A Method to Calculate Excess Power

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— Abstract —

An empirical calculation method for excess power based on 40 electrochemical experiments conducted by the author from 2007 to 2008 is presented. The method produced very close agreement with experimental results for all 40 experiments without adjusting any parameters. The cathodes in this study were processed and loaded with deuterium following consistent fabrication and loading protocols, as reported elsewhere.[1] The cathodes were stimulated with dual lasers at beat frequencies of 8, 15 and 20 THz, as discussed in previous papers by the author. The empirical model developed implicates the optical phonon frequencies of palladium deuteride, palladium vacancies and possibly the deuterium spin system interacting with an external magnetic field present in all 40 experiments. The Q used to reproduce all experimental results was 23.8 MeV, suggesting involvement of the deuterium-^{4}He reaction reported by various researchers in the CMNS field. Q was calculated from experimental data. The strengths and weaknesses of the empirical model are discussed in light of experimental results known to the field.

Introduction

In 2008, the author collaborated with Cravens and Hagelstein on a series of experiments that have been reported elsewhere.[1] The experiments used bulk palladium cathodes loaded with deuterium and stimulated by dual lasers operating at beat frequencies of 8, 15 and 20 THz. The cathodes had been prepared and loaded following a specific protocol reported at ICCF10.[2] During these experiments, Dr. Dennis Cravens suggested running two tests designed to demonstrate that excess power is proportional to cell temperature. Two experiments (669u and 669v) were run sequentially, with 669v cell temperature 14 degrees above 669u. The cooler cell produced an average excess power of 224 mW. The warmer cell produced an average excess power of 883 mW under otherwise identical operating conditions. Many physical factors were considered but only the number of cathode vacancies increased in the same ratio as excess power; this realization eventually led to the calculation method discussed in this paper.

Analysis of the First Experiments

For many years, Prof. Peter Hagelstein has stressed the importance of vacancies for the production of excess power in deuterated palladium.[3] Many researchers have also recognized the importance of elevated temperatures for the production of excess power from deuterated palladium.[4] However, the connection between cell temperature, vacancies and excess power had never been quantified before the results from experiments 669u and 669v were observed (Figure 1).

When the experiments were complete, the only physical parameter we could find that increased by the same amount as excess power was the number of calculated vacancies in the palladium cathode. The solid state literature discusses the methods used to compute the number of vacancies in a metal.[5] The cathode used for experiments 669u and 669v was bulk palladium of 0.999 purity obtained from Texas Nuclear, Austin, Texas. The cathode was a billet 6 x 8 x 0.2 mm with a volume of 0.0096 cc. This cathode and all others in this study were pre-treated using a 17 step protocol.[2] The protocol involved polishing, cold-rolling and annealing the palladium in a very consistent manner. This proved to be important for this study because all cathodes had the same vacancy formation energy of 1 eV. The vacancy formation energy (VFE) is probably the most critical parameter when discussing the formation of vacancies because this is the energy required to form a single vacancy in a crystalline metal. Natural palladium has a vacancy formation energy of 1.85 eV.[6] However, processing the metal and loading the metal to a D/Pd ratio of at least 0.85 apparently lowers the VFE to around 1 eV and allows vacancies to be formed. It is thought that the act of loading the palladium with deuterium (or hydrogen) not only creates vacancies but also helps to stabilize the vacancies once created.

