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COLD FUSION FROM A CHEMIST'S POINT OF VIEW

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ABSTRACT

Very small cracks are proposed as the location of the LENR process in a material. A resonance process is proposed to occur in these structures, resulting in fusion, while energy is emitted as coherent photons having a characteristic energy. The nuclear product depends on which isotope of hydrogen is present. Reasons are given why a crack structure is required to explain LENR.

INTRODUCTION

The phenomenon called low energy nuclear reaction (LENR) or cold fusion[1] requires solution of three basic problems. The first problem involves proving the phenomenon is real. This has now been done,[2] as attested by hundreds of papers describing the behavior, a major scientific journal (*Naturwissenschaften*) offering its pages to the subject, a major company (National Instruments) publicly endorsing the claims and dozens of laboratories in many countries continuing to study the phenomenon for over 22 years. Apparently, unexpected nuclear reactions can be initiated on occasion in what appear to be ordinary materials under ordinary conditions. The second problem requires learning the conditions required to make the effect occur on demand and especially at a high rate. This goal is still unattained, but growing closer. Public demonstrations of the effect have been made and several companies are proposing to develop a commercial product.[3,4] Nevertheless, the effect is still difficult to replicate. Finally, the third problem requires the mechanism be identified and the process understood. This problem is far from being solved, with many attempts being made without much success. I would like to suggest this failure is caused by trying to solve the problem the wrong way. Instead of using an approach typical of physics, I suggest basic principles common to chemistry be used to first discover the location of the process and only then identify the basic characteristics of the mechanism. Clearly, ordinary materials do not spontaneously initiate nuclear reactions, as conventional science has discovered from centuries of observation. The effect requires changes in a chemical environment for it to occur at all, so why not start with this requirement? Once the rare and unusual conditions are discovered, only then should assumptions be made and mathematical equations be applied to reveal the details. This paper has two goals: to suggest rules that apply to all theories and to propose a model that explains all behaviors of LENR while following these rules.

A useful discussion of theory requires agreed upon rules. Without such rules, any idea, no matter how far from reality, has to be given equal consideration with each feature being endlessly debated. This distracts from finding the correct explanation. In addition, without such rules, experimental observations cannot be given agreed upon interpretation and, as a result, experimental design suffers. We have been like blind men looking for gold, with luck being the only reason for success. Several rules are suggested in this paper along with the most important being: Each assumption is clearly acknowledged and justified.

The starting assumption for this analysis is: A single unusual environment or condition is required to produce LENR and this can be created several different ways in several different materials. This assumption permits the many separate observations to be brought together into a common logical framework to create a *single* explanation for *all* observations. Of course new information is needed and some of the observations are wrong, but we have to start somewhere—in this case by using the best of what is available. Although this paper is written as a stand-alone, it continues the discussion started in the paper published in *J. Condensed Matter Nuclear Science*[5] and is based on my collaboration with Brian Scanlan.

Before cold fusion can be explained, its relationship to the hot fusion process and the Coulomb barrier must be understood.

DISCUSSION

Behavior of Hot Fusion

The Coulomb barrier between nuclei prevents nuclear interaction except under very special conditions. These conditions have been studied for over 100 years, resulting in well-understood behavior. Even though the energy required to overcome the barrier greatly exceeds energy available under normal conditions, it can be overcome several different ways. [Energy invested = k/r, where k is a constant and r is the distance between the centers of two hydrogen nuclei. The strong force is proposed to take over and complete the fusion process at a critically small value for r.] A hydrogen nucleus can be given kinetic energy by being accelerated or by increasing its effective temperature. This method requires considerable energy to create useful rates in plasma, as shown in Figure 1. In this case, the two colliding nuclei of hydrogen come together with enough energy to exceed the Coulomb barrier, resulting in two new nuclei that are emitted in directions and with energies required to conserve momentum. [The reaction takes two paths that produce t + p and n + He^3 in nearly equal amounts. Only the t (tritium)

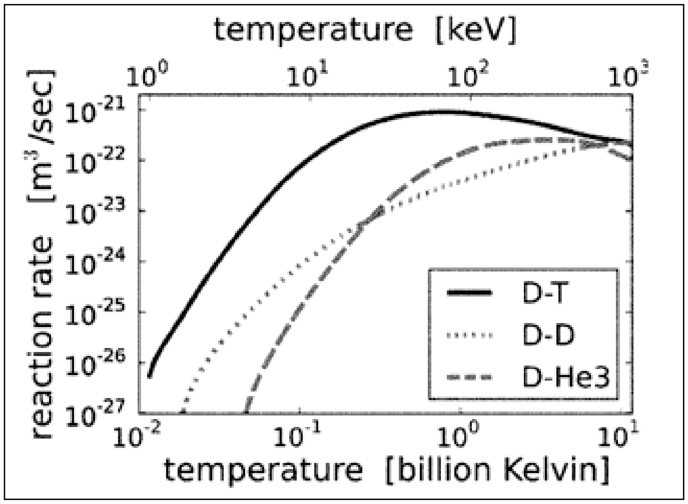

Figure 1. Energy required, expressed as temperature and keV, to cause fusion in a volume of plasma at the indicated rate (Wikipedia).

and n (neutron) are normally detected.] This process can be called the "two-in-two-out" rule, which is characteristic of all nuclear reactions initiated between two particles. When energetic deuterons are caused to bombard a material containing deuterons, the rate of fission is increased over that in plasma because the electrons in the material slightly reduce the effective barrier.[9-11] Nevertheless, this process also follows the two-in-two-out rule. In other words, when two nuclei combine in any environment, two or more particles must be produced in order to conserve momentum and dissipate the energy, as is taught in freshman physics. The barrier can also be reduced by using a muon[6,7] without applying energy. In this case, this heavy negative particle acts like an electron to form a D_2 molecule with a detectable fusion rate because the distance between the nuclei is sufficiently reduced. Calculations predict an observable rate[8] only at a distance less than 0.2 Å between nuclei. Consequently, even when two nuclei are caused to get sufficiently close without applied energy, the nuclear products follow the two-in-two-out rule. Other examples of this rule being followed can be found. For example, products from the hot fusion reaction have been detected when cracks initially form in material containing deuterium.[12-16] In this case, the very brief charge separation created by the process is thought to accelerate ions[17] to energies able to produce what is called fractofusion[18] and give typical hot fusion products. Even when helium is occasionally made during hot fusion, a gamma ray is the second product. Once again, the two-in-two-out rule is followed. In summary, forcing two d together by brute force, reducing the barrier using electrons, or allowing two d to get sufficiently close always results in two reaction products. Apparently no matter how the fusion reaction is initiated, it always satisfies the two-in-two-out rule. All of these examples produce typical hot fusion products, not those produced by cold fusion. This behavior must not be ignored even though it has been used to reject the claims for LENR.[19]

Behavior of Cold Fusion

The LENR process does not follow the two-in-two-out rule. Absence of this behavior makes LENR unique and creates a challenge. Instead, fusion between two d gives one helium nucleus without a gamma ray or any other detected particle.[20] [Occasionally, a trivial number of energetic particles such as alpha[21] or neutrons[22] are reported. The very low flux suggests they result only from minor secondary reactions that may not be directly related to LENR.] Even occasional production of tritium is not accompanied by the expected neutron or radiation. Transmutation produced by the cold fusion process also apparently violates the two-in-two-out rule.[23] In other words, *cold fusion is caused by a process completely different from and in conflict with the one causing hot fusion*. Therefore, attempts to explain cold fusion by proposing to concentrate energy or by forcing the d closer together is a waste of time because the typical hot fusion products would be expected. A different process is clearly causing fusion without the expected second particle being emitted. Apparently in this case, momentum is conserved in a different way compared to hot fusion. In addition, this process appears to operate in a rare and localized region of the material I call the nuclear active environment (NAE).[24] Finding where and how this unusual condition forms is part of any successful explanation. Let's start by discussing where I believe the NAE is *not* located.

Consequence of LENR Occurring Within a Chemical Lattice

A typical sample used to initiate LENR contains three separate regions with the bulk being a chemical structure consisting of a crystal lattice. This basic structure has a surface on which atoms are absorbed and contains flaws such as cracks. These different locations must be discussed separately because different rules apply. First, the situation within the chemical structure is discussed.

Some authors believe the entire chemical structure is involved.[25,26] This structure, called here the chemical environment (CE), consists of many different features including atoms located in well-defined positions determined by the lattice structure, vacancies where atoms are missing in this structure, slip planes or grain boundaries where the adjacent crystal structures do not align, and positions between the atoms—the so called tetrahedral or interstitial positions. [Atoms can be missing from both the metal and the deuterium sublattice in PdD. These two lattice sites have similar positions in the face-centered cubic structure, but have entirely different properties.] All of these features are determined by thermochemical properties of the chemical lattice and do not function as independent features. This environment does not include pores, holes, bubbles of gas and cracks, which are independent features determined by outside forces. These independent features will be discussed later. For LENR to occur in the CE, a change must convert part of an inactive lattice, which is the most common form, into a lattice in which nuclear reactions spontaneously occur. A proposed model must show why only these special locations, out of many other similar sites, become active and how this process takes place at a rate significant to explain the observed power. In the process, the description must also take into account several well-known laws.

Being a typical chemical system, the Laws of Thermodynamics apply to the collective behavior and the Law of Probability is used to describe random behavior of individual atoms and electrons. These random events might account for occasional nuclear products, such as the small amount of tritium found in volcanic lakes,[27] heat being generated in the deep earth,[28] or even the small neutron flux observed by Jones *et al.*[28] Nevertheless, once too many random "exceptions" occur, the average behavior is affected and the Laws of Thermodynamics apply. Consequently, the issue is magnitude. This magnitude can be quantified because we now know that more than 10^{11} events/sec must take place in that part of a material where the nuclear process occurs in order to give the frequently observed power of more than 1 watt when deuterium is used. Use of protium is expected to require a greater rate to generate 1 watt. [The overall reaction d + d = He^4 is now known to be the source of power when deuterium is used,[20] which means 2 d = 4.0271064 amu; 1 He^4 = 4.0014749 amu; Δ amu = -0.025632; energy = 23.875 MeV/He; rate = 2.6×10^{11} events/sec to generate 1 watt.]

The decision of which law applies depends on the fraction of the material in the sample involved in creating a nuclear reaction. If a significant fraction is involved in the process, the Law of Thermodynamics is used. A few random events involving a very small fraction of the nuclei or electrons are best described by the Law of Probability. Which of these laws applies can be answered by first identifying where in the material the NAE is located. A general location can be suggested from the behavior of the released helium[29-31] and tritium[32] combined with the observed location of transmutation products. These reaction products place the NAE within a few microns of the surface, with most of the material not participating in the nuclear process at all. In addition, even the general surface region might only contain a small fraction of active sites. This means that a small fraction of a small fraction of the total sample can be expected to be involved in the nuclear process. Consequently, 10^{11} "exceptions"/sec can be expected to represent a significant fraction of material at or near the active sites—perhaps too great a fraction to avoid applying the Law of Thermodynamics to the active region.

What do the Laws of Thermodynamics require? Any change in a chemical lattice requires a change in Gibbs energy. Most materials try and frequently succeed in achieving the lowest Gibbs energy for the conditions being applied. For example, the face-centered cubic structure of beta-PdDx forms because this has the lowest energy compared to any other structure. If conditions change, Gibbs energy comes or goes and x changes its value in response. Deuterons do not suddenly accumulate in large clusters, fill metal vacancies, or double-up in the deuterium lattice because this would require release of Gibbs energy, which cannot occur because the lattice has already achieved its lowest energy. In other words, unless the NAE is created initially as the lattice structure forms, it is not going to form spontaneously at some special site unless conditions cause it to become stable. One possible change in stability might involve a composition greater than D/Pd = 0.85 because heat production appears to require an average bulk composition greater than this value when electrolysis is used.[33] Presumably, once this composition is reached, the PdD converts to a novel form able to initiate nuclear reactions. However, no change in the properties of PdD near this composition has been observed to reveal such a change has taken place. In addition, not all materials having high deuterium content are observed to support nuclear activity and occasionally nuclear activity is detected at much lower compositions using other methods. These observations and requirements suggest other conditions besides the high deuterium content are important.

Nevertheless, a local special condition might happen on rare occasions by chance, a process that would be controlled by the Law of Probability. These laws show that the greater the number of atoms that are proposed to come together by chance, the smaller the probability that this number will actually accumulate. This process is identical to predicting how many heads a coin flip will produce in a row—with an increasing number being increasingly less likely. In other words, clusters of d cannot grow very large or very often by chance encounters, but must involve energy loss for them to cluster in significant numbers. To do this, the enthalpy of formation that binds the cluster together must be greater than the increased entropy resulting from the additional complexity times the temperature. [$\Delta G = \Delta H - T\Delta S$, where ΔG is Gibbs energy change, ΔH is the enthalpy of formation change, ΔS is the entropy change and T is the temperature. The greater the complexity of a structure, the greater its entropy, which then requires an increased change in enthalpy for it to form. As temperature is reduced, entropy becomes less important and complex processes with a very small enthalpy, such as BEC formation, can occur.] If this condition is satisfied, these conditions will occur throughout a normal lattice and not be unique to special regions as is required of the NAE, as pointed out in the previous paragraph. So far, we can conclude either the NAE forms by release of Gibbs energy, in which case it would be normally present throughout the CE, or it forms by chance, in which case the rate of formation would be too small to account for observed extra power. Of course, assumptions can be applied to avoid these conclusions, in which case the assumptions should be clearly stated and justified.

Some models propose to concentrate energy for the purpose of forming neutrons[34] or forcing the deuterons closer together. This proposal violates the Second Law of Thermodynamics that requires energy to always go from where it is greater to where it is less—from hot to cold, from high to low, from light to dark. Consequently, energy cannot be increased locally beyond certain very narrow limits, which are controlled by the Law of Probability. In this case, the greater the energy of a particle, the fewer particles will have this energy, which limits the number of active particles. When a random process does concentrate energy, a limit is created by the chemical nature of the environment, because too much local energy always finds ways to move elsewhere by interacting with the surrounding electrons. For example, a local energy of only 0.16 eV would break bonds between Pd atoms and be absorbed. Even electrons, as fundamental particles, can only acquire energy by moving or by occupying chemical states. Once this kinetic energy of motion becomes too large, it is rapidly reduced by interaction with many other electrons, as is well understood by observing how energetic electrons are absorbed by materials. No matter how energy is applied to a material, it moves as heat (phonons) to other regions, causes melting, or vaporizes nearby atoms. It never gets large enough to trigger a nuclear reaction unless it is present as large kinetic energy of a bombarding particle, in which case a two-in-two-out process occurs. In other words, any process that is proposed to occur spontaneously in a chemical system will cause physical-chemical changes long before it can cause a nuclear reaction. When a nuclear reaction does occur by external application of energy, the resulting reaction always follows the two-in-two-out rule. Once again, assumptions designed to avoid these basic behaviors have to be clearly stated and justified before they can be accepted.

For example, many theories ignore how gross materials are observed to behave by assuming nuclei and electrons are subjected to quantum rules, causing them to act as independent particles without interacting with their surroundings except to enter into nuclear reactions. This approach seems to contain a logical contradiction. If some unusual quantum effect is proposed as the process, this effect would be expected to have universal application and follow the laws described above, not just cause cold fusion. Deep electron states,[35] Bose-Einstein condensates (BEC),[36] large clusters,[37] quantum interaction,[25] "heavy" electrons[34] and structures[38] able to form Be^8 all involve proposed processes that would be expected to influence the chemical environment in obvious ways if the required rates of nuclear reaction were possible. In addition, in several cases the theories violate basic laws of Nature. Since this paper is not a critique of all theories, justification for this statement will not be given. The goal here is to suggest ways all theories need to be explained to avoid obvious conflicts with basic laws and understanding, which is the responsibility of those authors proposing an idea.

