear reaction to occur, the clusters must hide their nuclear charge. Fusion would require less reduction in charge than does transmutation, hence would involve smaller[3] hence more numerous clusters. However, the charge-hiding process requires a critical number of deuterons to be in a cluster before it becomes active. Even though small clusters are more numerous, they are not able to initiate a nuclear reaction until a critical number of deuterons are combined. This charge-reduction process is an essential feature of this model, but will not be addressed here.

Once a cluster reacts to produce a nuclear reaction, energy is dissipated. While this process might involve direct coupling of some energy to the atomic lattice, this paper focuses only on a method for particle production. If the cluster contains more deuterons than actually enter the nucleus during transmutation or are involved in the fusion reaction, these extra deuterons are proposed to dissipate the energy as energetic deuterons. However, the energy of these particles must be low enough not to produce secondary reactions, such as fusion with other deuterons the emitted deuterons might encounter. Consequently, the majority of clusters involved in the fusion reaction would need to contain nearly 50 deuterons and even more when transmutation occurs if all energy is dissipated this way. However, active clusters would not all have the same size, resulting in a spectrum of sizes. The complex variety of observed particle energies would result from clusters of various sizes being involved in a nuclear reaction. For example, Karabut et al.[25] detected a spectrum of individual peaks corresponding to energies from about 1 MeV to 18.5 MeV that they identified as alpha emission. This emission occurred immediately after glow discharge in D_2. This observation is similar to the radiation spectrum of individual peaks reported by Storms and Scanlan[26] during glow discharge that they attributed to deuterons. This behavior can be explained by energy being shared between a different number of deuterons. Smaller, less abundant clusters would produce a few very energetic emissions that could produce secondary radiation. This rare energetic primary radiation might be detected occasionally as periodic but low intensity secondary neutron emission. Meanwhile, most deuterons would have energy too low to be easily detected and too low to produce secondary reactions. While the large cluster size required by this logic seems implausible, the proposed process should be explored, perhaps in relationship to other dissipation processes.

These clusters of deuterons are proposed to form by an exothermic reaction requiring a catalyst or template. Once formed, an active cluster is small enough, thanks to its unusual structure, to diffuse through the PdD lattice and react with targets of opportunity. This catalyst is rare so that cold fusion occurs infrequently only when and near where this catalyst is present. This rarity results because the catalyst is proposed to be a complex combination of certain atoms that seldom combine in the require formation. 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 will be active. As a result, the amount of power produced by a cell will be highly variable, as is observed. The challenge is to identity the 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.

Depending on their size, these clusters react with deuterons where the deuterium concentration is highest to produce d-d fusion and with other atoms to generate transmutation products at a lesser rate. The environment in which this occurs is very inhomogeneous and complex, resulting in a wide variation in reaction rates including no detectable rate. The process can be detected by measuring short-range particle emission, low-energy X-rays, He^4, and extra heat. Tritium may be produced by clusters having a critical number of deuterons, hence is a rare product.

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 the development of more complete models. While many questions remain, the approach has many ways it can be tested and suggests how the cold fusion effect might be increased.

References

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[3] Smaller means fewer deuterons. The actual dimension is proposed to become smaller as the number of deuterons increases in a cluster as a result of an increased number of bonding states.

