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Research Article

Explaining Cold Fusion

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Abstract

Five assumptions are identified that apply to all theories. These assumptions and several others are used to create a new explanation of low energy nuclear reactions (cold fusion) based on formation of a novel active environment within a variety of materials. The method to form this environment and the nuclear consequences are described. The fusion process is proposed to occur when a form of metallic hydrogen is created in nano-cracks. Methods to test the model are provided. Engineering variables are identified and used to show how the process can be controlled and amplified. These assumptions can also be used to evaluate other proposed explanations.

Keywords: Cold fusion, Hydroton, LENR, Mechamism, Theory

1. Introduction

The phenomenon referred to as cold fusion (CF) in this paper is defined as a nuclear process initiated on specific occasions in apparently ordinary material without application of significant energy. The process produces unexpected heat and nuclear products without significant radiation when any isotope of hydrogen is present. This phenomenon, first discovered by Fleischmann and Pons [1], has now been demonstrated by many replications [2,3] and is on its way to commercial application [4]. Nevertheless, a satisfactory explanation has not been generally accepted, resulting in general rejection of the claims and inefficient investigation of behavior. This paper describes criteria useful in evaluating all proposed explanations and provides a new explanation consistent with these requirements. The assumptions on which this approach is based are justified and methods to test the resulting model are suggested. As required of a useful model, many new predictions are made and a path to improved reproducibility and control is suggested. The model has been expanded in a recently published book [5].

2. Assumptions

All the theories start with assumptions, which if incorrect will doom a model no matter now much argument and

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mathematical support are applied. Five basic assumptions are proposed here as a basis to judge all models, including the one described later in the paper.

Assumption 1. CF cannot occur in a "normal" material but requires formation of a unique condition called a nuclear-active-environment (NAE) [6].

Spontaneous nuclear reactions, other than radioactive decay, are not observed to occur in ordinary materials. Because spontaneous CF is observed, a unique condition in which the nuclear process can occur must be present. To fully appreciate this requirement, certain facts must be considered.

A chemical lattice consists of tightly coupled and interacting atoms having the lowest energy state for that configuration. Vacancy formation, such as is created by absence of an atom from the structure, is controlled by the same laws that control how the atoms themselves are arranged. These vacancies are considered by chemists to be part of the normal chemical structure and, therefore, not available to form the NAE.

These atoms and electrons rapidly interact and easily transfer excess local energy throughout the structure. Once local energy exceeds a few eV, chemical or structural changes will be produced. These processes will absorb energy before it can reach a level sufficient to affect a nuclear process. This well known behavior of a chemical system eliminates local concentration of energy in any form as a step in initiating the nuclear process.

In addition, if a novel quantum mechanical process were proposed, this process would have to be energetically favored in a chemical system and not cause chemical changes that would be noticed. In other words, not only must the nuclear behavior be explained but also the proposed process must not predict unobserved chemical behavior. This limitation can be avoided if the nuclear reaction occurs where these interactions with the chemical structure can be avoided, i.e. in a novel NAE. Identifying the NAE then becomes the challenge.

Assumption 2. The heat energy and nuclear products are produced by the same basic process operating in the same NAE.

An effect so rare and difficult to produce, as is cold fusion, would logically have only a single mechanism and condition for its operation. Nevertheless, the observations indicate several other kinds of nuclear processes might occur while the CF process is underway, which might cause confused interpretation. For example, hot fusion products can be generated as cracks form [7–10] (called fractofusion). In addition, energetic radiation might result from unusual energy states having no relationship to CF or energy might result on occasion from zero-point based processes [11]. As an example, claims for low-level energetic particle and neutron emission may have no relationship to the CF process [12,13], instead being caused by occasional hot fusion. Consequently, the observed effects need to be carefully assigned to the correct source and not used to confuse an explanation for CF by including behavior that might be in apparent violation of this assumption.

Assumption 3. Cold fusion is not hot fusion.