Consequence of LENR Occurring on a Surface

Several models are based on the unique property of nanoparticles to accumulate hydrogen to high concentrations.[39] This behavior is not relevant to the universal explanation we are seeking because the presence of nanosized particles cannot be identified during all successful production of LENR. Furthermore, no clear evidence supports nanoparticles as being the unique location of LENR under any condition even though some authors have made this claim.[40-42] Too many other plausible explanations exist.

Large clusters based on the Rydberg molecule have been proposed to form, especially on a surface.[37,43,44] These complex structures are proposed to be similar to a BEC and able to initiate fusion when formed from deuterium. Their ability to initiate fusion of protium has not been explained. In addition, dissipation of the resulting energy without detected radiation requires several implausible assumptions. These structures have been used to explain transmutation and suggested as a laser target for initiating a hot fusion reaction, but their ability to explain all aspects of LENR using all methods remains to be demonstrated.

Plausible Locations of the NAE

At this point, we are faced with a problem. LENR obviously takes place in a solid material, but we can reasonably conclude that LENR does not take place in most of the material. We are forced to suggest locations for the NAE outside of the chemical lattice if the limitations discussed earlier are to be avoided. Flaws or cracks in that chemical structure would provide the required unique sites while being rare and hard to create, thereby explaining the difficulty in replicating the behaviors. In addition, such flaws can be identified in material used during all successful attempts at causing LENR.

Flaws (cracks) can be created by stress relief at random locations to give flaws of a random size. This stress can be generated by gradients based on the hydrogen concentration and by local impurities added to the surface during electrolysis or by diffusion of impurities from the interior to the surface. The difficulty in causing LENR can be explained if the crack dimensions required to support LENR have a very narrow range of values. Besides these features, a crack or flaw has several other advantages over the NAE being in the chemical structure. These being: the Laws of Thermodynamics do not apply; advantage can be taken of the electric and magnetic symmetry that such a structure can provide; and a rigid structure of atoms is not present to interfere with a proposed process. The next challenge is to discover how a nuclear reaction could be initiated in such a flaw and how the resulting energy could be dissipated without violating the two-in-two-out rule and not producing radiation that could be easily detected outside of the apparatus.

To start the discussion, three assumptions are made as follows:

1. All LENR nuclear reactions occur in the same NAE.
2. All isotopes of hydrogen participate in LENR and result in fusion or transmutation, depending on unidentified details.
3. All fusion reactions involving isotopes of hydrogen are the result of the same basic mechanism.

Cracks are chosen as the universal NAE of LENR, thereby satisfying assumption #1. Next, we need to find a mechanism that can occur in a crack while satisfying assumptions #2 and #3. The following generalized process can be suggested and described using the crack configuration to achieve fusion without violating the two-in-two-out rule, conservation of energy, laws of thermodynamics, or any other law of physics.

Proposed Mechanism Causing LENR

Nuclei of hydrogen (all isotopes) might be confined by a crack structure in a special way. These nuclei can be imagined as floating equidistance between the walls of the crack supported by the charge present on each wall. If the separation were greater, the nuclei would be absorbed on each wall in the normal manner; if the separation were less, the nuclei would be tightly bound to the lattice structure. In other words, they are equally absorbed on each surface but not as tightly bound as they would be in the absence of the opposite surface. As a result, they can be considered to be floating in space with considerable freedom of movement. Furthermore, electrons present between each nucleus could reduce the energy of this structure. When a line of "floating" hydrogen nuclei, each separated by an electron, is created in the crack, this structure has the ability to resonate along its axis. Such a resonance can emit photons as long as a source of energy is available. Up to this point, the structure is conventional and not difficult to imagine, but obviously difficult to create.

Hydrogen is unique because as the distance between the nuclei in the proposed structure is reduced, the structure begins to look increasingly like a new nucleus. In other words, if the structure were to release energy and collapse, a new nucleus having less mass would result. Consequently, the assembly has an incentive to release energy by emitting photons to achieve this condition. This process is unique and is proposed to be only possible as a result of a resonating structure involving hydrogen nuclei trapped in a crack of a special size. This process is proposed as the basic mechanism causing LENR.

Eventually, a collection of H^4 nuclei result if the starting nuclei were deuterons (d), tritium nuclei would result if the collection were d + p, and deuterium nuclei would be the final product if the starting nuclei were ordinary hydrogen (p). The unstable H^4 immediately emits an electron to form He^4. [Electron emission is not the normal decay path for H^4, which creates a conflict with expectations that needs to be resolved by further studies. Nevertheless, for this proposed process to be internally consistent, either an electron must be absorbed and later emitted when the d-e-d fuse or additional assumptions have to be made. These additional assumptions will be discussed in a future paper.] Momentum is conserved by two coupled photons being emitted in opposite directions along the axis of the crack. Each photon has too little energy to be easily detected outside of the apparatus. Nevertheless, Piantelli *et al.* were able to detect this radiation while exposing Ni to H_2 and placed the energy at 744 keV.[45] The energy of photons emitted when deuterons are involved is expected to have a lower frequency because the resonating structure would have greater mass, hence the photon will be more easily absorbed by the apparatus and be even more difficult to detect. Radiation emitted by a mixture of d and p is predicted to have a broad range of energies because the average mass in each resonating structure will have a range of values from that of pure d to pure p. Since in each case the radiation is coupled to a resonance process, it will be coherent and act like an X-ray laser.

Transmutation is proposed to occur on occasion when a nucleus other than hydrogen finds its way into an active crack. These reactions are rare and limited by the low probability of a suitable nucleus being present at a critical location. Several p or d can be added at the same time, depending on the number of nuclei pairs in the resonating structure. Such a transmutation is proposed to destroy the crack and sometimes the resulting nucleus as a result of the large release of energy, thereby preventing a nucleus from experiencing a series of transmutations. This destruction process is proposed to be one possible source of energetic particles occasionally detected.

The critically small cracks are expected to be inherently unstable and rapidly grow too large to be active unless special conditions exist to stabilize them. I suspect successful production of LENR results mostly because new cracks are formed more or less as rapidly as they are lost, thereby accounting for the instability of the power and the limited duration of power production.

Other people have suggested cracks as being the NAE.[46-49] Consequently, only the suggested resonance process operating in a crack of critical sized is a novel idea. This process allows all the behaviors shown by the LENR process to be explained and several obvious predictions to be made as a test of the basic idea. Although this description lacks several important features that will be discussed in future papers, it provides a path to achieve better understanding of the LENR process.

SUMMARY

A logical conflict exists when LENR is assumed to occur in a lattice. If the process involves quantum effects at the atomic level, the number of these events must be small, because otherwise the events would change the average behavior. If the average behavior is changed, the Laws of Thermodynamics must apply. If the Laws of Thermodynamics apply, a novel region that is able to initiate a nuclear reaction cannot form unless it is stable and frequently present, which we know is not the case. On the other hand, a random process would not occur often enough to make the observed power. In addition, simply filling all the vacant deuteron sites, as some authors propose to cause formation of the NAE, does not always result in LENR and is not always required when LENR is observed.

A process completely different from and in conflict with the one causing hot fusion apparently causes cold fusion. The two types of fusion are not related. Therefore, a process known to initiate hot fusion, such as adding energy to or reducing the distance between nuclei, cannot be used to explain cold fusion.

The LENR process is proposed to occur in cracks having a very small size and involves a resonance process within a string of nuclei therein, with each separated by an electron. This resonance emits energy as photons having a characteristic energy as the string collapses to the final fusion product. The photons are emitted along the axis of the cracks in both directions as coherent beams of X-rays.

Pure deuterium results in H^4, which promptly decays to He^4; a mixture of p and d results in tritium, which decays slowly to He^3; and pure p results in deuterium, which is stable. Occasional transmutation involves nuclei located within the cracks, which generates the occasionally detected energetic particles.

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Comments on Storms' Ideas About the Location and Mechanism for Low Energy Nuclear Reactions

David J. Nagel*

Character and Role of Theory

Storms' view of where and how low energy nuclear reactions (LENR) occur has been called a theory, so we begin with an examination of the character of a scientific theory. A compact summary about theory in any science is available in Wikipedia: "A scientific theory is a well-substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment. Scientists create scientific theories from hypotheses that have been corroborated through the scientific method, then gather evidence to test their accuracy. As with all forms of scientific knowledge, scientific theories. . .aim for predictive and explanatory force."

The Wikipedia article continues, "The strength of a scientific theory is related to the diversity of phenomena it can explain, which is measured by its ability to make falsifiable predictions with respect to those phenomena. Theories are improved as more evidence is gathered, so that accuracy in prediction improves over time. . .Scientific theories are the most reliable, rigorous and comprehensive form of scientific knowledge. This is significantly different from the word 'theory' in common usage, which implies that something is unproven or speculative."

Scientific theories are unavoidably quantitative. Notice the emphasis on "accuracy" in the above discussion of theory. There is a sequence of steps for the development and testing of a theory. An idea comes first. Then, equations that embody the notion must be written down. Computational evaluation of those equations then yields values that can be compared with past measurements or used to design experiments to test the theory, possibly falsifying it.

We will compare Storms' idea about where and how LENR occur with these aspects of theories after a brief synopsis of the current status of LENR and a summary of Storms' viewpoints on the sites and dynamics of LENR.

Low Energy Nuclear Reactions

The overall situation regarding LENR seems quite clear. It is an active and challenging field of science. Experimentally, there is substantial and robust evidence for the ability to produce nuclear reactions using chemical energies. However, the experiments are neither adequately reproducible nor reliably controllable at this time. This is largely due to the fact that LENR are not understood. None of the few dozen theories has satisfactorily explained the mechanisms involved in LENR and their dependence on materials and other characteristics. Despite the experimental and theoretical shortfalls, a few companies are now engineering prototypes of energy generation products based on LENR, which they hope to bring to market in the near future. There is a remarkable degree of hype associated with the promises of products and their potential impacts.

The absence of understanding of LENR is not due to a lack of theoretical effort. Many ideas have been advanced in efforts to understand the fundamentals of these reactions. The Chechin *et al.* paper entitled "A Critical Review of Theoretical Models for Anomalous Effects in Deuterided Metals," which was published in 1994, listed and commented on more than 25 models. A large fraction of the papers at each of the last few International Conferences on Cold Fusion have been theoretical in nature. Because LENR theories are in diverse stages of development, some being only ideas, it is hard to determine where to stop counting. However, there are roughly three dozen theories in circulation. Some are no longer under development due to the passing of their authors. Others are being pushed vigorously. The credentials of the people putting forward LENR theories vary widely. Many of the authors are well trained in the physics and chemistry relevant to LENR. Very few of the theories have produced numerical predications, especially reaction rates. And, there has been scarcely any solid comparison of numerical results based on LENR theories with available experimental data.

Storms' Ideas About the Location and Mechanism of LENR

An examination of Storms' ideas on requirements for and production of LENR should not be confined to a review of his paper published in this issue. Earlier, he published a much longer article with 162 references in the *Journal of Condensed Matter Nuclear Science* (Vol. 9, pages 86-107, 2012, http://www.iscmns.org/CMNS/JCMNS-Vol9.pdf#page=91) with the title "An Explanation of Low Energy Nuclear Reactions (Cold Fusion)." The paper lists five "proposed requirements" that must be satisfied by a theory for LENR. It then goes on to compare some of the available theories with the list of requirements, stating which requirements are violated by which theories. The long paper is a good example of Storms' knowledge of the relevant literature and logical approach to an understanding of LENR. Judging from his writings and comments on the web, Storms has studied many, maybe most, of the theories on LENR. Comments on the new paper in this magazine are informed by what is in the earlier paper, as will be noted.

In both papers, especially the long article, Storms presents evidence and arguments for LENR occurring on the surface, and not within the bulk of materials. He then says, since LENR are not commonplace, they must depend on relatively rare conditions on the surface. That is, they are not prone to occurring on ordinary surfaces, many of which can be relatively simple structurally. However, it has to be recognized that surfaces in anything other than ultra-high vacuum conditions are chemically complex due to adsorbed layers, even if the underlying substrate is atomically smooth. Storms believes that "small" cracks on surfaces satisfy both the ideas that LENR occur on surfaces and in rare circumstances, which are largely uncontrollable. It is noteworthy that Storms does not explicitly quantify what he means by small.

Storms presents two interesting lists in the long paper. The first is a set of three "principles" that have to apply to LENR. The first of these principles states that a nuclear active environment (NAE) must form, and obey the known laws of physics and chemistry. The second is insertion of a hydrogen isotope into the NAE. And, the third is the actual nuclear reaction. This sequence seems reasonable. The second list, also with three items, deals with the major variables that determine the amount of energy generated by LENR. They are the concentration of the NAE, the concentration of protons or deuterons in the NAE, and the locally available energy to trigger the LENR. These points might be true, but it would be very useful to write out the coupled kinetic equations based on them, and then evaluate those equations using some reasonable parameters.

The paper in this issue by Storms posits three sequential steps for the production of LENR, which are more detailed than his list in the long paper. These go beyond the locations where LENR occur and essentially provide ideas about the fundamental mechanism for such reactions. The steps are (a) cracks form and are filled with protons or deuterons, (b) a resonant process happens to induce LENR and (c) the produced energy is carried off as coherent photons with characteristic energies. Each of these suggestions involves problems. While cracks on the surfaces of materials, including the materials in LENR experiments, are common, there is no direct evidence for cracks being the locations of nuclear reactions. The idea that cracks are the NAE was arrived at by a process of elimination. But, cracks have been found experimentally to degrade or defeat attainment of high loading of deuterons into palladium in electrochemical LENR experiments. Such high loading is known from experiments to be a necessary condition for observation of excess heat.

The occurrence of a "resonance process" is also speculative, and has even less support than the centrality of cracks for occurrence of LENR. Resonances are common in both electrical and mechanical phenomena. Mechanical structures from atomic lattices to the entire earth have resonances. In the current case, Storms envisions that, "Nuclei of hydrogen (all isotopes) might be confined by a crack structure in a special way. These nuclei can be imagined as floating equidistant between the walls of the crack supported by the charge present on each wall." This statement gives a rough calibration of the size scale of the cracks of interest, namely small enough for both walls to provide confinement. There is no suggestion in Storms' paper of the frequencies of the resonances. However, it seems clear that the frequencies have to be near or comparable to phonon frequencies (THz) because of the small size of the contemplated arrangements of nuclei.

Storms also wrote, "When a line of 'floating' hydrogen nuclei, each separated by an electron, is created in a crack, this structure has the ability to resonate along its axis." The statement that a "line" of atoms is involved is particularly interesting. An ordinary crack, which has a ribbon-like structure, could support a sheet, but not a line of atoms, unless only the bottom of the crack has dimensions small enough to do what Storms envisions. Then the line might run roughly parallel to the surface of the material. If the bottom of the crack is not the region of interest, then there would be no single line of atoms, no clean vibration frequencies and no preferred direction for escape from the solid of part of the energy from LENR.

If the existence of a line of atoms is accepted, a question arises about the contemplated separation of the nuclei by electrons. It is possible that the positive charges on the nuclei are neutralized by nearby electrons either in the crack or in the walls of the crack. That is, the electrons will not be solely between nuclei, but will have spatial distributions dependent on the local arrangements of protons or deuterons and the host material. The wave functions of electrons in solids do include regions between ions, but they are also extended in other directions.

