ISOTOPIC FUEL LOADING
COUPLED TO REACTIONS
AT AN ELECTRODE

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Abstract

The quasi-one-dimensional (Q1D) model for an electrode filled by an isotopic fuel may offer insight into both competitive gas-evolving reactions at the surfaces of the electrode and the impact of the ratio of the applied electric field energy to thermal energy \([k_B \cdot T]\) which appear decisive in controlling the loading. The Q1D model develops a solution separable into components determined by three non-dimensional factors, \( \Lambda_{\text{Pd, D}} \) the loading flux ratio, \( \Psi_{\text{ fus}} \) the fractional amount of intrapalladial deuterons which actually contribute to the desired reactions, and \( \zeta \) the electric order/thermal disorder ratio. The derived fusion flux equation links the deuteron loading flux from the solution into the metal and gas evolving reactions to potential reactions at that site.

Introduction

Classical calculations of the activities of an ionic electrolyte\(^1\)\(^2\) adjacent to a metal electrode have been applied to cold fusion reactions following loading of isotopic fuel into a metal\(^3\), and have been used to derive the distributions of deuterium in the palladium\(^4\) and the solution\(^5\)\(^6\). However one premise is that the systems are at equilibrium which may not be true\(^7\). Therefore, a quasi-one-dimensional (Q1D) model for an electrode filled by the isotopic fuel was formulated\(^5\). The Q1D model offers insight into the processes because it indicates how both competitive gas evolving reactions at the metal electrode surface and the ratio of the applied electric field energy to thermal energy \([k_B \cdot T]\) are decisive in controlling the loading of the metal by the deuterium\(^5\). We now extend that model and correct the derived fusion equation\(^8\) which links the deuteron loading flux from the solution into the metal for potential reactions at that site.
Development of the Model
Figure 1 shows the four regions of the electrochemical cold fusion cell. Within the heavy water solution, most deuterons are tightly bound to oxygen atoms. The power source generates the applied electric field intensity. The induced drift by the applied electric field is shown schematically in the figure; which does not mean that the deuterons actually are free to travel in such a simple fashion. The electric field distribution is altered as the solution and system each respond with complex conduction and polarization phenomena. Ionic drift, secondary space charge polarization, propagation of solvated deuterons, deuterons in clathrates, and L-,D-deuteron defects with their ferroelectric inscription in the heavy water, and the formation low dielectric constant bubbles abutting the cathode are the minimum expected. The double layer between the solution and the metal is created both by the cathode fall of ions and other polarization reactions.

**FIGURE 1 - THE 1D MODEL OF ISOTOPIC FUEL LOADING**
The applied electric field influences the spatial distribution of deuterons in aqueous solution. There are four compartments considered outside of the material (palladium electrode in this case) to be loaded with the isotopic fuel. The first is the anode. The induced drift in the second compartment (heavy water) by the initial applied electric field is schematically shown. There is a double layer region, the "width" of which is greatly exaggerated in the figure. The last compartment is the gas volume outside of the material.
In the absence of significant convection, the flux ($J_p$) of any $i_{th}$ species (here deuterons) results from both diffusion down concentration gradients and electrophoretic drift$^{5,7,10}$. 

$$J_D = - B_{D} * d[D^+(z,t)] - \mu_{D} * [D^+(z,t)] * \frac{d \Phi}{dz} \quad \text{(eq. 1)}$$

Three components of the deuteron flux ($J_p$) must be considered at the cathode. The first flux component is the entry of deuterons into the bulk of palladium ($J_p$). The second flux component is the loss of deuterons secondary to gas evolution ($J_p$). The third flux component is caused by those deuterons lost to any putative fusion reactions, and is represented as $J_{ix}$. $J_{ix}$ is assumed to be 0 in the bulk solution. The mathematical solution for the time rate of change of the deuterium in any given volume is determined by these fluxes and Gauss' Theorem$^5$.

Deuteron entry to the cathode is electron limited with all entry occurring at the cathode-double layer interface. At this boundary intermolecular deuteron transfer from the solution to octahedral sites within the palladium may control the loading$^5$. Within the metal, the deuteron diffusion has been considered by several models$^{4.4.12}$. Optical and acoustic phonon spectra$^{12}$, material defects, grain boundary dislocations, "zeolite"-like diffusion$^4$ and fissures all may influence the deeper loading of the metal.

**Critical Loading Flux**

The Q1D model links the deuteron flux from the solution into the pericathodic volume, and includes both into the metal, gas evolution, and any potential fusion reactions.

$$\frac{d[D^+(z,t)]}{dt} = \{B_{D} * d^2(D^+)\} + \{\mu_{D} * (D^+)*d^2 \Phi\} + \{\mu_{D} * d \Phi * d(D^+)\} + \{d(D^+)*dB_{D}\}$$

$$\quad + \{D^+ * d \Phi * d \mu_{D}\} - \{d \left[ \sum J_{ix} \right] \} \quad \text{(eq. 2)}$$

The mathematical solution of equation 2 is determined both by the boundary conditions and by conservation of mass. There is assumed conservation of deuterons with the exception of a loss ($J_{ix}$) to all putative fusion reactions, extremely small compared to either most loading rates or gas evolving reactions$^5$. As discussed previously$^5$, examination of the solution indicates that the deuteron loading rate into the electrode is critically linked to gas evolution and is also first order on $[ \mu_{D} * E ]$.

$$\kappa_{e} = ( \mu_{D} * E ) - ( \kappa_{s} + \kappa_{ix} ) \quad \text{(eq. 3)}$$
This loading rate equation relates deuteron availability (secondary to the applied electric field) to the losses of deuterons to both gas evolution and the fusion reactions. One simple but important corollary is that the evolution of D₂ gas and deuteron loading to the palladium cathode are mutually exclusive for any given applied electric field.