Hot fusion occurs when nuclei of deuterium are forced together by application of kinetic energy or by substituting a muon for the electron in D_2. The final nucleus then fragments and releases the excess mass energy as kinetic energy. Four products result with neutrons being the more easily detected. In contrast, cold fusion requires application of no additional kinetic energy and results in very few nuclear products, only weak radiation, and very few neutrons, if any. Ironically, CF was rejected because it failed to behave like hot fusion. Instead, the novel behavior of CF reveals operation of a new phenomenon having no direct relationship to how hot fusion operates. A visual comparison is made between the two effects in Fig. 1.

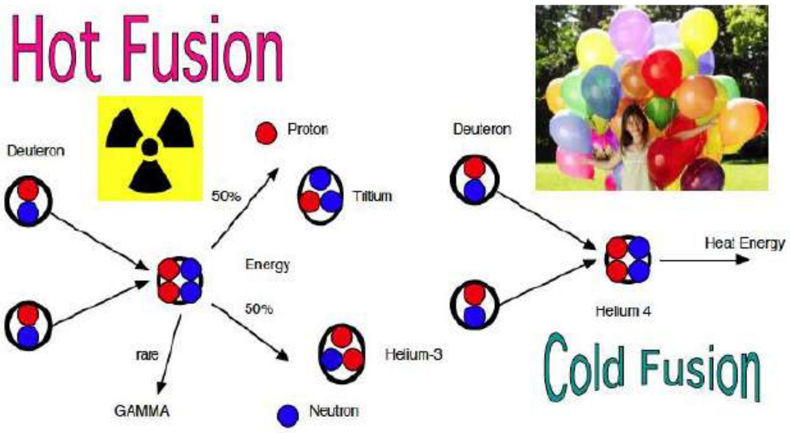

Figure 1. Comparison between hot fusion and cold fusion using deuterium.

Fusion can occur once two nuclei get close enough, either by forcing them together by applying kinetic energy or by forming a molecular structure using a muon [14]. Because the muon is about 200 times heavier than an electron, but has the same charge, it can act as a bonding electron and bring the two nuclei close enough to fuse. This process has been called cold fusion [15], an incorrect interpretation because although fusion occurs, the products known to result from cold fusion are not produced.

Ion bombardment of a material using low energy D^+ has been proposed to cause CF [16]. This is also an incorrect conclusion, because once again, the expected nuclear products produced by hot fusion result. Apparently, when two d are brought close enough for the strong force to operate, either by a muon or by applying kinetic energy, the products typical of hot fusion result, not those produced by cold fusion.

Cold fusion only occurs when a NAE is present that can support a unique fusion process. This process must first bring the two nuclei close enough to fuse and then dissipate the resulting energy without energetic particle emission. The process has no apparent relationship to hot fusion and needs to be viewed as a separate process, in the view of the author.

Assumption 4. The explanation must apply to each method for producing cold fusion and the resulting behavior.

CF can be initiated using at least five separate methods, each of which strives to inject hydrogen isotopes into a solid material. These methods involve different materials containing different impurities as well use of different levels of applied energy. A model must show how these different conditions can produce the same result by identifying an active feature common to all. This is an extension of Assumption #2.

Assumption 5. No Law of Nature is violated.

The important laws are:

The Laws of Thermodynamics apply to all processes within a chemical system. The laws state that energy is conserved, the energy cannot be spontaneously concentrated in local regions above a small limit, and all spontaneous changes require release of Gibbs energy. Any mechanism proposed to create a condition able to initiate a nuclear reaction in a chemical structure must take these laws into account.

Conservation of energy and momentum apply to all nuclear reactions when nuclear energy is released to the surroundings. Excess mass-energy is released by emission of particles that carry the energy as result of their velocity and mass, including photons. Release of significant mass-energy during conventional nuclear reactions by vibration of the nucleus to cause phonon generation is not observed. A relationship between CF and the Mössbauer Effect, which has been suggested, is tenuous at best because the Mössbauer Effect involves energy in the keV range while CF emits energy in the MeV range.

Laws of probability limit the reaction rate of a process when assembly of components is required before the process can start. Each member of the assembly requires time to accumulate in one location as they diffuse through the material by a random process. Because the cluster grows larger by addition of one nucleus at a time, assembly of a large cluster can be expected to be too slow to account for the observed amount of power.