The next problem is how the "resonance" of a line of atoms could induce nuclear reactions. The motions of the H or D nuclei in a crack are not unlike the motions of the same entities in a lattice, although they might be somewhat closer to each other. That is, their separations would not be determined by the host lattice, but by the electro-dynamics of the protons or deuterons and the nearby electrons in the crack.

Finally, where does the energy released by LENR go? Storms presents some possibilities, but they also are quite speculative. That is not to say they are wrong, but there is very little experimental basis for his surmises. Storms wrote in the published long paper, "As this resonance takes place, coherent photons (X-rays) are emitted, similar to what takes place in a laser. In this case, the energy does not come from outside sources, but from gradual conversion of hydrogen nuclei into another element, with the intervening electron being absorbed into the final nucleus. . .This unconventional relationship is forced on the system by the walls of the crack in which the process occurs." Later in the same paper, Storms wrote, "Analysis using mathematical tools will follow if the suggested model is found to be correct." This seems backwards, since the mechanism cannot be shown to be correct without prior computations (analysis) and comparison of their results with experiments.

Regarding the envisioned X-ray emission, Storms wrote in the paper in this magazine that, "Momentum is conserved by two coupled photons being emitted in opposite directions along the axis of the crack." Further, he states, "Since in each case the radiation is coupled to a resonance process, it will be coherent and act like an X-ray laser." There is no basis for assuming that the energy released by LENR will be photons in the X-ray region of the spectrum. And, there is no indication in either paper of the energy of such emissions. The basis for the envisioned X-ray photons being "coupled" and coherent is unclear. That they might originate at the same time does not make them coupled, as are the entangled photons in modern action-at-a-distance experiments. Low energy directed X-ray emission has been reported by Karabut for glow-discharge plasma loading LENR experiments. However, it cannot be due to laser action because of insufficient energy densities. The statement "act like an X-ray laser" is bothersome because lasers in all regions of the spectrum act by stimulated emission. That process certainly does not play a role in the emission of the imagined counter-propagating photons.

What is in Storms' model of where and how LENR occurs is only part of the situation. What is missing from his presentation is also important. Most basically, there is no clear picture of the atomic arrangements that might be held by the walls of crack and driven into resonant motion, presumably thermally. There are no equations describing the motions, which could lead to computations of the energetic and kinetics predicted by the model. In fact, his model is essentially descriptive and not quantitative. The picture offered by Storms does not satisfy the most basic quantitative aspects of a scientific theory, as stated in the opening paragraphs above. Storms' concepts could be the beginning of a thoroughly developed theory, but they are no more than ideas now.

Before finishing a critique of Storms' papers on the locations and mechanisms for LENR, it should be noted that he is entirely focused on fusion of light nuclei. His long paper tabulates and discusses specific nuclear reactions involving isotopes of hydrogen. Many scientists in the field think that experimental evidence for transmutations of much heavier nuclei requires more than a fusion-centric approach to understanding LENR.

Further Technical Comments

Since cracks are central to Storms' concept of where LENR occur, it is reasonable to consider the various types of cracks in which the reactions might occur. Cracks are ordinarily openings in a surface, which have a relatively small width and depth, and usually extend for longer distances along the surface. The widths and depths of cracks can vary in size from nanometers, that is, a few atoms on the low end to about a millimeter on the large end. The extent along the surface commonly ranges from something under millimeters to dimensions limited by the size of the piece of material, sometimes many centimeters.

It is also possible to have what might be called cracks that do not extend significant distances along the surface. They would have openings on the surface that are more or less equiaxed, that is, of comparable dimensions in both directions parallel to the surface. Their depth could vary from a small fraction of the dimensions of the opening parallel to the surface to many times deeper. It would be more natural to think of these features as holes in the surface, rather than cracks.

The geometry of ordinary cracks and holes in surfaces can vary widely. One possibility is to have flat and parallel sides orthogonal to the surfaces, with flat bottoms roughly parallel to the surface. Another is to have interior sides that slope almost smoothly from the opening downward to meet at a line or point in the bottom, essentially a "V" shape. Many intermediate possibilities exist, with sides stepped on an atomic scale.

A limiting case is a hole in the surface that is due to removal of only one string of atoms in the lattice. It might intersect the surface at a wide range of angles. However, we can consider it as perpendicular to the surface for purposes of discussion. Such a hole (not a crack in the usual sense of the word) would have an opening with dimensions on the order of interatomic separations, that is, fractions of a nanometer. It would be larger than the region immediately along the edge of a dislocation that emerges from a surface, but similar in having a structure with size comparable to atoms.

With these considerations of the range of possible crack geometries and sizes, we can examine them as possible sites for LENR. In any crack with dimensions larger than about one nanometer, hydrogen or deuterium atoms can have three kinds of relations to the solid. Some will coat the interior surface of the cracks, much like they coat the overall surface of the material. Others will be in more-or-less linear regions where the surfaces within a crack meet, possibly near the bottom of the crack, or else on atomic-scale ledges in the interior wall of the crack. The third possibility is for the H or D atoms to simply fill the crack without being in contact with the solid. That case would be similar to those entities in the electrolyte over the surface in an electrochemical experiments or the gas above a surface in a gas loading experiment. There might be nothing special about the first or third cases.

The main case of interest is the second possibility, namely H or D atoms or molecules being simultaneously in contact with two facets of a substrate along a linear structure of some possibly-long length. That is, lines of H or D atoms could form either in holes in a surface that are due to the removal of only one or a few strings of lattice atoms, or along much more likely ledges within cracks. It must also be noted that any surface of a crystal that is not parallel to some low-index lattice plane will contain ledges against which H or D atoms could also be in contact with the substrate atoms on two "sides." Hence, cracks into a surface are not necessary to produce a line along a surface where H or D atoms can contact metal atoms in two directions. In fact, cracks might be very undesirable, because they can serve as "leaks" from which H or D loaded into a lattice escape.

It is easy to contemplate ledges on the surfaces or the walls of the cracks of materials. The ledges have been observed with atomic force microscopes in experiments with ultra-high vacuum conditions. It is not possible to keep the surface of a substrate free of adsorbate atoms in most cases with a vacuum greater than about 10^{-9} torr. However, all electrochemical experiments, those for LENR included, have dense electrolyte in contact with the surface, and a very dynamic situation right at the surface. At the cathode in an electrochemical cell, H_2 or D_2 molecules are split into H or D atoms, which can either enter the cathode or recombine to form molecules. Diverse chemical reactions and depositions occur on or very near to the solid surface. That surface is very unlike the textbook picture of the surface of a solid. The same is also true for LENR gas loading experiments. Such experiments all have atmospheres near or well beyond one atmosphere, with unknown concentrations of unknown impurities in the atmospheres.

If it is assumed that lines of H or D ions form within cracks or along ledges on the surface of materials, the dynamics of the structures are likely to be very complex. The atoms near the hydrogen isotopes will be in thermal motion as phonons impinge on the surfaces. It seems unlikely that any mechanical (positional) excitations along the line of hydrogen isotopes would propagate over significant distances because of the orthogonal jostling of the nearby substrate atoms. H or D ions might either be ejected from the linear arrangement, or join it if there is an opening in the line. Substrate atoms will also be moving due to random diffusion on the surface. Their arrival at a ledge, or departure from a ledge, might disturb the line of the H or D ions.

There is the further question of the strength of bonding of the line of hydrogen isotopes to the nearby substrate atoms. That strength will largely determine the stability of the linear structure and its dynamics, including the resonance that Storms thinks leads to fusion. Of the several types of bonding in and on solids, it seems that some type of induced polarization, like a van der Waals force, might determine the bond strength. However, this is only an unsupported surmise now. Electronic structure computations with a code like Quantum Esspresso, might indicate the nature of the bonding and its strength. Molecular dynamics simulations of the linear H or D arrangements could exhibit the dynamics of the line of hydrogen isotopes, including its formation, stability and frequencies.

In summary, the lines of H or D ions that Storms apparently envisions can occur in different structures: (a) the bottoms of cracks, (b) ledges in the walls of cracks, (c) ledges on the surfaces of materials, even in the absence of cracks and (d) very small holes into the surface of a material. It is noted that there may not be a substantial database for the existence of the small holes with cross sections on the order of one nanometer or less. A literature search needs to be done to determine if such holes have been observed with atomic force microscopes or other tools of nanotechnology.

Given these geometries, it is possible to make simple estimates of the required densities for cracks and nano-holes by using the excess energies observed in LENR experiments. In the case of a line of H or D ions in the bottom of a crack or on ledges, we seek to estimate possible numbers of the LENR per sec cm^2 to produce specified powers. Assume that an experiment produces 100 mW of excess power for a cathode area of 5 cm^2. That is equivalent to 20 mW/cm^2 or about 5 x 10^9 24 MeV reactions/sec cm^2. Using 10^{10} reactions per sec cm^2, there would have to be a rectangular grid with 10^5 reactions/sec in orthogonal directions within the 1 cm^2. Since 1 cm = 10^7 nm, this power density would require one LENR within an area of $(100\ nm)^2$ each second. If the LENR occurred along linear structures of H or D ions, this estimate implies a very high density of cracks or ledges. If there is a lower density, then correspondingly more nuclear reactions per second would have to occur in at least some of the cracks. Similarly, if the LENR occur in lines of H or D within nanometer-scale holes in the surface, there would have to be a very high areal density of those holes.

Importantly, Storms wrote in the long paper that, "The puzzle still lacks a clear description of the mechanism operating within the crack. Once a mechanism is found to apply, later mathematical analysis can be used to further support the model and generate other predictions." I largely, but not completely, agree with both parts of this statement. An adequate model for the production of LENR in cracks has yet to be offered. And, once such a model for a mechanism is available (and prior to its being "found to apply"), it will be necessary to write down the governing equations and evaluate them to obtain numbers for comparison with experiments. Both the energetics and the kinetics (rates) should result from the "mathematical analysis."

Non-Technical Perspective

The technical comments just offered are a normal part of critical discussion in science. Beyond those, I have a non-technical complaint about the title of the article by Storms in this issue. He wrote ". . .from a Chemist's Point of View." That bothers me for two reasons. The first is the fact that the field of LENR has been plagued by inter-disciplinary hostilities from the outset. Continuing to emphasize disciplinary differences tends to perpetuate such problems. The field is intrinsically, inevitably interdisciplinary, so scientists with different backgrounds should collaborate on attacking the basic problem of understanding LENR. Storms actually acknowledges this. When commenting on the differences between physics and chemistry, he wrote in the long paper, "The phenomenon of LENR requires a marriage between these two fields of science."

The other reason that part of the title bothers me is concern about the larger question of being a scientist, independent of discipline. Certainly, one's academic and professional backgrounds influence and even determine how problems are approached. Storms has every right to be proud of his academic and professional backgrounds in chemistry. I am pleased with my training and work in physics (even though that subject often comes with a deficit of humility). Storms has served the field much more broadly than practicing chemistry. He is a scientist who has learned other disciplines, as required. In some sense, he does himself, as well as the field, a disservice in prominently emphasizing one discipline, no matter how essential that discipline is to studying LENR.

Storms' Contributions to the Science of LENR

My scientific and personal views above on Storms' two papers on the location of where LENR occur and the mechanisms leading to LENR are quite negative. However, my critical concerns about aspects of his ideas for the mechanism behind LENR are far from my overall perspective on the capabilities and contributions of Storms to the science of LENR. He has been and remains one of the most important contributors to the field.

We should pause to appreciate the three steps that Storms has taken to get to a point of being able to offer ideas about the locations of and mechanisms for LENR. He has (a) read thoughtfully much of the literature on LENR, (b) analyzed the implications of many measurements and ideas and (c) routinely interacted with the global scientific community, especially through the CMNS Google Group. His attention to LENR theories has had two effects. Storms has provided comments on many, though not all, of the theories regarding LENR. Most of those comments are criticisms of the flaws he perceives in the examined theories of LENR. And, recently he has developed his own concepts of the physical mechanisms that produce LENR. Now, Storms is further developing his ideas with the expectation of later mathematical analyses and experimental tests.

However his foray into theory turns out, Storms is a virtuoso experimentalist. His abilities to design, build, calibrate and employ sophisticated experiments are well documented in his many papers. He is skilled in glass blowing, electronics, mechanics, calorimetry, data acquisition and other capabilities needed for LENR experiments. Storms has done sophisticated engineering design, fabrication and testing of calorimeters and complex experiments. Photographs of some of his devices and set-ups are on the web at http://lenr-canr.org/?page_id=187. He is clearly much more than a chemist, as is necessary to grapple with LENR experimentally. Storms is a skilled scientist and engineer with very broad laboratory capabilities.

The results of Storms' studies of the experimental papers are useful complications of quantities and references, as presented in his book and elsewhere. The book is *The Science of Low Energy Nuclear Reaction*, published in 2007 by World Scientific. Overall, Storms is one of the best informed, most critical and consistently interactive of the scientists in the field. There is a need for more people to be like him. It is good news that he has decided to adventure beyond experiments to critique and develop theories for LENR.

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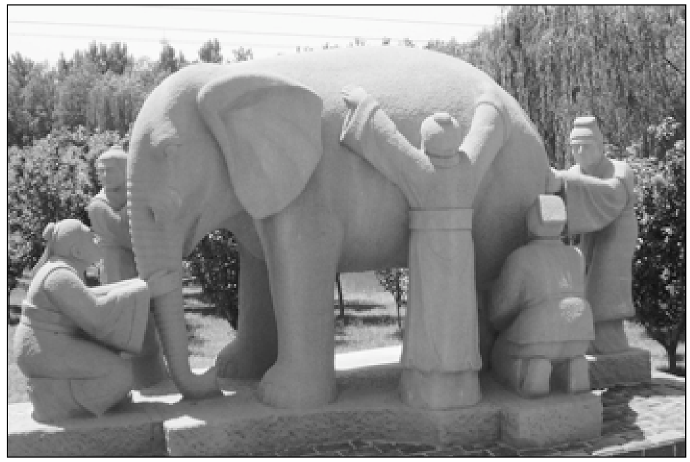
The Big Elephant and Blind Men

Xing Z. Li*

There were five blind men who tried to understand what an elephant was. The first touched the nose, and said that it was like a soft tube. The second touched the big ear, and said it was like a fan (ancient Chinese fans are made of a big piece of palm leaf). The third touched the big leg, and said it was like a pillar. The fourth touched the body, and said it was like a wall. The fifth touched the tail, and said it was like a rope. This Chinese fable tells us that after more than 20 years of experimental study of anomalous phenomena in metal hydrides (deuterides), we are supposed to integrate our knowledge about these phenomena and extract an image of this "big elephant." Infinite Energy initiated this discussion about the "elephant." Logically speaking, one should read the 162 papers in Storms' JCMNS paper, then comment on this new Storms paper. Nevertheless, I would like to support this initiative, and provide my imagination as a sixth blind after reading Storms' review.



I agree with Storms on the general statement that we are supposed to use assumptions as little as possible; then, we should avoid conflict with our consolidated knowledge of quantum mechanics, electrodynamics and thermodynamics. Early in 1989, we thought that the necessary product of any nuclear reaction between two positively charged particles was not necessarily a neutron, but charged particles (conservation of electrical charge). Then we started searching energetic charged particles using CR-39 (solid state track detectors) instead of using neutron detector in order to confirm any nuclear reaction. We also thought that there had to be some precursors before the anomalous phenomena appeared, because the anomalous phenomena could not appear in the normal crystal or any normal chemical environment. Therefore, thermal luminescence detector were used to detect any radiation from the metal deuterides because we believed that the precursor had to involve the movements of some charged particles during the loading processes, based on electrodynamics and thermodynamics. When Koonin published his calculation about the cross-section in *Nature*, and Peebles published his conclusion about "cold fusion" in his textbook on quantum mechanics, we noticed that both of them assumed tacitly "no resonance" before their calculations. If there was a resonance, then they were not allowed to throw away an important independent solution of the Schrödinger equation. Koonin and Peebles might argue that there was no evidence for the existence of such resonance. However, we might argue also that there was no evidence for them to allege "no resonance" because there was no such experimental data either. The beam-target experiments using accelerators could not reach such a low energy or such a sharp, narrow energy level. Therefore, the resonant tunneling was proposed to solve the first Huizenga puzzle—penetrating the Coulomb barrier.