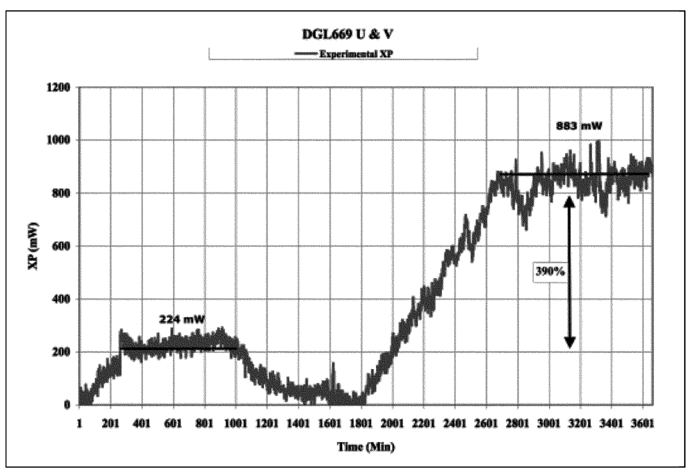

Figure 1. At 63C the dual lasers triggered excess power of 224 mW; an immersion heater was used to raise cell temperature to 77C and at the higher temperature excess power averaged 883 mW. The gain in excess power was 390%, equal in magnitude to the gain in cathode vacancies.

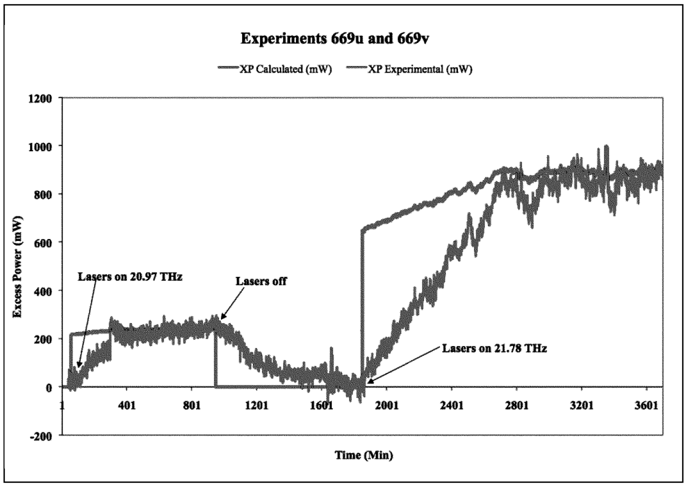

Figure 2. The unexpected close agreement between calculated and experimental excess power for 669u and 669v, which operated at 63C and 77C respectively.

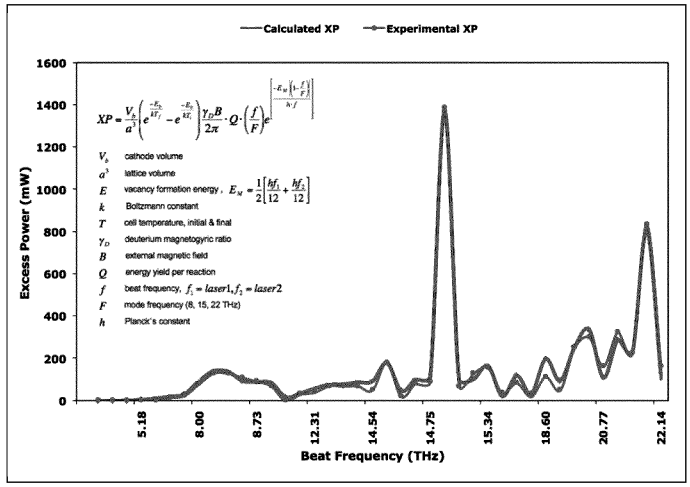

Figure 3. Forty experiments in a bulk Pd data set compared to calculated excess power. The close agreement with experiment was not expected.

The author's thinking was that if Hagelstein's ideas about the importance of vacancies were correct, then there ought to be a high correlation between excess power and the gain in calculated vacancies. The number of vacancies can be calculated according to commonly used equations from the solid state literature.[5,7] The ratio of the vacancies produced at high and low temperatures was equal to the ratio of the observed excess power in experiments 669u and 669v (see Figure 1).

$$\frac{XP_{hi}}{XP_{lo}} = \frac{Ne^{\frac{-E}{KT_{hi}}}}{Ne^{\frac{-E}{KT_{lo}}}} \sim 390\% \qquad (1)$$