No published model is consistent with all of these limiting assumptions and requirements. In addition, most models are either in conflict with one or more basic Laws of Nature or are in conflict with observed behavior when CF occurs. The theory proposed here attempts to avoid these deficiencies while maintaining logical consistency with known behavior.

3. Sequence of the CF Process

The process of initiating the CF reaction is proposed to involve four separated but connected parts, the first three of which involve normal chemical behavior. First, formation of the NAE must obey rules that apply to a chemical process (Assumption #1) because it forms in a chemical structure, and Gibbs energy (Assumption 5) must be released. Second, hydrogen ions must populate the lattice that surrounds the NAE, so as to be available once the fusion process starts. The resulting concentration is determined by the chemical property of the material and ambient conditions. Third, these ions must move and eventually find the NAE. This process involves diffusion and is influenced in part by temperature, concentration gradient, and applied voltages (electrodiffusion).

The forth and final stage in the process occurs when two or more hydrogen atoms come together within the NAE to create what is named a *Hydroton* for the purpose of this model. This structure is unique because it has the ability to reduce the Coulomb barrier while dissipating mass-energy in small quanta. The "magic" of the process is located in this molecular structure. Once this structure forms, rapid fusion takes place without further effort. Most theories only address this final aspect of the CF process while proposing an entirely different mechanism.

Nothing can happen until the NAE forms. Consequently, attention must first be directed to creating enough NAE to cause a detectable effect. Once the NAE forms, the reaction rate is determined by several variables, as described in section IV and not by anything done to directly influence the nuclear reaction process. In other words, once the Hydroton forms, no further external influence is believed possible, as would be expected for such an energetic reaction.

4. Basic Features of the Proposed Model

The NAE is a gap having a critically small size created by stress relief [17,18]. The gap size is limited by the physical size of the material in which it occurs and the morphology of the material in which the stress is generated. A source of such stress can be identified in all successful materials that have been studied [19–22].

The hydrogen nuclei assemble in the gap and form a covalent bonded molecule (Hydroton) with release of Gibbs energy, thereby stabilizing the gap to high temperatures. Each gap might host thousands of these molecular chains in various stages of formation and fusion.

The chain resonates along its axis, which allows two nuclei to periodically get close enough to start the fusion process, but not close enough for the strong force to operate. Excess mass–energy is lost by emission of a weak coherent photon from each nucleus in opposite directions. The resonance cycle briefly terminates this process before additional photons can be emitted. Another photon set is emitted at the next cycle when two nuclei briefly again get close enough. This periodic emission of photons takes place until all mass has been converted to energy (Table 1) and the two nuclei become a single nucleus without excess mass energy. The photons have a range of energies, with most of them being absorbed by the apparatus. A few of the most energetic photons escape and are detected.

Because the electrons have a high probability in the Hydroton structure of being located between the nuclei, the Coulomb barrier is reduced and the electron can be incorporated into the final nucleus when it forms after most excess mass-energy has been lost. An antineutrino is emitted at that time without significant energy because very little extra energy remains. Predicted nuclear reactions are summarized in Table 1.

Fusion of deuterium is proposed to produce ^{4}H, which decays by rapid emission of a weak beta and a neutrino. This reaction might be detected by a search for weak Bremsstrahlung. In the same manner, fusion of p and d creates tritium, which slowly decays by emitting a weak beta + neutrino, as is normally the case. Fusion of protium (light hydrogen) produces stable deuterium. This deuterium can then fuse with p to form tritium or with d to form helium. A few of the tritium nuclei can fuse with deuterium to produce helium and a neutron, which is the proposed source of the few neutrons observed when tritium is produced.

Figure 2 shows a cartoon of four stages in the fusion process. First, a small gap forms and the hydrogen ions located between the metal atoms diffuse into this gap. Once there, they react to form a chain of covalent bonded atoms. Normal chaotic vibration of this structure eventually becomes coherent and results in a resonance along the axis. As the resonance wave passes, each nucleus periodically gets close to its neighbor, whereupon a weak photon is emitted from each in opposite direction and with opposite spin. This process is proposed to be the great mystery of LENR. Photon emission continues until a sufficient number of photons have been emitted to convert all excess mass to energy, whereupon the two nuclei combine into a single nucleus along with the bonding electron. The frequency of the emitted photons is expected to increase as the structure collapses toward the final product. These photons are converted to heat by the usual process as they are absorbed well away from the NAE but before most photons can leave the apparatus.