When Huizenga proposed his second and third puzzles, he was using classical mechanics to discuss wave mechanics. Even if for the resonant tunneling at low energy he still assumed that a compound nucleus was formed first, and then it would decay into the reaction channel with the shortest lifetime. It was misleading, because it ignored the time necessary for a resonance process to build-up the wave amplitude in terms of constructive interference. The reaction channel with the shortest lifetime would not have enough time to build-up the wave amplitude. Only if the reaction channel has the proper lifetime can the resonance process enhance tunneling and result in nuclear reaction. As a consequence we realized that the resonant tunneling at low energy would not decay through the reaction channel with the shortest lifetime. Particularly, when the Coulomb barrier is thick and high, only the weak interaction channel would have the chance to construct a resonant tunneling and have a nuclear reaction. That is, the resonant tunneling would lead only to *neutrino* emission with no neutron or gamma radiation, because the strong interaction or electromagnetic interaction is too fast to allow any resonance process to build-up the amplitude of the probability wave for the low-energy penetration of the Coulomb barrier. The formation of a compound nucleus is equivalent to a "measurement procedure" in quantum mechanics. Huizenga separated a resonant tunneling process into two independent processes: compound nucleus formation and decay of compound nucleus. Then he concluded that gamma emission is the necessary product of resonant tunneling. Just like in the case of the famous double-slit diffraction experiment in quantum mechanics, if we measure the path of the electron at the position of the double-slits, we would interrupt the interference of the probability wave on the screen behind the double-slits. Unfortunately, *this important point of view has not yet been understood by everyone in our CMNS community*. This is the essential component of selective resonant tunneling.

When we accept the selective resonant tunneling to solve Huizenga's three puzzles by selecting the weak interaction channel, we might worry about the neutrino emission which would carry away most of the energy released in the nuclear reaction. Indeed, this would happen only if the nucleus—produced in accompaniment with the neutrino—was born in the ground state. If it was born in an excited state then most of the energy released in the nuclear reaction would still be kept by this excited state. The remaining problem is the decay of this excited nucleus. Usually, this excited nucleus would be supposed to decay through gamma-ray emission. Why don't we observe the gamma emission commensurate with the "excess heat"? The answer is that the internal conversion electron wins over the gamma emission due to the high nuclear spin and the dense nuclear energy levels in a resonant lattice.

We may use the nickel-hydrogen system as an example. In the Ni-hydride, ^{58}Ni+p might be in a resonance to form a ^{59}Cu-like state which would capture an electron to produce ^{59}Ni*+neutrino. This neutrino carries away only a small part of the reaction energy, because the excited ^{59}Ni* still have most of the reaction energy which would be transformed into "excess heat" later. The question is: Why doesn't this de-excitation energy appear as a single jump down from ^{59}Ni* to the ground state of ^{59}Ni? It appears as a series of small steps to chop this de-excitation energy into a series of small pieces of energy, ΔE. We learned from Defkalion's data, which was generously published during ICCF17 at KAIST. They have never observed any gamma emission beyond the range of 50 keV - 300 keV. This implies that the energy spectrum of ^{59}Ni* in the vicinity of (^{59}Ni*) is a dense distribution of energy levels. This would be in favor of an internal conversion process. In other words, the reaction energy in (^{59}Ni*) would go to the internal conversion electrons instead of gamma radiation. One more point in favor of this internal conversion process is the high spin of (^{59}Ni*) which was born during the resonant tunneling.

According to wave mechanics, the initial state of nickel-hydride is described by a wave function Ψ(^{58}Ni+proton in lattice) + $C\Psi$(^{59}Cu*)—the linear combination of (^{58}Ni+proton in lattice) and the copper. If there was no resonance, the coefficient, C, is very small, because the Coulomb barrier makes C exponentially small. When (^{58}Ni+proton in lattice) is in a resonance, the probability of appearance in state of Ψ(^{59}Cu*), $|C|^2$ is comparable with the probability of appearance in state of Ψ(^{58}Ni+proton in lattice), $1 - |C|^2$. Then, this initial state of nickel-hydride would transit to ^{59}Ni* in terms of electron capture process:

$$p + {}^{58}\text{Ni} + e \rightarrow {}^{59}\text{Ni}^* + \text{neutrino} + \text{part of total reaction energy}$$

As mentioned above, this neutrino would not carry away too much reaction energy, if ^{59}Ni* still keeps most of the reaction energy in it. Moreover, Defkalion scientists drive this electron into some Rydberg states using an electrical discharge process as a triggering method; hence, the electron in the left-hand-side of the equation might have a high orbital angular momentum, and would produce a ^{59}Ni* with high spin in the right-hand-side of the equation. This high spin would be in favor of the internal conversion process as well. Defkalion scientists observed very strong magnetic fluctuation after the electrical discharge triggering. It provides an evidence of a high spin state. Indeed, this Rydberg electron was necessary in order to have a good overlapping between the wave functions of the initial and final states.

This picture of selective resonant tunneling and the following weak interaction process is similar to Bethe's early work in 1938 when he explained the origin of solar energy in terms of

$$p + p \rightarrow \text{deuteron} + e^+ + \text{neutrino}$$

He was using the overlapping of wave function between (p+p) and deuteron (p+n) states as well. In our case, there are two new points: 1) the metal-hydride replaces the configuration of (proton beam + proton target); 2) The production of a positron is replaced by electron capture because there is not enough energy defect. The common feature is that a proton has been transformed into a neutron both in our case and in Bethe's calculation. The necessary energy, 782 keV, is provided by the binding energy. There is no "heavy electron" involved at all. We did not invoke "heavy electron" to provide the necessary energy for a process of $p + e^- \rightarrow n +$ neutrino, and we did not invoke "heavy electron" to transform reaction energy into emission of the infrared ray, because the high spin and dense energy levels are in favor of energy transfer from an excited nucleus to internal conversion electrons in many steps.

What is the necessary condition to have this resonant tunneling? It is the existence of an energy level of ^{59}Cu*, which coincides with the energy level of (^{58}Ni + the proton in the lattice potential well). We cannot control the nuclear energy level in ^{59}Cu*, nor in ^{58}Ni, but we may control the energy level of a proton in the lattice well in terms of boundary condition and shape of lattice well. The potential well in the lattice may be adjusted by the density of electrons and the lattice constant. In the past 20 years, a lot of methods were tried to adjust the lattice potential well, such as super-wave, ultrasonic wave, RF-wave, electrical discharge, electrical loading, gas loading, laser heating, electrical heating, pressure jump (pumping), additive doping (catalyst), etc. Because this resonance is very sharp, it is almost impossible to meet this resonance condition in a steady state; we may tune the metal-hydride system by a temperature or density gradient and a negative feedback mechanism to reach a self-sustaining state. This is the most difficult part of the experiment. However, we understand that electron density plays an important role in the lattice well, and the metal surface is the location where electron density changes rapidly. That is why the surface or the crack is in favor of this resonant tunneling. The same reasons may lead to the interface of different metals or metal-oxides in favor of resonant tunneling. The interface between α and β phases of metal-hydrides is the location where the lattice constant varies. Hence, we may predict that the resonant tunneling might appear near the interface between α and β phases of metal-hydrides as well.

The negative feedback mechanism plays a key role in reaching a self-sustaining resonant tunneling state; however, the only feedback factor we have known is temperature. The reaction heat would increase the temperature of the system. If the temperature increment drives the system away from resonance and reduces the reaction rate, then we may have a negative feedback mechanism. We noticed that in Defkalion's experiment, they have to trigger the system manually ten times every hour. Their negative feedback mechanism is not as good as that in Fleischmann and Pons' heat after death experiment where the dried system was kept in 100°C for three hours. We may guess that the hydrogen (deuterium) flux plays an important role there.

Now we may answer the question: Why do we need the powder of nickel instead of nickel rod? Because the weak interaction has a coupling constant of 10^{-4}sec^{-1}, it would provide a power of 1 MeV/10^5 sec per nickel nucleus in resonance. If only the nuclei in the surface layer would be in resonance, then the excess power would be much less than 10 kW in a piece of 50 gram nickel block. We have to break the nickel block into nickel powder, then we may have enough surface to supply the 10 kW power. As we understand, the nickel nuclei on the surface would be burnt in the resonance processes; then, we need more new surfaces to keep a constant power in six months. Fortunately, most hydrogen-storage metals (palladium, nickel and their alloys) would be broken into smaller pieces during the cycles of absorption and desorption. When we put these numbers (100 Angstrom thickness of surface layer, 10 kW, 50 gram nickel, etc.) into calculation we may find that the size of the nickel powder is in good agreement with the size in their patent.

Fleischmann and Preparata paid attention to the word "coherence." Twenty years of experiments gradually revealed the importance of "coherence." We already knew that even if a single nucleus jumped down to the ground state step-by-step through a series of dense nuclear levels, it would not produce the directional X-rays. However, Karabut observed directional X-rays in their electrical gas discharge experiments. Defkalion scientists observed strong magnetic field fluctuation in the order of 1.8 Tesla when the magnetic field of discharge current was 1 Tesla. A lot of triggering mechanisms involve the various waves. These all are reminding us that this anomalous nuclear process is not in a single beam-target configuration; it should be a collective "coherent" motion of protons and nickel nuclei. Indeed, we understand that the resonance between the nuclear level and the lattice level is a very sharp resonance due to the very long lifetime, and no modern accelerators would be able to provide such a low-energy beam of protons with enough current density and sharp enough in energy distribution. The "coherence" in the lattice is just a way to put protons on such a sharp energy level and provide the negative feedback mechanism to keep protons in resonance. We have to consider a group of protons in "coherence." Only a blind man with wide open arms would be able to tell the size of the elephant. A blind man using his single palm would never have the right answer.

To summarize, I agree with Storms' use of the term "resonance," which is the essence of the theory. An anomalous heat phenomena cannot appear in or at the normal chemical lattice. It seems that a triggering mechanism is necessary. It seems also that some additives are necessary as well. A surface location meets the conditions for resonance, and the crack is the right place to have surface. However, the essential point is the conditions for resonance.

Our main disagreements are as follows: In wave mechanics, we are supposed to think of the probability wave function only until the "measurement" is done. The physical quantities appear only after the "measurement." Before the "measurement," we might think only of the overlapping of the wave functions. The resonant tunneling and electron capture means:

(1) The coefficient C in wave function, $\Psi(^{58}\text{Ni}+\text{proton in lattice}) + C\Psi(^{59}\text{Cu}^*)$, increases greatly.

(2) The overlapping between $\Psi(^{59}\text{Cu}^*)$ and $\Psi(^{59}\text{Ni}^*)$ reaches it maximum. Then we may predict that the process of resonant tunneling and electron capture is possible even if the Coulomb barrier is very high and thick between the proton and nickel nucleus. The proton is transformed into a neutron in terms of electron capture, and the necessary energy 782 keV is provided by the binding energy of ^{59}Ni*. In wave mechanics, the whole process is not separable. The energy conservation is abided as a whole. Only in classical mechanics may we ask where the 782 keV is to transfer a proton into a neutron before penetrating the high Z Coulomb barrier.

We have to wait for more experimental data. At the Pontignano workshop in April 2012, the evidence of copper (~30%) was present. In 2011, it was said in Sweden that the copper (~30%) was found in nickel powder after six months operation of E-Cat. In 2012, it was said in Switzerland that there was no copper as a nuclear product in the E-Cat. At ICCF17 in 2012, Defkalion published their mass spectroscopy data in detail. Very little copper (0.053 ± 0.007%) was found there. Hopefully, we may see the definite answer in 2013.

Reviewers of this paper were asked if "a clear statement of assumptions is required of any proposed theory." Yes, we are supposed to make the assumptions as clear as possible; however, Koonin and Peebles did not mention the assumption of "no resonance" because they did not consider it as an assumption. Therefore, we have to figure out the assumption by ourselves sometimes.

Recently lithium battery fires in aircraft induced a discussion on the possible reason of the fire. Because lithium-6 has a low lying resonance energy level, but lithium-7 does not, it is advisable to analyze the ratio of isotope abundance in the batteries. Replacing the natural lithium with depleted lithium (*i.e.*, lithim-7 only) in a lithium battery might be a better option instead of using a Ni-Cd battery.

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Critique of "Cold Fusion from a Chemist's Point of View"

Jones Beene*

The following critique of Dr. Edmund Storms' recent observations and theory, "Cold Fusion from a Chemist's Point of View," can be called un-critical, in the sense that his arguments appear to be fully defensible, at least within a narrow focus. There is little to dispute within what Storms presents—but the problem, if there is one, goes to the validity of any underlying premise of simplification, which can be called "parsimony" or "Ockham's razor."

Specifically, having a single operational method or model which excludes all others, especially when based on a low probability kind of reaction (in the case of proton-proton fusion), limits the application of theory to a specific type of experiment where it has been seen, or limits it to a subset of all reactions where it applies. Thus, the theory may adequately explain only a small fraction of experimental results in the broader field. On the other hand, since the overwhelming assumption in physics is that there cannot be many similar-but-separate novel reactions with hydrogen—all of which lead to energy anomalies (yet none of them were appreciated prior to 1989)—Storms is on solid ground with his narrow focus. That search for simplicity is essentially what Ockham's razor is all about; but as a guiding principle, it seldom stands up to close inspection.

Storms' theory can be summarized as moving the locus of the thermal anomaly from the "lattice" (solid crystal interstices within a metal host) to "cracks" or fissures (larger geometry) not unlike fracto-fusion, and then further suggesting that protium fuses to deuterium directly and in a way similar to deuterium fusing into helium. If one had to choose a single hypothesis or theory amongst the many which have been floating around for over two decades, Storms' would likely be at the top of the list (for many observers in the field), since it is "comfortable" and comes with the reputation of a pioneer experimenter who backs his conclusions with high quality lab work. Additionally, it is derivative and evolved from other models which have been circulating for years, and not too far removed from hot fusion in energy expectation, per fusion event. But is it exclusive?

Within the community of LENR experimenters, there will be the usual complaints—to the extent that one cannot easily rationalize the total lack of gamma radiation with real fusion, and other details. But that lack of hot fusion indicia is also the knock on deuterium LENR, so it is no great leap of faith to apply a similar theory to protium, when one is convinced of the former. But the transition from deuterium to hydrogen is almost too effortless, given the much lower probability (cross-section of the reaction). And, in recent years, there are newer and more robust experimental claims, especially with catalyzed nickel alloys—which are not amenable to a "real fusion" explanation. This gets us back to the issue of simplicity-of-explanation. There are good arguments in physics—for and against—"parsimony" as a guiding principle. This seems to be an appropriate time to air them in the context of Storms' theory, compared to other compelling viewpoints which better match experimental results.

