CATASTROPHIC ACTIVE MEDIUM (CAM) 
THEORY OF COLD FUSION

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Abstract

The catastrophic active medium (CAM) theory hypothesizes a two-stage system for cold fusion that ends with the production of the cracks which absorb and dissipate, rather than create, the energy required to activate the desired reactions. Following adequate deuteron loading, a local inhomogeneity of heat distribution in the metal is hypothesized to cause an in-situ fractional desaturation of the fully-loaded palladium. This desaturation is facilitated by optical phonons, which couple with deuteron transport. The CAM theory of cold fusion hypothesizes that these desired reactions occur at select vacancies and defects. Catastrophic deuteron, plasmon, phonon, and polaron fluxes are coupled with further exothermic deuteron desaturation so as to create an active medium and at least one positive feedback loop. There is possible internal conversion of any potential fusion reactions to the lattice by coupling through the phonons, already present from the desaturation, and polarons which increase the effective mass of the deuterons. The dynamic instability continues either until the active media is drained or, by a second catastrophic process, the fusion-defect-site is no longer confined.

Introduction

Deuteron-deuteron fusion remains elusive because of electrostatic repulsion between the deuterons\(^1,2\). Many theories of cold fusion in palladium hypothesize tunneling\(^3,4\) within the crystalline metal, because the internuclear deuteron separation distance in Pd may be larger than for diatomic D\(_2\)^5. Tunneling may be facilitated by screening electrons\(^1,7\), changes in the effective mass of the electrons\(^5,9\) and deuterons\(^10\), deuteron energy fluctuations\(^11,12\), coherent screening\(^13\) and plasmons\(^4\). The coherent\(^14\) and superradiance theories\(^1,15,16\) discuss the neutrons and increased electron density between deuterons. However, the tunneling probability remains vanishingly small until the D-D internuclear separation distance decreases to less than \(-0.7\) Angstroms\(^6\).
The CAM model begins following the loading of isotopic fuel\textsuperscript{17}. It utilizes several special material properties of palladium, starting with its deuteron/hydrogen solubility and its hydrogen solubility-temperature relationship. Palladium holds so many deuterons (figure 1) that it acts like an "emphore" (i.e., vase\textsuperscript{18}). Furthermore, unlike most metals\textsuperscript{19} which also have low absorption properties (~one deuteron per 10,000 metal atoms), the deuteron solubility in palladium decreases with temperature (figure 2).

As a result, deuterium loaded into the metal may suddenly become an unwanted resident within the metal lattice. The CAM hypothesis thus treats the metal as an active medium capable of rapid desorption, and of two possible positive feedback loops creating both the bursts and a plethora of termination sequelae.

Present theories consider the atomic ratio \( x \) of deuterons to palladium.

\[
x_0 = \frac{[\text{D}^+]}{[\text{Pd}]} \quad \text{[eq. 1]}
\]

\( x_0 \) is related to the fugacity of the deuterons\textsuperscript{25}.

\[
x_0 = \Xi_D * \left[ \frac{P_{D}^{1/2}}{K + P_{D}^{1/2}} + \frac{P_{D}^{1/2}}{K_s} \right] \quad \text{[eq. 2]}
\]

The CAM theory describes the palladium by three compartments (figure 1). Compartment 1 is the deuteron-laden crystalline palladium. The second and third compartments include the defects, grain boundary dislocations, and larger defects. With subsequent cracking, fissuring, or other dislocations open to the ambient, the proportion of compartment 3 grows.

In contrast to \( x_0 \), the total quantity of deuterons in the physical volume of metal, \([\text{D}]_{\text{tot}}\), may reflect two terms involving the deuterons bound to the shallow-traps in the palladium lattice (compartment 1) and the amount in defect sites. The amount of each is related through the fractional defect parameter, \( \chi_D \).

\[
[\text{D}]_{\text{tot}} = [(1-\chi_D)^*\left(\sum \left( \Gamma_{D,i} * \Xi_{D,i,j} \right) \right)] + [P_0^*\left(\sum \left( \alpha_{D,Pd,j} * \chi_{D,j} \right) \right)] \quad \text{[eq. 3]}
\]

\( j=0,t \quad j=2,3 \)

In the first term, both octahedral and tetrahedral sites are considered. For the remainder of this paper, the approximation will be made to use equation 4 for simplicity, with the additional assumption that the parameters are the same for compartments 2 and 3 \((\alpha_{D,Pd,3}=\alpha_{D,Pd,2} \text{ and } \chi_{D,2,3}=\chi_{D,2})\).