The process satisfies all the requirements observed behavior has revealed by allowing mass energy to gradually leak out of the fusing nucleus. The resulting ^{4}H decays rapidly by weak beta emission. When tritium forms, it also decays by weak beta, but more slowly. The other possible product is deuterium, which is stable. The same mechanism operates regardless of which hydrogen isotope is present. Only the resulting products are different.

5. Scientific Predictions

The Hydroton is proposed to be metallic hydrogen (MH) [25–27]. Consequently, when attempts are made to form MH by subjecting H_2 to high pressure, a brief and intense nuclear reaction is predicted to produce heat and radiation once the MH forms, thereby causing observed damage to the diamond anvil used to apply huge pressure.

The heat claimed by Rossi [4] and others using Ni + H_2 does not result from transmutation, but is predicted to result from formation of deuterium, followed by tritium and helium formation.

Tritium is predicted to form at an increasing rate when H is used to initiate CF as a consequence of reaction with the deuterium that forms.

Table 1. Predicted nuclear reactions

d + e + d → ^{4}H (fast decay) → ^{4}He + e, $Q = \sim 23$ MeV
d + e + p → ^{3}H (slow decay) → ^{3}He + e, $Q = \sim 4.9$ MeV [23,24]
p + e + p → ^{2}H (stable), $Q = \sim 1.4$ MeV
t + e + p → ^{4}H → ^{4}He + e
t + e + d → ^{5}H >^{4}H + n → ^{4}He + e

The Q values give an estimated overall energy release.

Broad frequency RF radiation [22, 28] is predicted to result from resonance of the Hydroton structure, most of which is absorbed by the apparatus. This radiation is expected to carry away only a small fraction of the total energy.

6. Engineering Predictions

Engineering behavior is determined by variables over which a person hopefully has control. Knowing the mechanism, other than that hydrogen is the reactant, is not important. However, identifying the variables and showing their mathematical relationship to the overall process is important to achieve initiation and control. In the case of CF, power production is the behavior requiring control. Power production as heat is described by the following equation.

$$\text{Power generated} = K[XAC\,\text{exp}(-B/RT)]. \tag{1}$$

X is a value determined by which hydrogen isotope is reacting. If mostly deuterium is present, this number will be large. If mostly protium is used, the number will be small and variable, with a gradual increase as deuterium forms and fuses with either p or other d. (See Table 1 on previous page,) A is the number of NAE. The greater the number of sites in which the fusion reaction can occur, the faster energy can be generated. C is the concentration of hydrogen isotope in the material surrounding the NAE. This value depends on the chemical characteristics of the surrounding material, temperature, applied hydrogen activity, and rate at which the hydrogen can enter the material through the surface. Use of surface activation, ion bombardment, and high pressure (activity) will increase the concentration. B is the energy required to move hydrogen within the material. Several different conditions can be used to move hydrogen ions. This equation is based on the movement being enhanced by temperature as a driver for diffusion. Concentration gradients or application of an electric field will increase the rate of movement, thereby increasing power production by making