This past year, on the LENR forums and blogs, there has been resurgence in the belief that aside from deuterium reactions, the field is largely "non-fusion" and perhaps some of the thermal anomalies are "non-nuclear" to the extent that there is gain with absolutely none of the indicia of known nuclear reactions. A better descriptor of the "non-nuclear" sentiment is "quasi-nuclear" and/or "Millsean," in deference to the work of Randell Mills. Mills proposed an ostensibly non-nuclear "redundant ground state" reaction for thermal gain very soon after Pons and Fleischmann's 1989 announcement. Although Storms does not ignore alternative viewpoints, and gives mention to a few of them, he is clearly of the belief that thermal gain with both deuterium and protium involves real nuclear fusion, but without the known characteristics of fusion. He appears to be dubious of the suggestion that gainful quantum mechanical (QM) reactions can be involved which operate as a predecessor or enabling stage—which can then proceed to real fusion. Storms does acknowledge that any reaction must be novel to a substantial degree, since the traditional indicia of nuclear reactions are largely absent; so it is perhaps a bit disingenuous to limit novelty in such a way as to bolster only one's own explanation.

For many years Storms was at the forefront of experimentation with palladium and deuterium, so it is not surprising that he bases much of his "chemist's point of view" on the lessons learned there, and not surprising that he borrows from, and builds on, Pons and Fleischmann (P&F). His experimental background is combined with the mainstream perception that conservation of energy cannot be violated in ways which do not involve the nucleus. The ostensible alternatives would include not only Mills but an asymmetric Lamb shift, a dynamical Casimir effect and the zero point field, to name a few. It should be added that these alternatives can be understood to derive energy ultimately from the reduced mass of the proton (reduction of average mass) so they can be rationalized as "quasi-nuclear" if we accept the proposition that proton mass is an average and not quantized.

Along with a few others, Storms has championed the view that helium has been found commensurate with the excess heat which is seen in deuterium reactions. This claim, in particular, is highly contentious and seems to be losing ground—at least based on the number of cogent contrary opinions which turn up on blogs. When moving from palladium-deuterium to nickel-hydrogen, Storms is content to find the same kind of fusion reaction occurring in cavities or fissures which are called the nuclear active environment (NAE). He tends to rationalize evidence of gain from nanopowder, zeolites or other porous substrates as being the functional equivalent of the NAE, and many observers have no problem with that.

A more basic problem is that early researchers in palladium-deuterium "cold fusion" were using hydrogen as a control. If hydrogen was used as a control to show a baseline of no-gain 20 years ago, but now is shown in experiments to have higher gain than deuterium when catalyzed by nickel, this presents a curious dilemma and it is one that has not really been adequately addressed. Skeptics remind us of a cinematic court room scene where a witness who has changed his story is asked by the prosecutor: "Were you lying then, or are you lying now?" But in fact, this scenario of higher gain with protium and nickel is fully explainable under other theories than that of Storms—but the details which explain it will also make the hybridized modus operandi more complex than can be accommodated by any single theory of operation. Thus, we have another hit on Ockham (parsimony).

There are dozens of hypotheses and less-developed theories for LENR, and most of them have some backing from real data. One of the major competing theories comes from Widom and Larsen (W-L). It involves weak-force dynamics (beta decay) but relies on an invented particle, the "ultra low momentum" neutron, which is somehow different from the well-known ultra cold neutron. Storms has been vocal in opposition to this theory. The implication of W-L for deuterium fusion is that helium is more a relic of contamination of the experiment than of nuclear ash, so it is not surprising that Storms should be personally offended. He has essentially staked a large part of his reputation on the helium yields in reactions involving palladium and deuterium. Yet the W-L theory has been embraced by several high profile parties, including researchers at NASA. Ironically, proton fusion—as it happens in the solar environs—also depends on a rare predecessor beta decay event (of the transient helium-2 nucleus). Storms does not adequately explain how beta decay is avoided in his version of proton fusion when it is obligatory in the solar model. Curiously, another recent finding from Storms and Scanlan seems to be explained by a mechanism involving accelerated nuclear decay (of long-lived elements like potassium-40). Therefore, nothing has been set in stone on the theoretical front, even after 22 years.

In fact, a useful hypothesis/theory that appeared in 1990 to explain the P&F effect, called the "binuclear atom," is being reexamined since it seems to be more applicable to protons than deuterons. It is one of several older ideas which are largely uncredited today, but vestiges have been incorporated into hybrid concepts. In the binuclear atom, protons become bound as pairs, held together by electron charge, but not as a molecule. The two protons, despite Coulomb repulsion, become bound by 30 eV, which is close enough to Mills' theory to raise eyebrows (with its Rydberg multiple at 27.2 eV). Mills has been previously interpreted (by a few LENR proponents) to offer a way for ground-state orbital reduction to lead further—to real fusion at high levels of redundancy (in ground state)—although Mills has never claimed to see this in any experiment. In the end, as far as theory goes, it is not clear who deserves credit for a number of overlapping details—if in fact it is determined that protons will only fuse from lower energy states involving electron abnormalities as the prime ingredient.

Of the dozens of past hypotheses and partial explanations, there are at least seven workable concepts to explain thermal anomalies in hydrogen in metal matrices at low energy input. Kozima has made exhaustive attempts to include more, as has Gluck and others, and this listing is not intended to be complete. It overlooks many contributions, such as multi-body reaction concepts and exotic but unproved particles, based on the perception of extremely low likelihood. Here are viable candidates which are not mutually exclusive.

- The original theory of P&F—restricted to palladium and deuterium, involving fusion to helium or tritium caused by coherent electron effects. Later internal (virtual) pressurization due to overvoltage was mentioned—such as was presumed to exist in the interstices of the proton conductor.
- The original "hydrino" (fractional hydrogen) mechanism of Mills, now expanded or differentiated by Miley and others as inverted Rydberg hydrogen, or as a deep Dirac layer.
- The W-L beta decay mechanism, which is similar to a Focardi/Rossi/Brillouin mechanism. This mechanism involves the transmutation of nickel into copper or other metals following the adsorption of a cold virtual neutron. This theory can also explain helium ash.
- The Storms mechanism, which is evolved from P&F and from "fractofusion."
- Accelerated nuclear decay.
- A nanomagnetism mechanism, which is "quasi-fusion" (quantum chromodynamics, QCD, reversible-proton-fusion) and a strong force modality. The key "leap of faith" is magnon "radiation" from protons which interact magnetically with host nuclei like nickel. This is QM-based and consequently can have incidental trace radioactivity and transmutation.
- Any combination or permutation of the above—since none of them is mutually exclusive by nature. Not included are multi-body hypotheses, dark energy, or other exotic inventions—or generalized zero-point energy (unless it relates to a real effect, like the Casimir).

This listing, or any like it, is *not* what mainstream or even non-skeptical theorists want to accept: that there could be several overlapping mechanisms for gain in hydrogen-loaded nanocavities. Such a suggestion is anti-Ockham—but in fact, all of QM and especially QCD is anti-Ockham. Essentially we must ask: Why not interacting mechanisms? After all, most of the universe is composed of hydrogen, and there is no logical reason that quantum interactions of sub-nuclear hydrogen (quarks and pions, etc.) should be simple—just because the atom itself seems deceptively simple at first glance or to those who are put-off by QM. When broken down to quarks, gluons, goldstone bosons and color change, etc., simplicity disappears at the femtometer strata, and science is just now coming into possession of tools that peer into these dimensions.

An emergent "nanomagnetism" theory is one of the few theories which can account for non-chemical anomalous endotherm, which has been seen in some hydride systems—and is perhaps more of a shocking anomaly than excess heat. Endotherm, in this specialized case, means that when a large amount of outside heat is put into the system, a substantial fraction of that heat seems to physically disappear, as if there was a magic internal heat sink—far surpassing any chemical explanation. Celani, Technova, Ahern and others have seen this physical feature—but have not pursued it. Its appearance in experiments designed for excess heat is emblematic of the problem of systemic over-simplicity and a single blanket theory.

Another anti-Ockham complication to more complete theoretical understanding of LENR is the dynamical Casimir effect (DCE) which was introduced by Schwinger in a simpler form in 1992: "Casimir Energy for Dielectrics." Although Schwinger was a proponent of cold fusion, it is not clear to what extent he was promoting DCE as an alternative explanation for gain (or as a predecessor condition for nuclear reactions). It should be noted that Storms' NAE can have Casimir geometry, but this is not an important part of his theory. Schwinger simply did not have enough pieces of the puzzle then, but was suggesting the idea that electron tunneling and QM effects, such as the Lamb shift, can account for some or all excess energy. A later nuclear event would then be incidental or a time reversal of cause-effect. The Lamb shift, superparamagnetism and the DCE can be interleaved and together portend both anomalous heating *and* anomalous cooling so long as asymmetry enters the picture. All one needs to see the "counter-effect" of endotherm is the correct material in the correct geometry—somewhat in the same way that the Casimir force can be either attractive or repulsive. The explanation of internal thermal loss is a surprise to many observers, but is yet also another strike against Ockham.

To clarify, the Lamb shift is a small difference between two energy levels of the hydrogen atom in quantum electrodynamics (QED) and can be perceived to go either way (energetically: endotherm or exotherm). It is basically a spin-flip, and is tiny in each instance, but lattice phonons move at terahertz frequencies and higher, so the "transaction rate" for tiny incremental gain or loss in contained hydrogen, due to the Lamb shift, is substantial if asymmetric; it is the same with the dynamical Casimir effect of virtual photons, and the two fit like hand-in-glove. All one needs to realize either anomaly over time is to impose asymmetry in a lasting way. Magnets are good at that, and the so-called Letts-Cravens effect of magnetic field boosting in LENR becomes yet another nail in Ockham's coffin.

In the end, a contributory source of anomalous heat from DCE, zero-point energy or from the Lamb shift or other QM modality is not descriptive of the complete physics, since it is a "proximate cause," and not an ultimate cause. However, if we dispense with "parsimony," in the sense of overly-simplistic solutions, it can be appreciated that the ultimate cause of any anomaly will be conversion of a percentage of proton mass into energy. Proton mass can be understood not as quantized but as an average value around the value of 938.27 MeV, with the capability to supply as much as several keV of "overage" from the high end of the distribution. This would be due to color change in quark binding and could couple via magnons to other atoms magnetically. In fact, over the years, different values for hydrogen mass have been reported over time and in a cosmological context.

The irony of suggesting many routes to gain in protium also suggests a simpler kind of mass-to-energy transfer. A heavier fraction of protons can in principle supply energy via a number of bosonic coupling routes without permanent change or transmutation. Magnons, in QCD, are the quantum of spin and can transfer small amounts of mass-energy as "spin waves" to cause spin flips or simple core heating in elements with magnetic susceptibility. This is similar to the way that an electromagnetic core heats up. Magnon transfer can happen whenever quark color change happens with a proton (which is often in confined systems—where hydrogen is captured in Casimir cavities). The beauty of this route, on paper, is that it is open to falsifiability—once current measurement techniques improve. Already, there is new information coming out about large changes in proton physical properties associated with the Lamb shift—which indicate what will happen soon with mass variation (in a metaphorical or actual way).

Unfortunately QCD and cavity-QED were not well appreciated by early theorists, and are not considered by Storms other than passing mention. Quarks account for a small part of proton mass—far less than half, and the percentage is not certain (which itself indicates innate variability). If the non-quark mass of protons is substantial and variable, to the extent that there will be a statistical surplus in a distribution, then some mass is extractable. It is a mistake for any theory to neglect QCD in favor of parsimony, since the most prevalent nuclear reaction in the universe, by far, is reversible fusion—that is: proton fusion which will always involve quantum color change. A direct mass-to-energy conversion methodology from this kind of reversible fusion fits the facts of LENR as well as any alternative, and it is counterproductive to ignore the implications—in pursuit of Ockham or simple answers.

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The Problem of Creating a Universal Theory of LENR

Vladimir Vysotskii*

Introduction

It is well known that the total probability of nuclear reactions with participation of charged particles is defined as the action of the Coulomb barrier. This fundamental limitation stimulates the use of fast particles in the composition of a thermonuclear plasma, which leads at once to the necessity to solve the extremely complicated technological problems related to the formation and confinement of such a plasma. It is also obvious that the choice of the "thermonuclear" approach makes any attempt of using (under terrestrial conditions) the reactions of synthesis on the base of isotopes heavier than deuterium or tritium absolutely unreal.

The real alternative to hot fusion is LENR. Among numerous LENR problems, the most important one is connected with overcoming the Coulomb potential barrier during the interaction of low energy charged particles. The "standard" approach to nuclear physics leads to a very small probability of the tunnel effect and can't solve this problem. Other problems (*e.g.*, sharp change of ratio of reaction channel probability, suppression of neutron channel, abnormal sensitivity to variable environment, etc.) are directly connected to the "barrier problem."

These problems are considered in the present work. Outlooks and shortcomings of a "chemical" approach to LENR phenomenon, as proposed by Storms,[1] are discussed.

We consider a general and sufficiently universal mechanism of stimulation and optimization of nuclear reactions running at low energy with participation of both light and heavy nuclei. This mechanism can be applied with high efficiency to very different experiments (both the executed and planned ones).

Several successful dynamical correlated-induced LENR experiments are also analyzed.

Outlooks and Shortcomings of a "Chemical" Approach to LENR Phenomenon

It is known that the LENR problem is connected with interdisciplinary researches and needs the efforts of different experts and different points of view.

Storms has declared three basic requirements for LENR phenomena: experimental observation; full prediction and reliability of LENR effects; adequate understanding of LENR mechanisms on the basis of a full theoretical model.

These statements are correct, but there is also a fourth requirement: possibility and efficiency of practical use.

Storms has proposed a "chemical" (phenomenological) means for the analysis of LENR phenomenon. At the first step it is necessary to discover the location of the process and only then to identify the basic characteristics of its mechanism.

In a correct physical model of any phenomenon the absence of clear statement and numerical calculations is admissible in the initial stage of formation of the theory. In the final form such model should be strictly formulated and confirmed by detailed mathematical analysis. This can lead to success in special cases, *i.e.* if LENR is observed only at certain conditions for certain kinds of particles and in certain environments.

These requirements are satisfied, for instance, for the Mössbauer effect: it takes place only in a crystal matrix (1) made of heavy atoms, (2) at low energy of gamma-radiation, (3) and if the temperature of the crystal is less than the Debye temperature. In contrast to this example, LENR phenomenon was observed in different systems and in different environments (loaded crystal matrix, cooled deuterium gas, electric explosion of wire in water, electron beam implosion of metal targets, etc.).

Storms has declared that cracks in solids are chosen as the universal nuclear active environment (NAE) for realization of LENR on the basis of hydrogen isotopes. According to Storms' model, several nuclei of hydrogen (all isotopes) with accompanied joint (collectivized) electrons might be confined in the crack due to the action of charges situated on each wall of the crack.

According to this "voids model," the initial state of interacting particles (*e.g.*, Pd, d or t) corresponds, actually, to a deformed D_2 molecule (in the case of two particles) or hydrogen plasma (for large ensemble of hydrogen atoms) placed in a crack. The equilibrium distance between two nuclei in D_2 molecules equals $r_{dd} \approx 0.84$ A. The distance between nearest d nuclei in the discussed ensemble at usual laboratory condition is not less than r_{dd} because the same distance $r_{dd} \approx 0.84$ A corresponds to compressed D gas at high pressure of $P \approx 12000$ atm in crack volume.

Unfortunately, Storms does not consider the concrete mechanism and efficiency of overcoming the Coulomb barrier in these systems (in the paper there is only general speculation about the potentiality of nuclear transmutation). It is the most important problem for explanation of LENR experiments because in a typical D_2 molecule the rate of pair dd-fusion $\lambda_{dd} \leq 10^{-70}$ s^{-1} is very small. Such rate can't explain any of the numerous conducted experiments. This "voids model" does not explain reactions of transmutation with the participation of middle mass and heavy nuclei.