Quantity of Deuterons Contributing (Ψ₇₅₅₅)

In a successful cold fusion system J₇₅₅₅ is not zero. Therefore the non-dimensional parameter, Ψ₇₅₅₅, is defined as the fractional amount of intrapalladial deuterons which actually contribute to the desired reactions. When the filling of the palladium with deuterium is complete, J₇ would be on the order of J₅. This fusion rate equation can be examined for its relation to thermal processes by substitution using further non-dimensional parameters and the Einstein relation.

\[
\frac{B_D}{\mu_D} = \frac{k_B * T}{q} \quad (eq. 4)
\]

The Loading Ratio (Λ₇₅₅₅₅)

The non-dimensional parameter Λ₇₅₅₅₅ is defined as the ratio of the two largest and most important pericathodic fluxes; the loading flux (J₇) to the gas evolution (J₅). It is very much a function of the isotope and the material, hence the paired subscript.

\[
Λ₇₅₅₅₅ = \frac{J_7}{J_5} \quad (eq. 5)
\]

Thus if Λ₇₅₅₅₅ is .01, most of the current is going to gas electrolysis, whereas Λ₇₅₅₅₅ = 100 would indicate more efficient loading. Substitution of the translocation voltage, and Λ₇₅₅₅₅ as the loading factor, and the Einstein relation yields equation 6.

\[
J_{7₅₅₅₅} = \frac{[2Λ₇₅₅₅₅] * [B_D * <D₅>] * \frac{1}{q^*V} * \frac{[q^*V]^2}{[k_B*T]^2} * Ψ₇₅₅₅₅}{[2Λ₇₅₅₅₅+1] * L_e * [1 - \exp(_______)]/k_B*T} \quad (eq. 6)
\]

This fusion flux equation (equation 7) contains five terms after separation of variables. The first term results from gas evolution. The second term is composed of geometric and material factors. The next two terms reflect the applied electric field intensity and kₜ, and are dominated by the ratio of the applied electrical energy which are organizing the deuterons to the energy causing their random thermal disorganization. The final term is the fraction of deuterons which actually partake in any potential fusion process(es).
\( \Psi_{\text{fus}} \) is the fractional amount of intrapalladial deuterons which actually contribute to the desired reactions. Introducing \( \zeta \), the electric order/thermal disorder ratio, then simplifies this fusion flux equation.

\[
J_{\text{fu}} = \frac{B_D \ast <D_i>}{L_i \ast [1 + (2 \Lambda_{\text{Pd,D}})^{-1}]} \ast \frac{\zeta}{[(1 - \exp[-\zeta])]^2} \ast \Psi_{\text{fus}} \tag{eq.7}
\]

This relationship is demonstrated in Figures 2 and 3 which show the impact. In figure 2, for simplicity, \( J_{\text{fu}} \) is assumed to be 0. The loading flux of deuterons into the palladium at the cathode surface \( (J_e) \) is shown as a function of the electric field intensity, for various rates of gas \( [D] \) evolution rates \( (J_g) \).

The series of parametric curves indicates how the loading rates are sensitively dependant both upon the electric field energy as well as the competing gas evolving reactions. Examination of equation 7 indicates that although \( \Lambda_{\text{Pd,D}} \) has major effects for every \( \zeta \), however, that importance requires a level of \( \Lambda_{\text{Pd,D}} \to 1 \) to plateau its importance as is shown in figure 3.

Summary
The quasi-one-dimensional (Q1D) model has been modified using three non-dimensional factors, \( \Lambda_{\text{Pd,D}} \) the loading flux ratio, \( \Psi_{\text{fus}} \) the fractional amount of intrapalladial deuterons which actually contribute to the desired reactions, and \( \zeta \) the electric order/thermal disorder ratio.

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<th>Table of Variables</th>
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<th>electric charge</th>
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<tr>
<td>B_D</td>
<td>T</td>
<td>absolute temperature (Kelvin)</td>
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<td>[D^-]</td>
<td>V</td>
<td>voltage = ( \Phi ) the potential</td>
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<td>&lt;D_i&gt;</td>
<td>( \kappa_f )</td>
<td>first order deuteron fusion rate</td>
</tr>
<tr>
<td>E</td>
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<td>deuteron gas evolution rate</td>
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<tr>
<td>F</td>
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<td>first order deuteron entry rate</td>
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<td>I</td>
<td>( \Lambda_{\text{Pd,D}} )</td>
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<td>J_{e}</td>
<td>( \mu_D )</td>
<td>electrophoretic mobility</td>
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<td>J_{g}</td>
<td>( \eta_D )</td>
<td>electrical transference ratio</td>
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<tr>
<td>( J_{\text{fus}} )</td>
<td>( \Psi_{\text{fus}} )</td>
<td>fraction of deuterons involved</td>
</tr>
<tr>
<td>k_B</td>
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<td>electric order/thermal ratio</td>
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FIGURE 2 - LOADING RATE OF PALLADIUM

The relative values for the loading flux \( J \) is shown as a function of the electric field intensity, parametrically for various rates of gas \( [D] \) evolution rates at the cathode (characterized as \( J_\text{eff} \)). In this example, \( J_\text{eff} \) is zero. The curve is shown as a function of \( \zeta \), the electric order/thermal disorder ratio.

FIGURE 3 - PARAMETRIC EXAMINATION OF Q1D FUSION FLUX

This 3-D parametric graph represents an examination of the fusion flux equation based upon \( \zeta \) and \( \Lambda_{p, D} \) (see eq. 7).
References


8. Equation 18 in Reference 5.