\[
[\text{D}]_{\text{tot}} = \left[ (1-\chi_D)^* \Gamma_D^* \Xi_D \right] + \left[ \alpha_D^* P_D^* \chi_D \right] \quad \text{[eq. 4]}
\]

Total = Compartment 1 + Σ Compartments 2 & 3
\( \chi_D \) is the fractional volume of defect sites (compartments 2 and 3) located outside of the (e.g., \( \beta \)-phase) crystalline palladium lattice. The first term in equation 3 depends both upon the amount of deuteron binding material present, the number of intralattice sites available for the deuterons (\( \Xi_D \)), and the affinity of the palladium lattice for those deuterons. The second term is modeled as a conventional product of a Henry gas solubility-like coefficient and the deuteron partial pressure \( [P_D] \).

Within the palladium lattice a number of active binding sites \( -[Pd]_{\text{act}} \cdot (1 - \chi_D) \cdot \Xi_D \) enables the definition of the occupancy factor called the fractional saturation \( \Gamma_D \). \( \Gamma_D(P_D,T) \) is 0 when the metal is void of deuterons, and approaches 1 when the metal becomes fully loaded.

**FIGURE 1 - THE PALLADIUM IS FULLY LOADED**

The CAM Model assumes that the palladium is fully loaded, as from electrochemical loading using heavy water. On the right side, heavy water is seen to be constructed from the "hydrogen"-bonded \( D_2O \) in a near heavy ice-1, like structure. As a result of both electric polarization and a molecular vibration, there is intermolecular deuteron transfer. The important net result (arrow) is the filling up of one octahedral site within the palladium (located on the left side). The deuterons are represented as small spheres. The figure on the right side was adapted from J. Mara. 20.
FIGURE 2 - THREE COMPARTMENT CATHODE

This figure schematically shows a volume of metal highly loaded with deuterium. The bulk metal crystalline lattice is compartment 1, and neither its periodicity nor its atomic nature is stressed in this schematic figure. Large defects - not open to the ambient - which may be filled with deuterons and homonuclear diatomic deuterium compose compartment 2. With subsequent crack, fissure, or other dislocation formation, one of which is shown on the lower right of the palladium, compartment 3 is formed.

The intraelectrode deuteron flux is the result of the in-situ "depressurization". With rising temperature, the deuteron saturation $[\Gamma_D(T)]$ falls in palladium$^{21}$, so markedly that there is a 7-fold decrease from 5 to 50 Centigrade$^{22}$. This is assumed as the *raison d'être* for the rapid D-mass transfer from compartment 1 to 2 when the catastrophic desaturation begins.

The CAM hypothesis was examined by a computer model (figure 4). Several qualitative approximations were made including that the temperature would increase extremely slightly locally with each putative fusion event which themselves would occur only secondary to markedly increased deuteron pressures and local temperatures. These arbitrary kernals, chosen to find any case where this might occur, are similar to some used in hydrogen diffusion analyses$^{23}$.

$$\Gamma_D = [1.0 - (\exp[- C_P * P_0])^2] * (\exp[- C_T * T])$$

[eq. 5]
**FIGURE 3 - HYDROGEN IN PALLADIUM**

The quantity of hydrogen in fully loaded palladium is markedly temperature dependant. The curve shows the quantity [cubic centimeters (STP)] which can be contained in 100 grams of palladium.

Figure 4 shows the output of a computer simulation used to test the CAM hypothesis. This gendanken metal is capable of exothermic catastrophic fractional desaturation. Shown is the normalized deuteron pressure, temperature, and fractional saturation ($\Gamma_D$). With early loading there is a steady increase in deuterium content within the cathode, consistent with some models and experimental observations, the deuteron pressure ($P_n$) rises slightly.

Eventually compartment 2 is suddenly and catastrophically "fed deuterons" from the large vicinal volumes of the crystalline palladium lattice (compartment 1), further increasing the likelihood of temperature-incrementing reactions. After a certain point, a critical catastrophic event causes inversion of the fractional saturation as the temperature rises. This dynamic instability may result in local astronomic pressures.

The CAM hypothesis is that the desired reactions are driven by catastrophic fractional desaturation of deuterons, possibly focused, towards the defect site. The thermodynamics of fully deuterated b-phase suggests that deuteron desaturation from $\Gamma_D = 1$ to 0.8 is exothermic consistent with the CAM model. The catastrophic transfer of deuterons to compartment 2 incrementally may increase the pressure in-situ by thousands of atmospheres. A desaturation of six additional deuterons into a defect volume (compartment 2) of size equivalent to a unit lattice of the palladium, would generate 5000 circa atmospheres. The surface energy of the palladium prevents the escape, for a while, of the reactants thereby maintain close contact for the desired reactions.
Dynamic Inversion of $\Gamma_D(t)$, $P_D(t)$ and Temperature reach crescendo levels.