On the other hand, the problem of optimization of nuclear interaction in such cracks (including analysis of the possibility of suppression of Coulomb barrier action in different kinds of cracks, nanowells and voids with the participation of two nuclei or degenerated deuterium gas) has been investigated in many works.[2-10] In several of these works very detailed quantitative analysis of features of interaction between particles has been carried out.

It is necessary to make some essential remarks to the analysis conducted in the Storms paper.

Of course, the standard statement "cold fusion is caused by a process completely different from and in conflict with the one causing hot fusion" is correct. But, the reasons for such difference are not obvious. It is impossible to explain this difference on the basis of the assumption that features of hot fusion are connected only with additional excitation of compound nucleus at accelerated motion of interacting particles with energy $T = p^2/2m$. From simple analysis it follows that in the case of inter-nuclear reactions with the participation of heavy or middle mass nucleus with mass M_n and light particle (*e.g.*, proton of deuteron with mass m) it should not be the essential difference in final products of cold ($T_{CF} \approx 0.025$ eV) and "moderately" hot ("thermonuclear") fusion with $T_{HF} \approx 10$ keV. In both cases the additional energy brought by the light particle into the compound nucleus is very close to large binding energy $Q \approx 6 - 8$ MeV $\gg T_{CF,HF}$.

The difference exists only in extranuclear processes:

a) For the case of hot fusion the energy $W_R \approx (m/M_n)T_{HF} \geq 10 - 100$ eV of relative motion of compound nucleus is much greater than the binding energy of this nucleus in a lattice, and in the case of cold fusion it is much lower ($W_R \approx (m/M_n)T_{CF} \ll 0.025$ eV);
b) For hot fusion the duration of nuclear collision is very small and mutual reorientation of electric dipole momentums of interacting nuclei is impossible; for cold fusion the probability of such reorientation is high.

These reasons can lead to different types of reactions.

For the case of hot fusion the interaction usually leads to the formation of slowly moving compound nucleus and to "standard" multi-channel nuclear decay; for cold fusion (LENR) it leads to the possibility of reaction of incomplete penetration and single-channel reaction.

For the last type of reactions the orientation effects play an important role. They are similar to the Oppenheimer-Phillips reaction that can explain He^4 formation:

$$d+d \equiv \frac{1}{2}\begin{Bmatrix}(p+n)+(n+p)\\(p+n)+(p+n)\end{Bmatrix} \to (p+n)+(n+p) \to (p+n+n+p)^* \to He^4 + N\gamma \quad (1)$$

and absence of free neutrons

$$d+d \equiv \frac{1}{2}\begin{Bmatrix}(p+n)+(n+p)\\(p+n)+(p+n)\end{Bmatrix} \to (p+n)+(n+p) \to (p+n+n)^*+p \to t+p+\Delta E \quad (2)$$

in dd-reactions.

For fast particles (hot fusion) the probability of Reaction 1 is very low because of the necessity of the presence of an additional nearest heavy nucleus for satisfaction of the momentum conservation law. For Reaction 2, the impossibility of mutual reorientation of deuterons leads to identical probability of two reaction channels by formation of compound nuclei

$$d + d \to He^{4*} \to \frac{1}{2}\begin{cases}(p+n+n)^* + p = t + p + \Delta E\\(p+n+p)^* + n = He^3 + n + \Delta E\end{cases} \quad (3)$$

and incomplete penetration with the same probability

$$d + d \equiv \frac{1}{2}\begin{cases}(p+n)+(n+p) \to (p+n+n)^* + p \to t + p + \Delta E\\(p+n)+(p+n) \to (p+n+p)^* + n \to He^3 + n + \Delta E\end{cases} \quad (4)$$

The presence of distant from nucleus neutron potential well for even-odd more heavy nuclei (virtual neutron traps at distance of 10 - 30 fm)[11] also leads to the optimization of reactions of incomplete penetration. For LENR in solids the Mössbauer-like process with transfer of recoil energy to a lattice is also possible.

One more statement made by Storms demands elaboration. The author[1] asserts that mandatory requirement of LENR is the satisfaction of the "Second Law of Thermodynamics that requires energy to always go from where it is greater to where it is less—from hot to cold, from high to low, from light to dark. Consequently energy cannot be increased locally beyond certain very narrow limits, which are controlled by the Laws of Probability." This requirement is correct only for equilibrium systems. For such systems the role of fluctuations is small. In such systems any phase relationships are absent. For density matrix approximation it corresponds to full relaxation of nondiagonal and diagonal matrix elements.

These assumptions are totally incorrect for use of the method of coherent correlated states (CCS)[12-15] for interacting particles in non-stationary LENR (see below).

I also disagree with another "standard" belief that Storms asserts: ". . .attempts to explain cold fusion by proposing to concentrate energy or by forcing the d closer together is a waste of time because the typical hot fusion products would be expected." It is very important that the CCS method can unite both these conditions—the barrier is overcome with high probability during fluctuation with virtual, very high energy and reaction goes as real (stationary) low energy.

It has been shown[12-15] that the use of CCS can lead to such effects. Below we briefly consider the possible methods of formation of such states and their application to real experiments (including LENR in non-stationary cracks).

Application of Correlated States of Interacting Particles in LENR Phenomena

2.1. Principles of formation of coherent correlated states of interacting particles at low energy

The presence of wave properties and the possibility of the tunnel effect for microparticles are one of the basic distinctive peculiarities of the quantum mechanical description of Nature. In a concentrated form, these properties are expressed in the form of uncertainty relations which determine, in fact, the limit of the applicability of the classical and quantum descriptions of the same object. This limit is connected with the Planck constant $\hbar$.

The Heisenberg uncertainty relation for the coordinate and momentum,

$$\sigma_q \sigma_p \geq \hbar^2/4 \quad (5a)$$

and its generalization

$$\sigma_A \sigma_B \geq |\langle[\hat{A}\hat{B}]\rangle|^2/4,\ \sigma_C = \langle(\Delta\hat{C})^2\rangle \equiv (\delta C)^2,\ \Delta\hat{C} = \hat{C} - \langle C\rangle \quad (5b)$$

for arbitrary dynamical variables A and B are the base relations of quantum mechanics. In modern interpretation, Equations 5a and 5b correspond to uncorrelated states.

In 1930, Schrödinger[16] and Robertson[17] generalized Equation 5b and derived a more universal inequality called the Schrödinger-Robertson uncertainty relation

$$\sigma_A \sigma_B \geq |\langle[\hat{A}\hat{B}]\rangle|^2/4\,(1 - r^2),\ r = \sigma_{AB}/\sqrt{\sigma_A\sigma_B}, \quad (6a)$$
$$\sigma_{AB} = \langle\Delta\hat{A}\Delta\hat{B} + \Delta\hat{B}\Delta\hat{A}\rangle/2 = (\langle\hat{A}\hat{B} + \hat{B}\hat{A}\rangle)/2 - \langle A\rangle\langle B\rangle$$

where r is the correlation coefficient between A and B with $|r|\leq 1$, σ_{AB} is the mutual variance of A and B corresponding to the mean value of the anticommutator of the error operators $\Delta\hat{K} = \hat{K} - <K>$.[12,18]

The Schrodinger-Robertson uncertainty Equation 6a is an obvious generalization of the Heisenberg-Robertson uncertainty Equation 5b for correlated states and is reduced to it at $r = 0$.

It was shown[12-15,18] that for a model system including a particle with coordinate $q(t)$ and momentum $p(t)$ in the field of a nonstationary harmonic oscillator

$$V(q,t) = \frac{mq^2\omega^2(t)}{2} \tag{7}$$

a decrease in the particle oscillation frequency $\omega(t)$, leads to an increase in the correlation coefficient $|r(t)|$, and a change of the uncertainty relation,

$$\delta q\delta p_q \geq \hbar/2\sqrt{1-r^2},\ r(t) = <q\hat{p} + \hat{p}\,q>/2\delta q\delta p, \quad \delta q \equiv \sqrt{<q^2>},\ \delta p \equiv \sqrt{<p^2>} \tag{6b}$$

From the formal point of view the change in the correlation coefficient in the uncertainty relation can be taken into account by introducing the variable Planck constant $\hbar^*$

$$\hbar \rightarrow \hbar^* \equiv \hbar/\sqrt{1-r^2} \tag{8}$$

at $|r| \rightarrow 1$ we have $\hbar^* \rightarrow \infty$.

When a strongly correlated particle state with $|r| \rightarrow 1$ is formed, the product of the variances of the coordinate $<q^2>$ and momentum $<p_q^2>$ increases indefinitely. This leads to the possibility of a much more efficient particle penetration into the sub-barrier region $V(q)$ than that for the same particle in an uncorrelated state. It was shown[13-16] that very low barrier transparency (tunneling probability) for the initial uncorrelated state,

$$D_0 \equiv D_{r=0} = \exp\{-W(E)\} << 1, \quad W(E) = \frac{2}{\hbar}\int_R^{R+L(E)} |p(q)|dq,\ |p(q)| = \sqrt{2M} < \sqrt{V(q)-E} > \tag{9}$$

that corresponds to the conditions $E << V_{max}$, $W(E) >> 1$ for the formation of CCS can increase to maximal possible value, $D_{|r|\rightarrow 1} \rightarrow 1$ at the same low energy $E << V_{max}$. In Equation 9 R is the nucleus radius, $L(E)$ is the "barrier width" and M is the reduced particle mass.

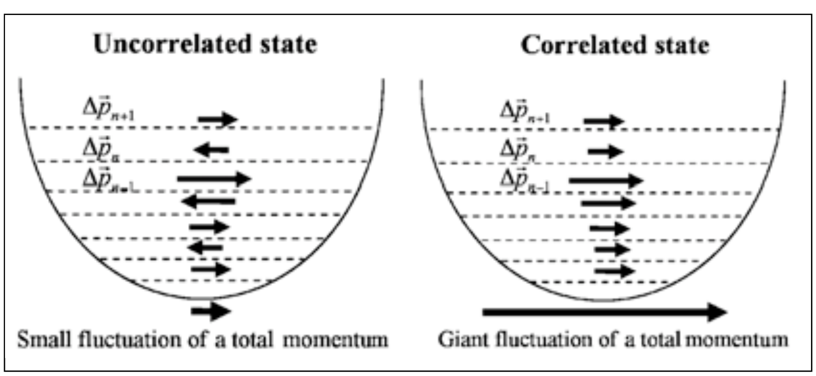

Figure 1. Formation of total fluctuating momentum of a particle in potential well in uncorrelated and correlated superpositional states.

In a very simplified form, this effect can be taken into account by the formal (not quite correct) substitutions

$$W_{r=0}(E) \rightarrow W_{r\neq 0}(E,\hbar) \equiv W_{r=0}(E,\hbar^*) = W_{r=0}(E,\hbar)\sqrt{1-r^2}, \quad D_{|r|\neq 0}(E) = (D_{|r|=0}(E))^{\sqrt{1-r^2}} \tag{10}$$

In this case the barrier transparency for a particle in a correlated state increases by a factor of

$$D_0^{\sqrt{1-r^2}}/D_0 = 1/D_0^{1-\sqrt{1-r^2}} >> 1 \tag{11}$$

which is close to the result of exact barrier clearing calculations at different r using rigorous quantum mechanical methods.[12] Although these estimates with the substitution $\hbar \rightarrow \hbar^*$ are not quite correct (they are made just for illustration of order of the effect) and must be justified every time, they clearly demonstrate a high efficiency of the use of CCS in solving applied tunneling related problems in the case of a high potential barrier and a low particle energy.

The physical reason for the huge increase in barrier transparency for a particle in coherent correlated superposition state is related to the fact that the formation of a coherent correlated state leads to the cophasing and coherent summation of all fluctuations of the momentum $\Delta\vec{p}(t) = \sum_n^N \Delta\vec{p}_n(t)$ for various eigenstates forming the superpositional correlated states. This leads to great dispersion of the momentum of correlated state

$$\sigma_p = < \left\{\sum_n^N \Delta\vec{p}_n(t)\right\}^2 > = N\left\langle(\Delta\vec{p}_n)^2\right\rangle + N^2\left\langle\Delta\vec{p}_n\Delta\vec{p}_m\right\rangle \tag{12}$$

and very great fluctuations of kinetic energy

$$<\Delta T> = <(\Delta\vec{p}(t))^2>/2M = N^2\left\langle\Delta\vec{p}_n(t)\Delta\vec{p}_m(t)\right\rangle/2M + N\left\langle(\Delta\vec{p}_n(t))^2\right\rangle/2M \sim N^2 \tag{13}$$

of the particle in the potential well and increasing of potential barrier penetrability. This situation is presented in symbolic form in Figure 1.

A CCS can be formed in various quantum systems. The most easy way to form such state is when the particle is in a nonstationary parabolic potential well (Equation 7). The formation mechanism in such system was considered.[13-15]

The coefficient of correlation $r(t)$ can be obtained by analyzing the equation of motion for a classical oscillator with a variable frequency that in dimensionless form is

$$\frac{d^2\varepsilon}{dt^2} + \omega^2(t)\varepsilon = 0,\ \varepsilon(0) = 1,\ \frac{d\varepsilon}{dt}\Big|_0 = i,\ \omega(0) = \omega_0 \tag{14}$$

where $\varepsilon(t) = \varepsilon^{\varphi(t)}$ is the complex amplitude of the harmonic operator normalized to $x_0 = \sqrt{\hbar/M\omega_0}$; $\varphi(t) = \alpha(t) + i\beta(t)$.

The correlation coefficient is defined by the expression[12-15,18]

$$r = Re\left\{\varepsilon^*\frac{d\varepsilon}{dt}\right\}/\left|\varepsilon^*\frac{d\varepsilon}{dt}\right|,\ r^2 = 1 - \omega_0^2/\left|\varepsilon^*\frac{d\varepsilon}{dt}\right|^2 \tag{15}$$

Equations 14-15 are equivalent to equations for the real functions $\alpha(t)$ and $\beta(t)$

$$\frac{d^2\alpha}{dt^2} + \left(\frac{d\alpha}{dt}\right)^2 - \exp(-4\alpha) = -\omega^2(t) \tag{16a}$$

$$\beta(t) = \int_0^t \exp\{-2\alpha(t')\}dt' \quad (16b)$$

$$|r| = \sqrt{(d\alpha/dt)^2\exp(4\alpha)/[1+(d\alpha/dt)^2\exp(4\alpha)]} \quad (16c)$$

The problem of influence of both damping and presence of additional fluctuation force was solved and discussed.[15]

It is very important that the CCS can be formed, at least in principle, within any system of levels of quantized motion that are not subjected to an external intense dephasing action, provided that a certain coherent action is superimposed on it.

2.2. Methods of formation and effectiveness of application of coherent correlated states at low energy of interacting particles

In our works[12-15] the method of formation of coherent correlated states of a particle at monotonic $\omega(t) = \omega_0 \exp(-t/T)$[12,13] and periodical[13-15] changing in the frequency $\omega(t)$ of a nonstationary harmonic oscillator was investigated.

The first regime can be provided, for example, at a constant depth of the potential well V_{max} in which the particle is located and for monotonous increase its width $L(t)$

$$L(t) = L_0\exp(t/T),\ L_0 = \sqrt{8V_{max}/M\omega_0^2} \quad (17)$$

The efficiency of excitation of the correlated states greatly depends on time (see Figure 2).