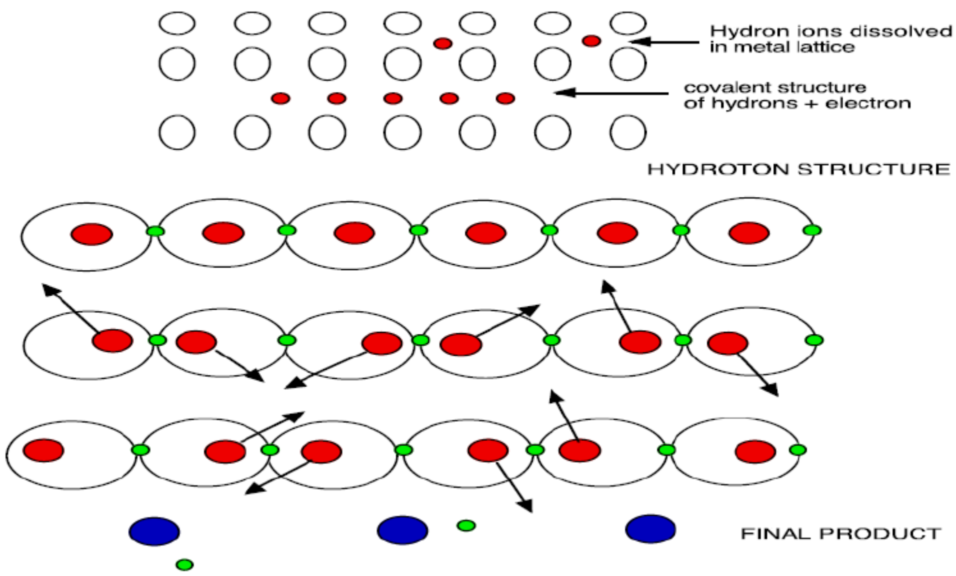

Figure 2. Cartoon of the sequence in the proposed fusion process. The green colored electrons are shown in their most probable location while traveling in the indicated path.

the hydrogen more available to the NAE [29,30]. T is the temperature (K) of the material surrounding the NAE. K is the constant used to resolve the measurement units for the different variables. R is the gas constant.

The temperature reached within the generator depends on how effectively power can be lost. Transfer of energy occurs several different ways, including by radiation, conduction, and convection. For this discussion, the controlling loss will be assumed to result from conduction through the material surrounding the NAE, as described by the following equation.

$$\text{Power Loss} = \Delta T * \lambda \tag{2}$$

where ΔT is the average temperature difference across the barrier having a thermal conductivity = λ. As long as the rate of energy loss is equal to the rate of energy creation by the CF process, temperature will remain stable.

Arbitrary but plausible values for the variables in Eqs. (1) and (2) are used to show the effect of temperature on power production and power loss in Fig. 3. The amount of power produced will be modified somewhat by changes in hydrogen content $[C]$ as temperature is changed, but this variable will not be considered right now. As can be seen in Fig. 3, at low temperatures, the effect of temperature is small, allowing the system to dissipate energy without runaway heating. However, once the rate of production exceeds the rate of loss, where the loss rate line crosses the production rate line, further increase in temperature cannot be stopped until hydrogen loss from the material or destruction of the NAE stops fusion.

These equations can be used to understand the behavior of all energy generators using CF including the E-Cat HT as designed by A. Rossi and tested by Levi et al. [31] The active core in this generator, consisting of Ni + H_2 with an unstated activator, does not produce significant energy at room temperature, as would be expected based on Eq. (1). Consequently, application of electric power to resistors surrounding the core is used to increase the temperature of the core. To start the process, the core is heated from room temperature until what they call a self-sustaining mode is observed. Based on Fig. 3, such a condition would seem to occur when temperature began to show a large effect