FIGURE 4 - QUALITATIVE COLD FUSION ANALYSIS
A qualitative model was used to test the response of an active medium capable of exothermic desaturation. The three curves are 1) the normalized deuteron pressure, 2) the normalized local cathode temperature, and curve 3, which is the fractional saturation ($\Gamma_D$) of the isotopic fuel (deuterium) located within the active medium (palladium) as described in the text. The kernels used were $\Gamma_D = [1.0 - (\exp[- C_p * P_D])] * (\exp[- C_T * T])$ and $T->T +[ 0.0011* (10/(10+P_D))*\exp(( P_D -50)/2000)]$.

Interpretation
This sudden desaturation is a reasonable assumption because of the natural characteristics of palladium and its deuteron diffusivity which increases with temperature$^{24}$ and increasing grain-boundary formation$^{25}$, would form during such catastrophic changes. Discussed elsewhere$^{20}$ defects, grain boundary dislocations, "zeolite"-like diffusion$^{25}$, differences in phases$^{22}$, and fissures may all influence deuteron diffusion in the palladium, but the phonon spectra are also important. Deuteron migration is aided by phonons at lower temperatures$^{26}$. This coupling may also offer a pathway of phonon-assisted tunneling$^{28}$. Further coupling of such optical phonon modes$^{26}$ to the lattice occurs through polarons$^4$. The catastrophic deuteron flux will be followed by plasmons, for charge neutrality$^1$,

There are actually two separate vibrational spectra which result form the small mass of the deuteron in the transition metal. The deuteron modes are far above the lattice modes$^{26}$. The phonon energies ($\sim 32-48$ meV for PdD) have significant zero point motions$^{29,30}$ so therefore initially the phonons are optical. Eventually acoustic phonons may contribute to the observed excess enthalpy. The transmission resonance theory$^{31}$ postulates that deuterons of specific momentum
(wavelength) penetrate the metal as "diffusons". Positive feedback comes from the saturation-temperature relation and perhaps from the phonon-softened coupling. The active site (compartment 2) may be the very location towards which the intrapalladial deuteron flux may migrate secondary to phonon mode softening which occurs for some vacancies in f.c.c. transition metals.

Within the defect sites there may occur gas formation (J.) by way of deuterons to D2 gas which would also contribute energy for fusion. The energy release per deuterium recombination is ~7eV or less, but the CAM hypothesis is based upon the volume desaturation surrounding a small compartment. Consideration of the available deuteron concentration reveals that a radius of only a dozen lattice lengths gives a quantity which may provide a requisite number of deuterons.

There are many factors which contribute to possible fusion. These include electrical charging of the cathode to a high negative voltage, the deuteron band structure, Bloch-symmetric Bose-Bloch condensates, plasmon exchange, electron screening, the increased effective mass of the deuterons due to polarons, as well as the high local temperatures, local feedback, phonon-flux coupling, and confinement discussed in the CAM theory. Furthermore, the lattice may directly enhance fusion because the diffusion flux of deuterons within the palladium may be proportional to the tunneling matrix element. We also postulate that basal-plane shift secondary to shear stress along the tetragonal-plane-axis may play a role in bringing deuterons together for the fusion reactions, perhaps thereby forming compartment 2 from the tetrahedral deuterons in that plane (figure 1). The fusion reactions, if generated, will supply significant local heat causing release of more deuterons.

We are presently calculating for the reactions where some of the energy is coupled to the lattice through the CAM processes. Analyses will require statistical and fractal methods, with inclusion of polarons in octahedral and tetrahedral systems, consideration of Anderson localization, and phonon-electron interactions including anharmonicities. There are many reactions to generate the observed excess enthalpies. These sources of heat include collisions, polaron formation and drift, both optical and acoustic phonon generation, lattice deformation and fracture, diatomic deuterium formation, and any potential fusion reactions.

The temperature rise occurs as the acoustical and optical phonons become unable to carry off all of the momentum and excess energy of the reactions. For times between t=τc and t=τe (see figure 5), the CAM model suggests that internal conversion, by way of the plasmons and phonons, may contribute to the observed branching ratios by enabling deexcitations to couple with phonons, already produced during the CAM desaturation, perhaps in times as short as 10^21 seconds.
End of the Catastrophic Reactions
In the CAM hypothesis it is the movement of deuterons to compartment 2 which begins the cold fusion process at that location. The reactions occur at select sites of the deuteron-loaded periodic palladium lattice, driven by sudden local catastrophic fractional desaturation of deuterons. However, because no material can withstand an indefinite buildup, there comes a time when the internal pressures are able to exceed the energy needed to create fresh new surfaces in the palladium.