The fast increase of correlation coefficient $|r(t)| \rightarrow 1$ at such deformation of width $L(t)$ leads to a "giant" increase of barrier transparency (Equation 10) $D_{|r|\neq 0}(E) \rightarrow 1$ at low energy. Such effect is possible at monotonic deformation ("growing") of mechanical cracks with deuterium gas in solids, *e.g.* or into nonstationary microwells[1-4] at growth of biological objects.[19,20]

A more realizable situation takes place for a harmonic law of change in $\omega(t)$ in the case of a full-scale change of the oscillator frequency,

$$\omega(t) = \omega_0\,|\cos\Omega t| \quad (18)$$

or a change of this frequency in a limited range,

$$\omega(t) = \omega_0\,(1 + g_\Omega \cos\Omega t) \quad (19)$$

where $|g_\Omega|<1$ is the modulation depth.

This regime can be provided, for example, at a constant depth of the potential well V_{max} in which the particle is located and for a periodic change in its width in the interval

$$L(t) = L_0(1+g_\Omega\cos\Omega t),\ L_0 = \sqrt{8V_{max}/M\omega_0^2} \quad (20)$$

The efficiency of excitation of the correlated states greatly depends on a ratio of ω_0 and Ω.

Figure 3 presents the time dependences of the correlation coefficient   for a periodic and limited change in the oscillator frequency (Equation 19) at $\Omega = 2\omega_0$.

It follows from these results that the duration of formation of CCS decreases with the increase of frequency modulation depth, *e.g.* for the case presented in Figure 1b, we have $|r|_{max} \geq 0.999998$ at $t \geq 500/\omega_0$. For such value of $|r|_{max}$ the probability of tunneling effect for reactions d + d and Pd^A + d at room temperature increases from $D_{r=0} \approx 10^{-100}$ (for non-correlated state of interacting deuterons) to $D_{r=0.999998} \approx 0.8$ (for correlated state of d) and from $D_{r=0} \approx 10^{-4600}$ (for non-correlated state of interacting particles d and Pd^A) to $D_{r=0.999998} \approx 10^{-8}$ (for correlated state of d) in potential well of nearest Pd^{A+} ions).

From the detailed analysis it follows that the process of formation of CCS with $|r|_{max} \rightarrow 1$ at action of limited periodic modulation (Equation 19) is possible only at any of two conditions: $\Omega = \omega_0$ (resonant formation) or Ω is close to $2\omega_0$ and lies inside the interval $(2 - g_\Omega)\omega_0 \leq \Omega \leq (2 + g_\Omega)\omega_0$ (parametric formation).

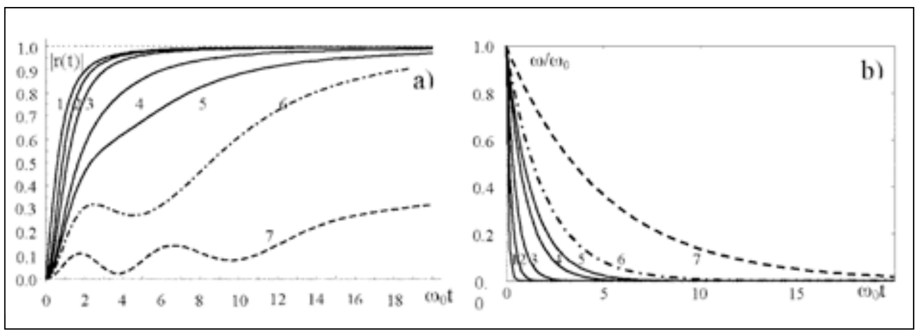

Figure 2. Time dependences of the correlation coefficient $r(t)$ (a) at various rates of monotonic decrease in the harmonic oscillator frequency $\omega(t) = \omega_0\exp(-t/T)$ (b). Curves 1-7 correspond to T = $0.1/\omega_0$, $0.25/\omega_0$, $0.5/\omega_0$, $1.0/\omega_0$, $1.33/\omega_0$, $2/\omega_0$, $5/\omega_0$.

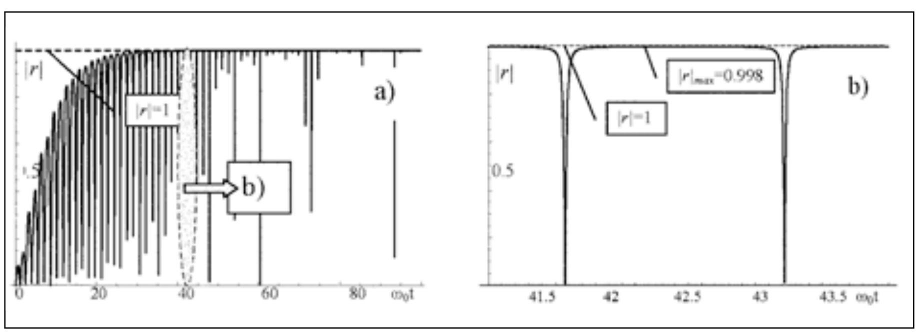

Figure 3. a) Time dependences of the correlation coefficient r for a limited change in the oscillator frequency $\omega(t) = \omega_0\,(1 + g_\Omega\cos\Omega t)$ at $g_\Omega = 0.1$, $\Omega = \omega_0$; b) Increased fragment of (a).

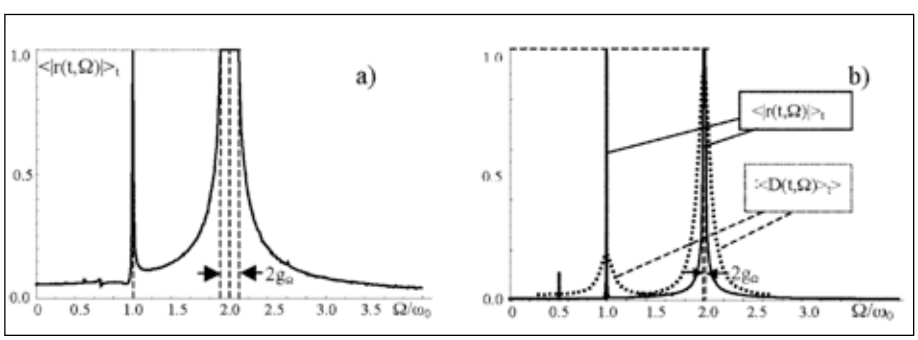

Figure 4. Dependences of averaged correlation coefficient $<|r(t,\Omega)|>$ and normalized averaged coefficient of barrier transparency on frequency Ω at $|g_\Omega| = 0.1$ (a) and $|g_\Omega| = 0.01$ (b).

The results of calculation of averaged correlation coefficient

$$<|r(t,\Omega)|>_t \equiv \frac{1}{\Delta t} \int_{t_0-\Delta t/2}^{t_0-\Delta t/2} | r(t,\Omega)|dt \qquad (21)$$

are presented in Figure 4a-b for $\Delta t = 10^3/\omega_0$ and different values of modulation depths $g_\Omega = 0.1$ ($t_0 = 1500/\omega_0$) and $g_\Omega = 0.01$ ($t_0 = 10^4/\omega_0$).

In Figure 4b the results of calculation the averaged coefficient of barrier transparency

$$<<D(t,\Omega)>_t >= \frac{1}{\sqrt{\pi\delta\Omega}} \int \left\{ \frac{1}{\Delta t} \int_{t_0-\Delta t/2}^{t_0-\Delta t/2} D(t,\Omega')dt \right\} \qquad (22)$$

$$\exp[-(\Omega - \Omega')^2/(\delta\Omega)^2]d\Omega'$$

at non-monochromatic periodic modulation of $\omega(t)$ are also presented.

From these results follows a very important statement: in any experiments with the use of external periodic modulation with limited frequency interval, the suppression of action of potential barrier on the effectiveness of nuclear reaction with the participation of charged particles is possible only for frequencies $|\Omega - \omega_0| \leq \delta\Omega$ or $|\Omega - 2\omega_0| \leq |g_\Omega\omega_0 + \delta\Omega|$.

This statement is in very good correlation with "terahertz" laser experiments[21,22] on the stimulation of nuclear reaction at joint action of two laser beams with variable beat frequency on a surface of PdD cathode during electrolysis in D_2O. Figure 5 shows the experimental frequency dependencies of thermal energy release[21] in these experiments.

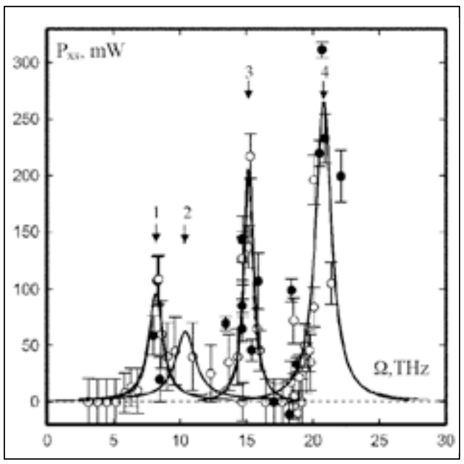

Figure 5. Frequency dependencies of energy release at joint action of two different lasers with beat frequency Ω and monochromaticity $\delta\Omega \approx 1$ THz on a surface of PdD cathode during electrolysis in D_2O.[21]

Formation of CCS in this system is connected with the direct or indirect (by plasmon excitation or phonon mode modulation) action of electromagnetic radiation with frequencies Ω on optical phonon modes $\omega_0^{(k)}$ of deuterons in PdD compound. Four resonances of energy release $\Omega_1 \approx 7.8...8.2$ THz, $\Omega_2 \approx 10.2...10.8$ THz, $\Omega_3 \approx 15.2...15.6$ THz, $\Omega_4 \approx 20.2...20.8$ THz in Figure 5 are the result of averaging of about 30 experiments and subsequent statistical processing of experimental data.[21]

Comparison of frequencies of all four resonances shows that the ratios between these frequencies are $\Omega_3 \approx 2\Omega_1$ and $\Omega_4 \approx 2\Omega_2$ with good accuracy. By the way, from the given experiments it follows that the amplitude of high-frequency maxima in each of these pairs (accordingly Ω_3 and Ω_4) greatly excided the amplitudes of the maxima corresponding to the "basic" frequencies Ω_1 and Ω_2. Such relation directly follows from comparison of Figure 4b and Figure 5. These experimental results completely correspond to the theoretical model of CCS.[23]

This model also explains the presence of a resonance of nuclear reactions (d + d and Pd^A + d) on frequency $\Omega_4 \approx 20.2...20.8$ THz (at action of beat frequency Ω_4). It is known that in the region $\omega_0^{(k)} > 16$ THz there are no optical phonon modes for PdD compound (see analysis in Hagelstein *et al.*[22]). So, the resonance of these nuclear reactions at action of beat frequency Ω_4 is connected (by parametric interaction at formation of coherent correlated state) with the optical phonon mode in PdD with the frequency $\omega_0^{(2)} = \Omega_4/2 = \Omega_2$.

A different situation takes place if there is a full-scale (maximally possible) change of the oscillator frequency $\omega_0(t)$ (Equation 18). In this case the process of formation of a totally correlated state is possible at various actions on the system (including the use of low frequency $\Omega << \omega_0$). It was shown[13,14] that at $\Omega = \omega_0/100\pi \approx 0.03\omega_0$ we have $|r|_{max} \geq 0.999993$ at $t \geq 4000/\omega_0$.

Obtained results can also explain Rossi-Focardi experiments at action of RF-irradiation to hot NiH nano-powder situated in a closed chamber with the presence of compressed H_2 gas.[24-25] In this case the action of irradiation on the surface of nano-particles leads to modulation $\omega(t) = \omega_{0n}(1 + g_\Omega \cos \Omega t)$ of acoustic phonon and plasmon modes ω_{0n} of these nano-particles. Such modulation leads to formation of CCS, a sharp increase of Coulomb barrier transparency and stimulation of nuclear reactions $Ni^A + p \rightarrow Cu^{A+1} + \nu$ (A = 58,60,61,62,64). Barrier transparency for these reactions at temperature $T \approx 400...600$ C increases from $D_{r=0} \approx 10^{-1000}$ (for non-correlated states of interacting p and Ni^A nuclei) to $D_{r=0.999993} \approx 10^{-6}...10^{-4}$ (for correlated state of p).

The similar effect of formation of CCS and stimulation of effective nuclear dd-fusion (including generation of neutron bursts) takes place in cooled D_2 gas at changing of strong external magnetic field in interval 8...10 kOe.[26]

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About the Author
Dr. Vladimir Vysotskii has a Ph.D. (1975) from Bogolyubov Institute for Theoretical Physics (Kiev, Ukraine) and D.Sci. (1992) from National Shevchenko University for Theoretical Physics and Solid State Physics (Kiev, Ukraine). Since 1976, he has been employed by the National Shevchenko University, currently as head of the Theoretical Radiophysics Department. Vysotskii has authored about 300 papers and eight books.

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Comments Regarding the Storms Paper

Jean-Paul Biberian*

The paper, "Cold Fusion from a Chemist's Point of View," is divided in two parts. In the first part, Storms explains the difference between hot fusion and cold fusion. The mechanisms of hot fusion and cold fusion cannot be the same. For example, in fractofusion the mechanism is identical to hot fusion (it is not LENR), and the reaction products are the same as those of hot fusion. Cold fusion operates under a different mechanism. Storms assumes that hot fusion operates under the basic laws of thermodynamics which explain the data observed. On the other hand, cold fusion operates under the laws of statistics. This is the explanation of the different behaviors between hot and cold fusion. Storms assumes that the mechanism of LENR is the same for all isotopes of hydrogen, and should occur in the same type of environment which he calls the nuclear active environment (NAE). This first part of the paper is factual and, according to Storms, all theories should be in accordance with the experimental observations.

In the second part of the paper, Storms makes a proposal. He suggests that the NAE is in fact a crack. The reaction between hydrogen isotopes occurs in the middle of these cracks. They are, according to Storms, sort of floating in the center of the cracks. Because of this special configuration, the nuclei can get closer and closer, losing energy by emission of soft X-rays, which are difficult to detect because they are absorbed by the material. They are the cause of the heat production.

There is not much to criticize in the first part which is observational. However, in the second part, Storms makes a guess, which is not easily proven. The idea that hydrogen nuclei are sitting at equal distance on the walls of the crack is only possible if repulsive forces are acting on these nuclei. If they were attractive, they would immediately stick on one side or the other. Storms does not say anything about this point. Also, experiments have shown that it is necessary to be in a dynamic state in order to have LENR. Storms does not emphasize this point. The emission of soft X-rays is very appealing, and looks like what is happening in chemical reactions where no photon of the binding energy is emitted during a chemical reaction, but many photons of lower energy are emitted during the reaction process.

I am not a theoretician. However, in order to perform experiments, I need to use a model which is not a theory, but a guideline that will facilitate my experimental options. In my mind, it is necessary to be in a dynamic state. It has to be some condition where diffusion occurs, for example by a gradient in the pressure, by electrical current, or even a temperature gradient.

Any theory, should explain all the experimental observations, be they major or secondary. Obviously, this is very difficult, because of the large variety of experimental observations. It is clear to me that the reaction occurs in a special environment, otherwise LENR would have been discovered long ago. This environment is not necessarily a crack or a void, but is, to my understanding, a surface effect. A crack defining two surfaces is as good as a surface.

About the Author
Dr. Jean-Paul Biberian was a physics professor at the Aix-Marseille University in France. He has been working for 20 years in the field of LENR, performing experiments by electrolysis and in gas phase. Dr. Biberian is Editor-in-Chief of the *Journal of Condensed Nuclear Science*.

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Review of the Storms Paper

Andrew Meulenberg*

Edmund Storms' paper, "Cold Fusion from a Chemist's Point of View," has some serious flaws, but it also has some good points.

A major flaw of the paper is its dependence on a hypothesis of "two-in-two-out." The argument is flawed and is based on physics quite different than that suggested in the paper. It is used throughout the paper and, by it being incorrect, thereby vitiates the value of the paper.