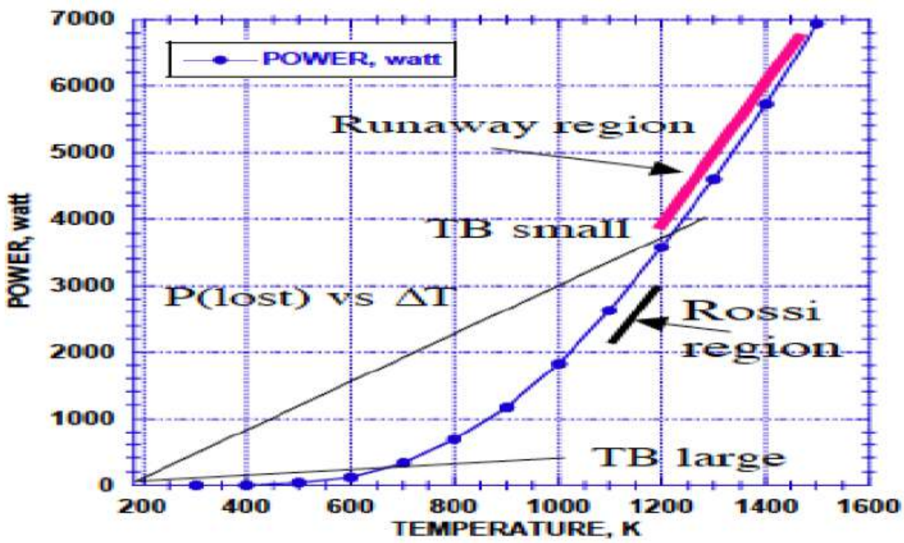

Figure 3. Effect of temperature on the amount of power. The straight lines show the relationship between power loss and ΔT for two different amounts of thermal resistance (TB). Runaway occurs when power produced exceeds power loss, as indicated by the red line. The "Rossi region" indicates where the E-Cat HT is operated below the runaway region.

on power production near 700 K. Temperature is increased further until significant power is generated, but without runaway. To insure runaway does not occur, applied power is then turned off briefly until temperature drops, after which power is again applied and temperature is allowed to reach the previous level before applied power is again stopped. Thus, control is achieved by periodically changing applied power to keep the temperature below the runaway region, but hot enough on average to produce significant power. This method avoids the challenge of exactly matching produced power with dissipated power so near the runaway temperature. The equations show how control can be achieved several other ways as well. For example, fusion at each temperature can be increased by increasing the concentration of hydrogen isotopes in the material several different ways, by using deuterium instead of light hydrogen, and by increasing the number of NAE sites in the generator. Local runaway might occur but this would be self-limiting as hydrogen concentration in the local region is reduced at the higher temperature.

"Ignition" of a large sample (1 cm cube) reported by Fleischmann and Pons [1] can also be explained. In this case, a cube of palladium had been electrolyzed in D_2O for many hours, allowing a large amount of deuterium to enter the metal. Apparently, the electrolyte boiled dry, thereby exposing the sample to gas, which is much less effective in removing heat compared to the liquid. As result, temperature of the cube rose rapidly as runaway started. The hot metal melted through the glass beaker, burned through the bench top, and dropped to the concrete floor before loss of deuterium allowed the metal to cool. Similar less-dramatic runaway events have been observed on other occasions and are called "life-after-death", a term applied when heat continues after electrolysis has stopped.

7. Proposed Test of the Model

The model can be tested as follows:

(1) The tritium production rate can be related to the D/H atom ratio in the material. When pure H is used, the rate will start at zero and increase with time as deuterium is made and fuses with the surrounding H. The concentration of deuterium and ^{4}He will also increase as energy is made. Of course, the NAE must be present for this reaction to start.
(2) Weak photon radiation can be detected when CF energy is made, which has a large range of energy, with most photons having too little energy to leave the apparatus. The radiation is expected to have coherent characteristics. Rapid beta decay of ^{4}H is also expected when helium is detected.
(3) The CF effect can be initiated as result of nano-sized crack formation, generally in the surface region as a result of stress relief. This stress can be created many different ways in many different materials.
(4) The rate of energy production can be described by Eq. (1).

8. Conclusions

Cold fusion is real, not related to hot fusion, and requires a significant change to take place in a material for it to occur.

Present lack of acceptance and progress is caused by lack of effective guidance by theory.

Behavior of all materials using all isotopes of hydrogen can be explained by a single basic mechanism operating in a single NAE.

The NAE is created as nano-gaps resulting from stress relief mainly in the surface region.

The nuclear-active structure, called *Hydroton,* is a form of metallic hydrogen that forms in the nano-gaps.

Heat is generated by formation of ^{4}He, tritium, or deuterium, depending on which hydrogen isotope is present, accompanied in each case by emission of weak photon radiation having a range of energy.

Transmutation results only as consequence of a fusion reaction, which provides the energy required to overcome the large Coulomb barrier.

9. Summary

A collection of five plausible assumptions can be used to evaluate proposed theories of cold fusion. When applied, no present theory is consistent with all of them. Consequently, a new model is created that is consistent with all the proposed assumptions, violates no Law of Nature, is consistent with all major observations, and can predict many new behaviors. The model can be applied to guide engineering development by creating more efficient devices, improving reproducibility, and achieving better control of energy production. Tests to determine if the model is correct are suggested. Mathematical descriptions will be undertaken once the concept is demonstrated to be correct.

Acknowledgement

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