What is now known about cold fusion?
(Addendum to the Student's Guide)

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This is an addendum to the "Student's Guide to Cold Fusion" that clarifies several issues based on the growing understanding. Because this is a stand-alone summary, some of the basic information given in more detail in the Guide is briefly repeated here. Nevertheless, the reader is encouraged to consult the Guide for more complete information.

What is cold fusion? The phenomenon to which this name is applied was first announced by Martin Fleischmann and Stanley Pons (Univ. of Utah) in 1989 [1]. Since then, studies in over eight countries have supported the claims and added to our understanding. The common belief that the effect was rejected because it could not be reproduced is simply not true and is based on ignorance. While the effect is difficult to produce, it has been replicated hundreds times and this work has resulted in over 1000 papers[2], many of which can be easily found in conventional peer reviewed scientific journals or on the web[3]. So much supporting information has now been published, continued rejection has no rational reasons.

Because additional nuclear reactions besides fusion of deuterons have been observed, the name has been expanded to LENR, (low energy nuclear reactions) and CMNS (condensed matter nuclear science). Nevertheless, cold fusion remains the common identifier because most people relate this name to the phenomenon and the word 'fusion' accurately describes the general nature of the reactions.

How does cold fusion differ from the hot fusion (plasma fusion) phenomenon? Fusion between two deuterons[1] normally requires application of considerable energy to cause the nuclei to approach close enough to fuse. This energy is required to overcome the barrier created by the positive charge on each nucleus, i.e. the Coulomb barrier. When this kind of fusion occurs, the products are always a mixture of energetic particles consisting of neutrons, helium-3, tritium, and protons, each in nearly equal amounts. Even when energetic deuterons bombard a metal, such as palladium, these products always form even when the applied energy is very low.[4] However, as the applied energy is lowered, the rate of reaction becomes too small to measure well before the energy associated with cold fusion is reached. Fusion can be made to occur more rapidly at low energy by replacing the electron in the D_2 molecule by the heavier muon[5-7], thereby bringing the nuclei closer together. Once again, the products typical of hot fusion result. In other words, any process that does no more than reduce the distance between deuterons produces the products associated with hot fusion, not with cold fusion, regardless of how

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[1] Deuterium is a natural occurring isotope of hydrogen containing a proton and a neutron and has a concentration of one atom of deuterium with 6400 atoms of ordinary hydrogen in all water.

low the applied energy might be. In addition, the lower the applied energy, the smaller is the rate of reaction.

Since reducing the distance between nuclei alone produces a low-level hot fusion effect rather than cold fusion, there must be some other aspect of the cold fusion reaction that not only overcomes the Coulomb barrier but also changes the mixture of energetic particles from the reaction. This new aspect can only exist in a special solid material. In addition to changing the nuclear products and eliminating energetic particle emission, this feature permits a very high rate of reaction even at low applied energy. The major reaction is found to be formation of ^{4}He, with occasional formation of tritium and transmutation products, but without neutrons. In other words, the two types of fusion result from entirely different conditions and produce different reaction products. In addition, hot fusion requires application of high energy and is relatively insensitive to the environment, with plasma even being a suitable environment. Cold fusion requires very little energy and is very sensitive to the chemical environment. These important differences were missed early in the field’s history, leading to much confusion then and even today about how hot- and cold-fusion are related. This relationship is further complicated by the conventional belief that the chemical environment cannot affect any nuclear reaction, which is not true in the case of cold fusion. In fact, the nature of the chemical-physical environment is essential to the operation and understanding of cold fusion.

The special chemical-physical condition required for cold fusion to be initiated is called the “nuclear active environment” (NAE). This is created largely by chance during attempts to replicate the effect. This is why success has been so difficult to achieve. The challenge is to understand the nature of this environment and fabricate it in large amounts on purpose. This is difficult because the NAE, when it forms at all, is rare and is located in isolated, tiny spots, leaving most of the sample totally inert. The problem becomes one of trying to find a needle of unknown size in a very large haystack.

Efforts to define the kind of needle we are looking for get complicated because this depends on the theory being proposed. Some proposed mechanisms require a surface between two different materials[8]. Others require special sites in a palladium lattice [9, 10]. Some mechanisms even propose that neutrons[11-13] or other particles[14] are involved. The number of ideas and variations is too large to discuss here, but it is fair to say all the mechanisms have serious flaws and none has shown how to make active material. Furthermore, once a theory is proposed, it is seldom changed to be consistent with new observations or criticism except by adding additional ad hoc assumptions. Consequently, useful theoretical understanding is not being achieved and understanding is mostly based on experimental observation. These observations have gradually defined the required conditions and expected behavior.