Storms writes that the "two-in-two-out" rule is "characteristic of all nuclear reactions initiated between two particles." Is this a rule in nuclear physics? It is not universal in physics and probably not so even in nuclear physics. Or, is it based on *The Science of Low Energy Nuclear Reaction*, by Storms? If so, it is an observation, not a rule.

The paper indicates that "momentum is conserved in a different way compared to hot fusion." In physics, energy and momentum can be conserved in an inelastic (fusion) collision between two equal-mass bodies with *no* extra output particles or radiation. This is a two-in-one-out event. If this does not happen in nuclear physics (ever) then it would be worth a publication (or at least a reference).

Storms seems to ignore "triggered" cold fusion. If this is the intent, then triggering should be stated explicitly as "outside" the chemical environment.

On page 4, Storms writes that the process is "unique and is proposed to be only possible as a result of a resonating structure involving hydrogen nuclei trapped in a crack of a special size." This resonance model is essentially that proposed by Schwinger ["Nuclear Energy in an Atomic Lattice," *Proc. First Annual Conference on Cold Fusion*, Salt Lake City, 1990) except that Schwinger uses phonons, not photons, and ends up at the first excited state of $^4He^*$, giving off 3.8 MeV, not at the ground state. This gives tritium production, *i.e.* hot fusion. However, at the time of Schwinger's publication the ^4He end product of cold fusion had not yet been confirmed. I suggest updating the Schwinger model to include a transition to the ground state, giving off the 24 MeV as phonons rather than a single photon. Thus, with both levels accessible via phonon decay (the first excited state and the ground state of ^4He), Schwinger's and Storms' models both provide for negligible neutron production, low tritium production and no ~24 MeV gammas from DD fusion.

Storms claims that there is no energetic radiation in the form of n, T or 24 MeV gammas. His energy-decay mode is via double-photon decay instead. However, this ignores the possibility of screened tunneling into the fused D-D state and the natural "hot fusion" consequences of that action. He also does not seem to recognize the low transition probability of the double-photon decay relative to phonon decay in a lattice. While the double-photon decay explains some reported experimental observations, and therefore is a major contribution to the subject if confirmed, it certainly cannot be the major decay mode as Storms proclaims. A recognition and understanding of Schwinger's heretical model would give Storms' paper a physical and mathematical basis and put a Nobel Laureate's knowledge and prestige behind at least a part of his model.

Storms writes (page 5) that "a collection of H^4 nuclei result if the starting nuclei were deuterons (d). . ." How does the ^4H nucleus form from deuterons? Does the energy concentrate by resonance to ~3/4 MeV in this environment so that $p + e \rightarrow n$? More likely it would be the protons in the deuterons forming a deuteron with one of the linearly transiting electrons. Further, Storms writes: "The unstable H^4 immediately emits an electron to form He^4." This part is very weak. There needs to be a description of what the energy levels involved look like (with delta E = ~1.5 MeV) and why the radiation is paired (two-in-two-out doesn't cover this). Did Campari *et al.* (Storms, Reference 45) give any clues as to the nature of the levels and why a unique energy should result?

In the summary, three items are presented as "proven" in the paper: 1) Hot and cold fusion are completely different; 2) Each hydrogen is separated by an electron. (This is not a proper description.); 3) ^4H is an initial D-D product. These conclusions are probably wrong. They are certainly not adequately "proven" in the paper.

One of the paper's good points is that it provides a possible physical structure that fits much of the known information about hydrogen in metals and could be a basis for an early mathematical description provided by a prestigious physicist. The structure needs to be properly defined (it is presently flawed) and its connection to the theory should be described. This is important because the author's model goes against expected physics and, coming from a chemist, would be automatically rejected if not supported by Schwinger's paper. While the paper is "from a chemist's point of view," it should not casually dismiss known physics.

About the Author
Andrew Meulenberg, Jr. earned a Ph.D. in Nuclear Physics from Vanderbilt University. He spent 27 years at COMSAT Labs, responsible for predicting, monitoring, correcting and preventing space-environmental effects on communications satellites; he developed and managed the space-environment-simulation laboratory, and developed new devices and concepts for space-satellite systems. After five years as an independent aerospace consultant and five years as Principal Scientist in the Opto-Electronics Department at Draper Labs, he retired to teach and do independent research as Visiting Scientist at the Indian Institute of Science and, more recently, as Visiting Scientist and now Senior Lecturer at Universiti Sains Malaysia.

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Agreements and Disagreements with Storms

Ed Pell*

Storms points out that cold fusion (LENR) does not produce a high energy particle as part of the final product. There is ample experimental proof of this and I agree.

Storms includes all lattice defects as being lattice and not potential reaction sites. I disagree. I still see lattice defects as potential sites, particularly single atom vacancies. I do agree that regular undisturbed lattice material is not where reactions occur, even when loaded greater than 0.9 with deuterium.

Storms states every system seeks the lowest Gibbs energy. I agree completely.

Storms points to cracks as the locations of reactions. He seems to be referring to cracks that have one small spacial dimension and two extended spacial dimensions. I disagree. I see two (or three) small spacial dimensions and one (or zero) extended spacial dimensions as required to forbid typical quantum mechanical behavior and allow a classical collapse of d + e + d → He + free-electron. For me, small is significantly less than two Bohr radii, so an electron cannot form a self-reinforcing periodic orbit.

Storms makes three assumptions. I see no experimental evidence to tell us what the reactants or the products are for hydrogen on nickel, nor for deuterium on nickel, so I do not yet see a reason to have one mechanism or one site. I still consider p(d) + Ni → Cu as possibly the channel for both hydrogen and deuterium on nickel.

The section entitled "Proposed Mechanism Causing LENR" is the meat of the article; much is hinted at and much is unspecified. At the start we cannot tell if the line of protons and electrons proposed are vibrating bound particles, like atoms in a lattice, or free moving particles with thermal velocities that would take them out of a neat line in about 0.1 picoseconds. Storms seems to want the best of both worlds, but does not explain how that would work.

The other feature offered is a resonance. We are not told what is resonating, nor what is driving the resonance, nor how they are coupled. I do not see a stable, nor quasi-stable, resonator in the proposed line of charged particles.

Storms offers a reactants in/products out description that in the middle requires an extravagant use of the weak force to convert e + p → n on demand. This will require experimental proof before I would accept this channel, but it is worth keeping the idea open.

What it is that Storms finds appealing about small cracks needs more explicit statement. I find small confines that forbid typical quantum mechanic behavior and allow the electrostatic collapse of d + e + d → He + free-electron the most likely mechanism for cold fusion. I do not believe that a line of charged particles with two open dimensions can evade quantum mechanics. Quantum mechanics will lead to typical chemical behavior where an electron's average distance from a proton is about one Bohr radius and where two protons typically hold two Bohr radii apart by their respective electron clouds. I believe two restricted spacial dimensions are required. Storms seems to be offering one restricted dimension. How this works is not obvious.

Storms is one of the world's most capable and productive experimentalists in cold fusion. I look forward to his experimental results. I also look forward to an elaboration of his theory.

About the Author
Ed Pell has a B.S and M.S. in physics from Columbia University focusing on experimental particle physics. He has been in semiconductor product design, lithography and EDA (electronic design automation).

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RESPONSE TO REVIEWER COMMENTS

Edmund Storms

I want to thank the reviewers (*IE* #108) for taking the time to make interesting and sometimes useful comments on my paper, "Cold Fusion from a Chemist's Point of View." This is the first and hopefully not the last time a proposed explanation of LENR has been reviewed publicly in such detail. The process is effective in revealing not only flaws but also how the ideas can be better explained to avoid misunderstanding. I will comment on each review in the order they appeared in *IE* #108.

David Nagel

Nagel understands my basic proposal with a few exceptions. His requirement that a theory be tested by quantitative calculations is normally correct but this kind of test cannot be used here. LENR occurs as individual nuclear events that are invisible as a single event. Only the average heat effect or radiation flux can be measured. The average is determined by variables over which no control exists. For example, the number of active sites present in a sample will determine the amount of generated power. We have no way to measure the number of active sites. Therefore we have no way to predict from theory the total power that might be expected. In addition, each active site will have a different access to the reactant. Consequently, the rate at which fusion takes place will be different at each site, which again cannot be determined from theory. The *only* test of such a model is verified predictions of general behavior.

As for the comment about using the word "chemist" in the title, chemists and physicists do look at the world in different ways and do arrive at different kinds of explanations. We might not like this condition, but it is a fact of life I find necessary to acknowledge because the other theories are mostly created by people trained in physics. Consequently, the approach they use is much different from the one I'm using. This difference is important because physics tends to focus on the cause while my focus is on the result. The latter focus is more effective in understanding LENR than is the former because only the overall effect can be studied, not the cause.

Xing Li

Li took this opportunity to evaluate the early critique by skeptics of the claims made by Fleischmann and Pons, and to supply an explanation of his own. He examines the claimed Ni-p transmutation reaction, which my theory rejects as a significant source of energy, and places this reaction in the lattice, which my theory predicts is not the location of any LENR process. By paying no attention to what I wrote and suggesting processes that are in direct conflict with what I propose, I assume Li does not find my ideas worthy of comment. Consequently, no response is required.

Jones Beene

Yes, many explanations of LENR have been proposed, but this fact does not invalidate my use of Ockham's razor. The challenge is to evaluate these other ideas and determine how many are correct. If my explanation remains as the only nearly correct explanation, my use of Ockham's razor would have proven its value. In any case, all explanations naturally seek to find the least complex path because otherwise the ideas become too complex and numerous to evaluate or test. The important choice is which assumption is retained and which is eliminated. Beene does not address this choice.

In contrast to the statement made by Beene, my theory has absolutely no relationship to fractofusion and it applies to all methods known to cause LENR, not just the method used by Fleischmann and Pons.

Yes, many features used in my theory also have been used in previous theories. Nevertheless, my approach is a unique combination of features that is able to explain behaviors other combinations failed to explain. Using the example provided by Beene, the claims for nuclear heat resulting from using normal hydrogen are not novel, as Beene suggests. Fleischmann and Pons noted extra heat from this source, as did many other researchers. This claim did not result from errors in calorimetry because calibration was frequently based on use of Pt as the cathode in D_2O or on using a resistor, not Pd as the cathode in PdH. But this result has no relationship to my theory other than I can predict this behavior and can explain why it occurs.

Vladimir Vysotskii

Vysotskii understands what I propose, except for one confusion. I do not believe that the D_2 molecule plays any role in the process, neither deformed as he describes or not. The hydroton molecule that I propose to form is based on the "p" electron orbit, not the "s" orbit that forms normal D_2. This difference is important and is not simply a distortion of normal D_2. In addition, the dimension provided here is the equilibrium distance between the nuclei in D_2. If the hydroton is to function as I propose, this distance must gradually decrease as energy is lost. Consequently, the initial distance between hydrons is not important.

In the process of describing what I propose, Vysotskii reveals a basic conflict with how I understand Nature to behave by his description of hot fusion and the law of thermodynamics. These differences are too basic to address here in detail. Nevertheless, I need to emphasize that energy does not and cannot spontaneously accumulate in local regions in a material. If this accumulation were possible, no explosive would be stable. Spontaneous accumulation of energy is clearly limited to magnitudes that cannot affect chemical processes, which are sensitive to much lower levels than are nuclear interactions. Consequently, LENR cannot be initiated by a spontaneous accumulation of energy but must rely on a basic change taking place in the material. Yes, enough energy can be *applied* to a material to initiate fusion, but that is not the issue I was discussing by invoking the laws of thermodynamics. In addition, when this is done, hot fusion products are formed—not cold fusion.

The LENR phenomenon presents a dilemma for any explanation. Two D must eventually combine to form He—an event that requires mass-energy to be converted to heat-energy. This process must occur in a unique condition in a material. Yet, all proposed conditions fail to support such a process without violating some law or expectation, including the one I suggest and the one proposed here by Vysotskii. The solution to this problem generally degrades to applying mathematical equations based on concepts that are so complex to defy understanding or to simply ignore the problem. An approach needs to be found to encourage agreement about the basic requirements a theory must have, because at the present time many theories are in conflict with fundamental and basic concepts about how Nature is known to behave.

Jean-Paul Biberian

Biberian summarizes my claims well, but his understanding of how I claim the hydrogen nuclei can float in the gap is not complete. Also, the conclusion that my claim cannot be easily proven is not correct. The unique feature about the gap is that it allows the H+ to be equally attached to both surfaces. Of course, if the gap is too large, the nuclei will favor one surface over the other, as Biberian imagines might be the case. Achieving this critical distance creates great difficulty in causing the effect and in maintaining nuclear activity in a material.

As for a test of my model, I suggest three. A search for deuterium production can be made using the Ni-H_2 system, a search for the effect of the D/H atom ratio on tritium production rate can be undertaken, and cracks can be made by nano-machining followed by examination for nuclear activity. These studies would test several predictions. Failure of any prediction would immediately invalidate my model.

Andrew Meulenberg

Meulenberg fails to understand much of what I wrote in spite of many private discussions. I do not object to my idea being rejected, but this must at least be based on a correct understanding of what I propose. I will attempt to address the major misunderstandings.

1) The two-in-two-out rule is simply a restatement of the conservation of momentum law when applied to a nuclear reaction. When two atoms come together to make a single nucleus, the energy cannot be released without another particle being emitted. In the case of D+D to make He, the second particle is either a gamma ray or the helium nucleus splits into fragments consisting of two particles. In general, energy can only be communicated from a nucleus to the surrounding material by emission of something, which results in two particles being produced; thus the two-in-two-out rule.

2) Ignore triggering of the reaction because according to my model, once the gap is formed and filled with the required resonating structure (the hydroton), mass-energy conversion starts spontaneously and continues until all hydrons in the gap have been converted to the expected nuclear product. Once the nuclear product leaves the gap and the reactants are again assembled, the process repeats. The only limit is how fast the hydrons can enter the gap and form the hydroton. This rate is determined in part by applied energy, but it is not triggered by applied energy.

3) My model has absolutely no relationship to the process Schwinger proposed, although I admire his willingness to suggest an idea that I'm sure he would have modified later. Andrew does note the conflict but nevertheless says, "This resonance model [mine] is essentially that proposed by Schwinger," which is not the case. I would not mind standing on Schwinger shoulders as Meulenberg suggests, but my model is not even close to what Schwinger described.

4) My description of H^4 formation and subsequent decay results from the need to explain tritium formation by LENR. To form tritium from H and D, the plausible reactants, an electron has to be added to the final nuclear product. I assume this addition occurs in all cases of LENR, regardless of which hydrogen isotope is used. This means D+D+e gives H^4, which has to decay by beta emission in the same manner as H^3 decays. If Meulenberg wants to reject this idea, he should note that H^4 is thought to decay by neutron emission, not by beta emission.

5) I make no effort to prove anything in the paper. Such proof is, in fact, impossible. I only explain how the model is created, what it explains, and what it predicts. Proof comes if the predictions are confirmed and the explanations provide a better guide for experiment.

Ed Pell

Pell makes his disagreements clear, but again his conclusions are not based on what I wrote. I do not address the Ni-p reaction except to note in several papers the conflict this claim has with what is observed and what is required to initiate such a reaction. This reaction makes only one product, which does not permit the energy to be released. If this reaction is to be believed, this problem must be addressed. I do not attempt to explain transmutation in this paper even though my model can explain this process as a very minor part of the main fusion reaction.

Pell objects because I have not explained every aspect of the resonance process. This kind of detail requires a different paper and many more pages available to provide such information. This detail is gradually being provided.

I have never claimed that the process evades quantum mechanics. In fact, several people have been encouraged to apply quantum mechanics. I await their success.