1. Storms, E.K., *The science of low energy nuclear reaction*. 2007, Singapore: World Scientific. 312.
2. Takahashi, A., *Some considerations of multibody fusion in metal-deuterides.* Trans. Fusion Technol., 1994. **26**(4T): p. 451.
3. Takahashi, A. *Tetrahedral and octahedral resonance fusion under transient condensation of deuterons at lattice focal points*. in *ICCF9, Ninth International Conference on Cold Fusion*. 2002. Beijing, China: Tsinghua University: Tsinghua Univ., China.
4. Kim, Y.E. and A.L. Zubarev. *Ultra low-energy nuclear fusion of Bose nuclei in nano-scale ion traps*. in *8th International Conference on Cold Fusion*. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy.
5. Iwamura, Y., et al., *Detection of anomalous elements, X-ray and excess heat induced by continuous diffusion of deuterium through multi-layer cathode (Pd/CaO/Pd).* Infinite Energy, 1998. **4**(20): p. 56.
6. Iwamura, Y., et al. *Correlation between behavior of deuterium in palladium and occurance of nuclear reactions observed by simultaneous measurement of excess heat and nuclear products*. in *Sixth International Conference on Cold Fusion,Progress in New Hydrogen Energy*. 1996. Lake Toya, Hokkaido, Japan: Lake Toya, Hokkaido, Japan.
7. Iwamura, Y., et al., *Detection of anomalous elements, X-ray, and excess heat in a D_2-Pd system and its interpretation by the electron-induced nuclear reaction model.* Fusion Technol., 1998. **33**: p. 476.
8. Iwamura, Y., et al. *Observation of nuclear transmutation reactions induced by D_2 gas permeation through Pd complexes*. in *ICCF-11, International Conference on Condensed Matter Nuclear Science*. 2004. Marseilles, France: World Scientific.
9. Iwamura, Y., et al. *Observation of surface distribution of products by X-ray fluorescence spectrometry during D_2 gas permeation through Pd cathodes*. in *Condensed Matter Nuclear Science, ICCF-12*. 2005. Yokohama, Japan: World Scientific.
10. Miley, G.H. and J.A. Patterson, *Nuclear transmutations in thin-film nickel coatings undergoing electrolysis.* J. New Energy, 1996. **1**(3): p. 5.
11. Miley, G. *Characteristics of reaction product patterns in thin metallic films experiments*. in *Asti Workshop on Anomalies in Hydrogen/Deuterium Loaded Metals*. 1997. Villa Riccardi, Rocca d'Arazzo, Italy: Italian Phys. Soc.
12. Arata, Y. and Y.C. Zhang, *Formation of condensed metallic deuterium lattice and nuclear fusion.* Proc. Jpn. Acad., Ser. B, 2002. **78**(Ser. B): p. 57.
13. Arata, Y. and Y.C. Zhang, *Anomalous production of gaseous ^{4}He at the inside of 'DS cathode' during D_2O-electrolysis.* Proc. Jpn. Acad., Ser. B, 1999. **75**(10): p. 281.
14. McKubre, M.C.H., et al. *Concerning reproducibility of excess power production*. in *5th International Conference on Cold Fusion*. 1995. Monte-Carlo, Monaco: IMRA Europe, Sophia Antipolis Cedex, France.
15. McKubre, M.C., et al., *Replication of condensed matter heat production*, in *ACS Symposium Series 998, Low-Energy Nuclear Reactions Sourcebook*, J. Marwan and S.B. Krivit, Editors. 2008, American Chemical Society: Washington, DC. p. 219.
16. Dus, R. and E. Nowicka, *Segregation of deuterium and hydrogen on surfaces of palladium deuteride and hydride at low temperatures.* Langmuir, 2000. **16**(2): p. 584.
17. Kuji, T., et al., *Hydrogen absorption of nanocrystalline palladium.* J. Alloys and Compounds, 2002. **330-332**: p. 718-722.
18. Marwan, J., *Study of the nanostructured paladium hydride system*, in *ACS Symposium Series 998, Low-Energy Nuclear Reactions Sourcebook*, J. Marwan and S.B. Krivit, Editors. 2008, American Chemical Society: Washington, DC. p. 353.
19. Hagelstein, P.L. *Phonon-exchange models: Some new results*. in *11th International Conference on Cold Fusion*. 2004. Marseilles, France: World Scientific Co.
20. Chubb, S.R. *Roles of approximate symmetry and finite size in the quantum electrodynamics of $d+d={}^4$He in condensed matter nuclear science*. in *8th International Workshop on Anomalies in Hydrogen/Deuterium Loaded Metals*. 2007. Catania, Sicily, Italy: The International Society for Condensed Matter Science.
21. Chubb, T.A. *The dd cold fusion-transmutation connection*. in *Tenth International Conference on Cold Fusion*. 2003. Cambridge, MA: World Scientific Publishing Co.
22. Szpak, S., P.A. Mosier-Boss, and F. Gordon, *Further evidence of nuclear reactions in the Pd/D lattice: emission of charged particles.* Naturwiss., 2009.
23. Mosier-Boss, P.A., et al., *Characterization of tracks in CR-39 detectors obtained as a result of Pd/D Co-deposition.* Eur. Phys. J. Appl. Phys., 2009. **46**: p. 30901.
24. Lipson, A.G., A.S. Roussetski, and G. Miley, *Energetic alpha and proton emissions on the electrolysis of thin-Pd films.* Trans. Am. Nucl. Soc., 2003. **88**: p. 638.
25. Karabut, A.B., Y.R. Kucherov, and I.B. Savvatimova, *Nuclear product ratio for glow discharge in deuterium.* Phys. Lett. A, 1992. **170**: p. 265.
26. Storms, E.K. and B. Scanlan. *Radiation produced by glow discharge in a deuterium containing gas (Part 2).* in *American Physical Society*. 2008. New Orleans.