The fusion of deuterium is hypothesized to continue until the crystalline palladium (the active medium because of its high fractional saturation and its exothermic desaturation tendency) is spent of its deuterons or until, by a second catastrophic process, the fusion-defect-site is no longer confined. Leakage now occurs and the sample becomes, at best, locoregionally inactive.

Fractofusion\textsuperscript{41} hypothesizes that cracks create cold fusion by the high electric field generated across crystalline fractures. In contrast with the fractofusion theories, but consistent with theories of adhesion and surface energy requirements\textsuperscript{42} for generating new surfaces in a material, the CAM theory hypothesizes that the desired reactions end with the production of the cracks which absorb, rather than create, the activation energy for any fusion reactions.

Correlation with Cold Fusion Phenomena
The CAM hypothesis must be tested against the findings reported. It is consistent with metallurgical examination of those electrodes which have exhibited excess heat bursts or have undergone full deuteron loading. Surface cracks, increased intragranular roughness, "alpine" features\textsuperscript{43}, pitting\textsuperscript{44} all occur. Four probe resistance measurements indicate the development of subsurface cracks following deuteron loading\textsuperscript{47,41}. These changes could be consistent with the development of compartments 2 and 3.

The CAM hypothesis is consistent with corrosion theory\textsuperscript{47} because hydrogen diffusion is both intermittent and flows towards imperfections. The intracathodic compartment 3 could be similar to the better-known endstage hydrogen embrittlement, which declares itself when the hydrogen explodes into the ambient as the metal fissures or otherwise irrefutably changes of shape. The calculated fugacities involved are enormous\textsuperscript{45-47}.

The CAM model suggests why temperature cycling of deuterided palladium and titanium\textsuperscript{48,49} may initiate excess power. Temperature change may alter the deuteron saturation directly, or by secondary changes in the metal volume, specific heat, or by a phase change. Full, or near-full, loading of palladium with isotopic fuel appears to be the requisite -- but insufficient by itself -- of the CAM model, and this is consistent with reports. The catastrophic nature might also explain the relative-incontrollability of the processes as this time.
FIGURE 5- CAM MODEL OF COLD FUSION BURST

This figure shows several curves representing a hypothetical successful cold fusion burst. The loading is shown to first rise continuously based upon the fractional saturation of the deuteron sites ($\Gamma_D$). At some time just after $\tau_c$ the catastrophic reaction occurs and the pressure ($P_D$) rises with the temperature lagging but then going critical. This continues until there are catastrophic changes in the material ($\chi_D$ approaches 1) and there is outgassing, loss of saturation, and ultimate fall off of temperature. The second catastrophic change (formation of compartment 3) begins at $\tau_e$.

References

The CAM hypothesis may be consistent with the fact that the increase in the volume for better performing cold fusion palladium samples are less, which may be consistent with the hypothesis that compartment 3 terminates the favorable reactions. The CAM hypothesis may be consistent with the inhomogenous "footprints" of reactions seen upon cold fusion cathodes by x-ray film. This may be because of the catastrophic, hence sporadic, nature of the CAM effect. The CAM hypothesis may be consistent with reports of packed hydrogen atoms observed at vacancies [eg. up to six], and theories of three- (or other multi-) body, reaction(s) which could occur in compartment 2.

Summary
The catastrophic active medium (CAM) theory of cold fusion is hypothesized to occur at certain vacancies and defects by the sudden fractional desaturation of deuterons. Catastrophic deuteron flux, coupled in positive feedback with a further exothermic deuteron desaturation of the active medium, and possible optical phonon mode-softening towards the defect, drives the system until, by a second catastrophic process, the fusion-defect-site is no longer confined (figure 5). The defect site may enable confinement, and possibly focussing, enabling novel reactions. Coupling of the deuteron flux to the lattice through optical and acoustic phonons, and secondary polarons and plasmons, may also provide fusion-lattice coupling. The CAM hypothesis may offer explanations for the tremendous "difficulties" observed by many experimenters attempting to repeat their, and others' experiments, for the bursts of excess energy seen, for the very tardive appearances of both the excess energy and the rare bursts.

TABLE OF VARIABLES

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<th>Description</th>
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<td>B_D</td>
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<td>[D⁻¹]</td>
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31. D. A. PAPASTANTOPOULOS, B.M. KLEIN, et alia, "Band structure and