XP_{hi} is the excess power produced at 77C, XP_{lo} is the excess power produced at 63C, N is the number of lattices in the cathode but this value cancels, E is the vacancy formation energy commonly used for metals of 1 eV[5] and can be calculated from experimental data, K is Boltzmann's constant and T_{hi} is 350.3K, T_{lo} is 336.6K. There is high correlation between the ratio of vacancies and the ratio of excess power observed in 669u and 669v (Figure 1). The equation for E was derived from Equation 1.

$$E = K\ln\left(\frac{XP_{hi}}{XP_{lo}}\right)\left(\frac{T_{hi}T_{lo}}{T_{hi}-T_{lo}}\right) \qquad (2)$$

Encouraged by a small success, the author then wondered if excess power could actually be calculated for the power gain observed in 669u and 669v, which was 0.66W. The author reasoned that excess power might depend on just three factors: (1) a reaction Q, (2) the gain in vacancies due to a cell temperature increase and (3) a reaction rate. Then XP = Q x vacancy gain x (a rate equation).

Based on the work of Miles and others, the author felt the use of the Q associated with a D + D → ^{4}He reaction was justified,[8,9] so Q was assumed to be 23.8 MeV (see Figure 3a for the actual computation). The gain in vacancies was computed as $G_v = 3.45 \times 10^5$. Based on work done in 1993 by the author,[10] the deuterium spin system was considered as a candidate for the rate equation. The deuterons inside the cathode are thought to precess at the Larmor frequency computed as:

$$L = \frac{\gamma B}{2\pi} = 4.098x10^5 Hz \text{ where } \gamma = 4.1066x10^3 \frac{rad}{G\cdot\sec} \qquad (3)$$

with B = 625 Gauss, the external magnetic field applied in all experiments. Then the final calculation became Q x G_v x L = 0.66W, producing exact agreement with the gain in excess power observed experimentally. This simple equation was then checked to see if it would hold across both experiments 669u and 669v; the equation was put into a spreadsheet with the actual experimental data and a comparative plot was made (Figure 2).

Additional Experiments

In 2011 the author decided to see if the 2008 calculation could be applied to 40 experiments that produced excess power in 2007 and 2008. The goal was to make the calculation without manipulating the data. The parameters and assumptions that were applied to the first experiments in 2008 were applied in the same manner to all subsequent experiments. The surprising result is shown in Figure 3.

The largest peak in Figure 3 was produced when the cell operated at 81C; the next largest peak was made at 77C. The other experiments ran at 50C-60C, confirming the idea that higher temperatures produce more vacancies in the cathode that in turn produce more excess power. It's important to note that excess power scales with the calculated number of vacancies—cell temperature itself is not the key scaling parameter for excess power.

The equation shown in the upper left corner of Figure 3 was used to retro-fit all 40 experiments in the data set without changing any parameters and is shown below as Equation 4.

$$XP = \underbrace{\frac{V_c}{a^3}\left(e^{\frac{-E}{kT_f}} - e^{\frac{-E}{kT_i}}\right)}_{1}\underbrace{\frac{\gamma_D B}{2\pi}}_{2}\cdot \underbrace{Q}_{3}\cdot\underbrace{\left(\frac{f}{F}\right)e^{\left[\frac{-E_M\left|\left(1-\frac{f}{F}\right)\right|}{h\cdot f}\right]}}_{4} \qquad (4)$$