What observations must a person consider in order to believe the phenomenon is real and on which a worthy explanation might be based? The most obvious and well-documented behavior is energy production greatly in excess of any plausible chemical process. The recent claims by Rossi[2] of having produced up to 12 kW for hours by exposing special nickel to H_2 add significantly to this evidence. A rational reason no longer exists for these claims to be in dispute because accurate calorimetry has been used in most cases and all of the published suggested prosaic processes have been addressed. Although replication is not easy, it has been accomplished on enough occasions to qualify cold fusion as a reproducible effect. As described in more detail below, this heat has been found to result from production of helium. In addition, tritium, a radioactive isotope of hydrogen, has been made in amounts that can only result from a novel nuclear reaction. This tritium is not accompanied by neutrons or energetic radiation, hence does not result from the hot fusion process. Heavy elements not present initially in the material have also been detected on many occasions. Although some of these elements can be identified as normal contamination, all cannot be explained this way because some have abnormal isotopic ratios and some are present in too high a concentration[3]. Occasionally energetic radiation is detected, but not often nor in amounts consistent with hot fusion. Chemical processes cannot produce such radiation no matter how small an amount is detected. This large and growing collection of novel and anomalous results is most easily explained to result from nuclear reactions of various types. A combination of errors capable of explaining all observations is now too improbable to consider.

Early in the field’s history, light hydrogen (proton) was found to enter into nuclear reactions as well as deuterium, thereby producing heat [15] and various nuclear products[16]. Two protons alone cannot produce a stable product if they should fuse, so the observed extra energy was attributed to formation of the observed transmutation products[17]. These products result from a reaction in which a proton goes into the nucleus of a larger atom such as palladium, potassium, or other advantageous elements[18]. Recently, Rossi has found a way to make nuclear reactions involving hydrogen occur at a very high rate as indicated by generation of impressive amounts of power and energy. Because no other nuclear products are detected, this energy is proposed to result from a proton going into Ni to create copper. This mechanism has some serious problems and is not likely to be the source of most energy. Only better measurements will sort out this mystery. Nevertheless, Rossi has discovered a very efficient way to make large amounts of NAE.

Is the mechanism operating in the hydrogen + Ni combination related to the one operating in the Pd+D combination? This becomes an important question in deciding

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[2] See: http://www.nyteknik.se/nyheter/energi_miljo/energi/article3108242.ece.
http://www.nyteknik.se/nyheter/energi_miljo/energi/article3111124.ece.
http://rossiportal.com/
http://en.wikipedia.org/wiki/Energy_Catalyzer
http://pesn.com/2011/03/07/9501782_Cold_Fusion_Steams_Ahead_at_Worlds_Oldest_University/

[3] The role of transmutation is discussed in detail in “Low Energy Nuclear Reactions: Transmutations” by M. Srinivansan, G. Miley, and E. Storms in Wiley Encyclopedia of Energy and Technology, Vol. 1. Nuclear Energy (S. B. Krivit, ed.) 2011.

whether nature has a single mechanism with variations, or two different mechanisms. A single mechanism seems more likely because the process has such unique requirements. If so, a proposed theory has been further limited in its characteristics by needing to explain the behavior of light hydrogen, which eliminates most present suggestions. Consequently, Rossi's success has advanced application of the phenomenon while creating a serious challenge to theoreticians.

It was incumbent upon those who proposed that this extra energy results from fusion to identify the nuclear product and demonstrate that it is proportional to the energy. This has been done with respect to the energy/helium relationship. This literature has been reviewed by Storms[2, 19], from which a value for the energy/He of 25±5 MeV/He is obtained. This value is consistent with the expected energy of 23.8 MeV/He produced by fusion of two deuterons. No other nuclear reaction produces so much energy when helium is produced. On the other hand, other nuclear reactions have been detected occasionally, which might add energy during these measurements and result in the reported value being only coincidentally similar to the expected value for D-D fusion. How likely is this? Tritium is occasionally produced and the maximum rate reported is about 10^8 atoms/sec.[20] If the tritium results from D-D fusion, which produces 4 MeV/tritium, the power would be 0.0064 mW. Even if the tritium production rate were underestimated by a factor of 100, this is still far too small to influence the calculated value for energy/helium. Furthermore, tritium production by the cold fusion process is unlikely to involve D-D fusion, so the energy/tritium value would be even smaller and even less power would be produced at a plausible tritium production rate. Transmutation is also known to occur while cold fusion operates. The rate of this reaction is difficult to estimate because the transmuted products are highly localized and their production rates have not been accurately measured. Nevertheless, the rate is very small[21] and unlikely to make a significant contribution to observed power. If other reactions were occurring, they would have to contribute in exactly the right proportion during each measurement for the result to fall so close to the expected value in each case and to have such a small variation. This seems like an unlikely coincidence. The proposed contribution by the nuclear reaction between deuterium and lithium[22] to produce helium, giving about 13 MeV/He, is not possible during the measurements reported by McKubre[23] using gas loading of a so-called Case catalyst because significant lithium was not present. Yet, the values show general agreement with measurements using electrolysis where lithium was present[24]. Although the data still have significant uncertainty, the most probable conclusion is that observed power results mostly from fusion of two deuterons to produce helium even though a simple, direct fusion of two deuterons is unlikely.