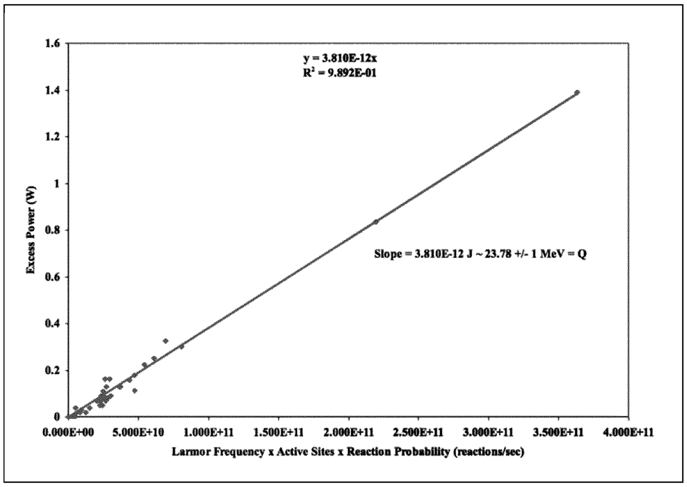

Figure 3a. Excess power is proportional to Larmor frequency x calculated vacancies. The proportionality constant is the slope of the line and is approximately 23.8 +/- 1 MeV, which is the conjectured energy release per reaction and is associated with the D+D → ^{4}He reaction.

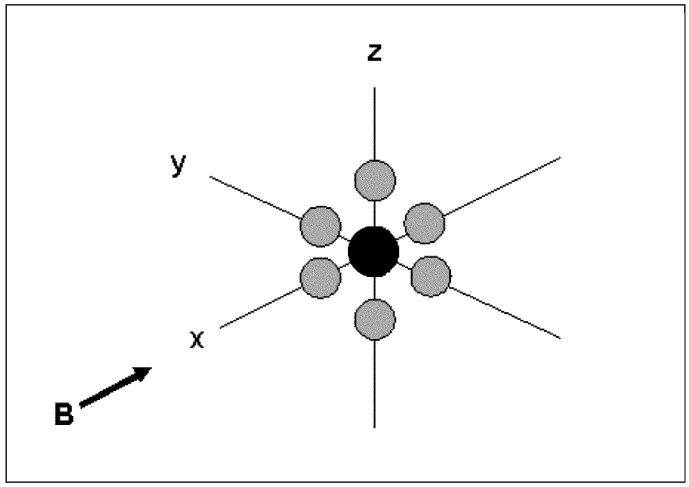

Figure 4. A schematic depicting a possible palladium vacancy that is surrounded by six deuterons; it is conjectured that a deuteron may occupy the vacancy and be in a better position to interact with other deuterons.

Equation 4 consists of four parts: Part 1 computes the number of lattices in the cathode and the gain in the number of vacancies in the lattices as a result of temperature increase, Part 2 computes the Larmor frequency, Part 3 is the proposed Q of the conjectured reaction and Part 4 is an empirically derived equation to scale computed excess power when the beat frequency is off resonance. f is the beat frequency in THz, F is a resonant beat frequency of 8.3, 14.8 or 21.78 THz. E_m is the laser energy shared by DD, DH and HH bonds in the lattice. Each of the three bonds has four degrees of freedom representing optical, acoustic, transverse and longitudinal modes, producing a 12-way sharing of laser energy as shown in Equation 5.

$$E_m = \frac{1}{2}\left[\frac{hf_1}{12} + \frac{hf_2}{12}\right] \tag{5}$$

where h is Planck's constant and f_n represents the frequencies of the two lasers used to form the beat frequencies.

The agreement between calculated and experimental excess power is exceptionally good, especially near the peaks where the dual lasers were tuned to peak resonance near 8, 15 and 22 THz. The author doesn't understand why such a simple equation appears to match experimental results so closely.

Diverse Individual Experiments

The empirical equation discussed in this paper appears to fit a wide range of experiments conducted over two years. The measured parameters used to make the calculation are cathode volume, cell temperature and the external magnetic field of 625 Gauss. There are two critical parameters used in the equation—the vacancy formation energy E and the reaction Q. These parameters were derived from the experiments and remained constant for all experiments discussed in this paper. The fit was very good for all experiments under all conditions tested.

E was derived from the known equations used to compute bulk vacancies in metals as was shown above.

$$E = K\ln\left(\frac{XP_{hi}}{XP_{lo}}\right)\left(\frac{T_{hi}T_{lo}}{T_{hi} - T_{lo}}\right) \tag{6}$$

K is Boltzmann's constant, XP_{lo} is excess power produced at T_{lo} and XP_{hi} is the excess power produced at the higher temperature T_{hi}. For experiments 669u and 669v, E = 1.00 +/- 0.03 eV. As pointed out by Dr. Melvin Miles in a personal communication, the calculation of XP is very sensitive to E, so a 3% variation in E produces a very large variation in calculated excess power. Nonetheless, at an average of E = 1 eV that held for all cathodes in this study, excess power was calculated with a high degree of accuracy and consistency, as shown in Figure 3.

The reaction Q was also calculated from the experiments by analytical and graphical methods. The graphical solution is shown in Figure 3a.

The Importance of Vacancies

When deuterium is loaded into a palladium cathode, the deuterium ions populate the face centered cubic lattices and spend most of their time traveling between the heavier palladium atoms that form the lattice. It's not hard to demonstrate that even at high loading ratios, the deuterons never get close enough to each other to produce a nuclear reaction. Vacancies are important to produce excess power in deuterated palladium because the vacancies permit the deuterons to get close enough to interact. A schematic is shown in Figure 4 that depicts a possible vacancy in a palladium atom site. The vacancy can be filled by a deuteron and then be in a position to have more intimate contact with other deuterons. The calculation used in this paper computes the number of such vacancies in the cathodes used and suggests that the bulk vacancies spread over the entire cathode may be the sites for the heat-producing reactions that we measure and calculate. The physics suggests that vacancies would tend to accumulate at the near surface.

Vacancies were produced in the palladium cathodes by loading them to high ratios with deuterium and subsequently increasing the metal temperature. For years it has been known that high loading is required to produce excess power[11] but the author believes the reason for high loading is to create the vacancies required to produce deuteron interactions in the lattice. Hagelstein has stressed the importance of vacancies for many years.

Discussion

It was surprising how well a simple empirical equation reproduced all 40 of the dual laser experiments. The author doesn't claim to know how the heat-producing reaction proceeds, but this study suggests that:

- Excess power can be calculated for a diverse range of experiments.
- Excess power is directly proportional to calculated vacancies.
- Excess power depends on the Larmor frequency of deuterium.
- Higher cell temperature produces more vacancies and more XP.
- Bulk cathode VFE was 1 eV for all 40 experiments.
- Laser stimulation was surface/local but the vacancies were located throughout the cathode, perhaps at the near-surface.
- The Q that reproduced all 40 experiments was 23.8 MeV.

In spite of the close agreement with a wide range of experiments, acceptance of this empirical calculation is likely to be slow because the calculation method is based on ideas that seem to contradict previous experimental results. For example, several researchers have reported the presence of ^4He in the cathode but mainly at the near-surface. Additionally, it is hard to accept that a highly localized laser stimulation would produce reactions in the entire cathode, far away from the stimulation site. Another shortcoming of this calculation method is the fact that it is highly sensitive to the vacancy formation energy, E_v. A small variation in the vacancy formation energy produces a very large variation in calculated excess power.

In spite of its shortcomings, the calculation method discussed in this paper may be useful in discovering the mechanism underlying the cold fusion heat effect. Additionally, the calculation method suggests future experiments that can be conducted to test its validity. For example, a detailed study of the relationship between the external magnetic field and excess power should be undertaken. Excess power should scale in a predictable manner in direct proportion to the external magnetic field strength. Many researchers have reported excess power without an external magnetic field but the external magnetic field was critical to produce excess power by laser stimulation in the series of experiments discussed in this paper.

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About the Author

Dennis Letts has been working on electrochemical heat systems since 1990. He has built over 600 cells to study deuterium in palladium systems. He has pioneered the use of radio frequencies and lasers to trigger exothermic events in D-Pd electrochemical cells.

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