What unusual processes are likely to operate to give some clue about the nature of the process? The work of Iwamura et al.[25] shows production of something at the Pd-CaO interface that can diffuse from this region through palladium and interact with advantageous elements to cause transmutation by spontaneously adding up to 6 deuterons to the target nuclei. This means clusters of deuterons are involved and these can diffuse through palladium lattice as independent structures from where they are made at the CaO-Pd interface to the surface where the target elements are applied. In addition, they can reduce the Coulomb barrier between themselves and target nuclei, while dissipating the resulting energy without emission of energetic radiation. Of course, if one of these clusters should react with a deuteron, helium would result and release the expected 23.8 MeV/He by the same process that results in transmutation. This observation suggests a plausible mechanism for all of the observed reactions.

Now that the effect has been proven to be real and the source of energy from the deuterium branch of the effect has been identified, how can it be explained? A few requirements are known to apply. To summarize: the mechanism must reduce the Coulomb barrier between clusters containing deuterium and/or hydrogen and a target nuclei; dissipate the nuclear energy as low-energy emissions as the nuclear reaction takes place; the clusters must be able to diffuse through palladium and react with deuterons to produce helium when the deuterium concentration is high and tritium when protium is also present. Each of these requirements must operate without application of significant energy and without disrupting the chemical bonds in the material. The latter requirement is frequently ignored, but it is important because a spontaneous process that concentrates energy at the D-D site will first alter the chemical bonds at this site, and the accumulating energy will be absorbed by this process before it can achieve a level required to cause a nuclear effect. This effect is well known and is described by the Second Law of thermodynamics[4] and Le Chatelier’s Principle.[5] Besides, when highly concentrated energy is added on purpose, it always results in hot fusion, not cold fusion. Therefore, the cold fusion process cannot involve a spontaneous concentration of energy at a D-D site, or, indeed, anywhere in a solid lattice beyond levels that would cause a chemical-physical process. These requirements are ignored so often in proposed theory to cause even a casual reader of theory to be aware of how far from basic principles the suggestions have drifted. Absence of a useful theory has resulted because the basic behavior and accepted understanding of materials has not been considered while trying to explain the nuclear aspects of the process.

These requirements can be further refined. Electrons must bond the protons (deuterons) in the clusters and these bonds must have a novel structure, which may be similar to the unusual bonds formed in a Rydberg molecule[26, 27] or propose by various theories [28, 29]. Regardless of the details, when the nuclear reaction finally occurs, it is likely the bonding electron will be sucked into the resulting nuclear product on occasion. Tritium

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[4] A simplified statement of this law is that energy does not go up hill and it does not accumulate from sources having a lower energy. Of course, random processes or resonance can cause small accumulations. Nevertheless, if these small accumulations were common, the consequences to chemistry would be obvious. For example, explosives would not be stable. Therefore, how can energy be accumulated from a source having less than one eV to levels of hundreds of keV needed to influence a nuclear process and how would this extra energy alone cause the unique behavior of cold fusion? A proposed theory that assumes this process must answer this question with convincing evidence.

[5] This Principle says essentially that nature will try to undo any change that is attempted. In this context, nature will try to prevent accumulation of energy by various processes, such as changes in bonding characteristics, atom location, emission of photons or creation of phonons, as a few examples.

could result when D-H fuses and acquires the bonding electron. This reaction would release 2.6 MeV/T. If this process should occur when the protium concentration is high, deuterium would result from fusion of two H with absorption of the bonding electron and release 1.4 MeV/D. Consequently, this single process can account for energy production and transmutation in both the deuterium- and protium-based systems, with the energy being dissipated by the same process, which is still not understood. The main difference between the palladium- and nickel-based systems is that nickel holds the fuel (H or D) to higher temperatures than does palladium, which results in larger reaction rates being available because higher temperatures can be used without losing the fuel. Failure to explore the higher temperatures may be one reason success has been poor using nickel before Rossi showed the way.

The phenomenon is now well documented and only awaits sufficient knowledge and acceptance to be useful as a source of clean energy. The need for such energy is so desperate that all plausible ideas should be explored rather than rejected outright, regardless of the reasons for rejection. Skepticism is a luxury we can no longer afford.

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