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# The Nature of the Nuclear-Active-Environment Required for Low Energy Nuclear Reactions

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## ABSTRACT

A collection of observations is used to characterize the nuclear-active environment required to initiate low energy nuclear reactions (LENR).

## I. INTRODUCTION

Nuclear reactions initiated in an atomic lattice at modest temperatures have been studied since the initial claims of Pons and Fleischmann (P-F) [1, 2]. However, the claimed effects have been hard to replicate. This paper will suggest this difficulty to be caused by a failure to properly identify the nuclear-active-environment (NAE) with respect to its location and chemical structure. This paper will argue that the NAE is located in the surface region and that a reevaluation of attempts to produce the P-F effect and theories based thereon is required. In addition, the NAE has been assumed to be beta-PdD with a composition near its upper limit. This paper will argue that the NAE is a complex alloy, not beta-PdD.<sup>1</sup> In addition, a variety of other methods found to produce the effect suggest several characteristics of the NAE, which might be universal to all methods.

We will start by making the assumption that most claims for low energy fusion and transmutation are correct. Support for this assumption is readily available in the literature[3-5]. The challenge of this paper is to learn about the environment in which these nuclear reactions occur by assuming that the environment has universal characteristics common to all methods found to produce the effect.

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<sup>1</sup> Beta-PdD is a face-centered-cubic structure of the NaCl-type, which exists as a defect-structure between about PdD<sub>0.7</sub> and PdD<sub>1.0</sub>, depending on applied pressure and temperature.

## II. DISCUSSION

### Where is the NAE Located during the P-F Effect?

The P-F effect is produced by electrolyzing a cathode of palladium in an electrolyte containing  $D_2O$ . A high average D/Pd ratio for the bulk cathode is required to produce anomalous energy, i.e. energy in excess of that applied to the cell[6-8]. Consequently, a great deal of effort has been devoted to increasing the amount of deuterium loaded into the entire cathode. However, diffusion theory predicts[9] and measurements show[10] that the highest composition is present at the surface. To the extent that composition is important, the nuclear reactions would be expected to occur first within the surface region. Indeed, measurements of open-circuit-voltage, which is related to the activity of  $D^+$  in the surface, show that a critical surface activity is required to initiate energy production[8, 11]. These arguments and observations focus attention on the surface as the region of nuclear activity.

Another indication that the nuclear effect occurs in the surface region is provided by the behavior of helium production. Miles et al[12] and Miles and Bush[13] independently measured helium-4 produced from active cathodes and found an amount in the gas consistent, within a factor of two, with the measured energy proposed to be caused by  $D + D$  fusion. However, Abell et al.[14] observed that He-3 produced from tritium decay in PdH is removed as gas only if the material is heated above  $1300^\circ C$ . Consequently, for the amount of He-4 detected by the former studies to appear in the surrounding gas at room temperature, the He-4 would have to be produced very near the surface.

Direct proof of heat production in the surface region was obtained by Mosier-Boss and Szpak[15] who observed, using an IR camera, many individual hot spots on a nuclear-active cathode. Physical examinations of many cathode surfaces show melting in very small spots within the surface region[16-19]. Jiang et al. [20] placed small slits in the edge of a palladium cathode and found anomalous elements, some of which were radioactive, at these locations after extended electrolysis in  $D_2O$ . When evidence for nuclear transmutation is reported, anomalous elements are only found in the surface region with diminished concentration away from the surface. A number of studies have measured weak radiation using

autoradiograph that produces spots on a film in contact with previously active palladium or titanium[21, 22]. These observations provide direct proof that nuclear activity occurs within the surface region.

#### What are the unique characteristics of the NAE?

Once the surface region is accepted as being a source of anomalous energy, the characteristics of this region need to be understood. Electrolysis of long duration creates a very complex surface[23-35] involving many different elements, including a high concentration of lithium [25, 36-40]. As a result, the active surface region is a complex alloy, which can even be palladium-free [41]. Some of these elements are proposed to result from contamination and some from nuclear reactions. Besides being a complex alloy, the near-surface deuterium content is significantly in excess of  $D/Pd = 1.0$  [10, 42-45], the upper limit of the beta-phase.

Application of thin layers to an inert substrates is also found to produce anomalous energy. Storms[46] produced an active region as thin as several microns on platinum, a layer that does not involve palladium. Miley found similar results when thin films of various metals were applied to glass[47]. When palladium is present, the thin layers are found to be active without extensive electrolysis, as required of bulk palladium[48]. Clearly, the universal focus on pure beta-PdD, as being the nuclear-active material, has been misplaced. Indeed, every attempt to make the palladium cathode and electrolyte as pure as possible has failed to produce anomalous energy.

Other methods to initiate the effect suggest several other characteristics of the NAE involving microcrystals. Warner and Dash [49] found excess heat using a Ti cathode in a dilute sulfuric acid electrolyte. In this case, the effect was only observed when a fine powder of  $TiD_2$  was formed at the edges of the cathode, a powder that gradually fell off and settled to the bottom of the cell. Palladium was also found to form microcrystals on the surface during electrolysis[32]. The Case [50] and Arata and Zhang[51] effects, which use finely divided Pd, make the importance of microcrystals clearer. Arata used palladium-black, which is a fine powder of palladium containing a range of particle sizes in the submicron to micron range. Sintering during processing makes the exact particle size uncertain and variable. They reacted the powder with very pure  $D_2$  gas at room temperature and observed excess heat and helium production. Case

used finely divided Pd deposited on carbon<sup>2</sup> and subjected the material to D<sub>2</sub> gas at about 200°C. In this case, the average particle size is about 30 nanometers. Both studies were duplicated by McKubre et al. [52]. In both cases, the palladium would have contained an unknown collection of impurities having an unknown concentration. The small size [53] and presence of impurities will significantly increase the expected D/Pd ratio. These observations support the proposal that finely divided material is part of the NAE.

A very important observation has been reported by Iwamura et al. [54], which can be interpreted as involving very small domains of a palladium alloy. They sputter-deposit alternate layers (1000Å) of CaO and Pd on a Pd substrate. This was covered with a thin layer (400 Å) of Pd, into which Cs or Sr were electrodiffused from an electrolytic solution. When D<sub>2</sub> gas was allowed to pass through the assembly, the deposited Cs was converted to Pr or, in separate experiments, the Sr was converted to Mo. These reactions were observed within 20 Å of the surface into which the Sr or Cs had been diffused. The question is, what was the nature of the environment within this thin region? Important to an answer is the observation that the CaO was essential for the effect to occur even though it was well below the region where the nuclear reactions were observed. Logic requires CaO to have an effect only if it can change the nature of the structure within 20 Å of the surface. This could be accomplished if the 400 Å layer of Pd is forced to crystallize into microcrystals having the required nanometer dimensions. The process would involve epitaxial<sup>3</sup> growth from exposed Pd located between CaO particles at the base of the 400Å layer. These microcrystals would be a complex alloy of Sr or Cs in Pd, which would be converted to an unknown deuteride structure having an unknown but high D/Pd ratio. In addition, the reaction rate for transmutation would be expected to be proportional to the fourth power of the deuterium concentration. Therefore, most of

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<sup>2</sup> A commercial hydrogen catalyst based on Pd applied to charcoal was used.

<sup>3</sup> Epitaxy is a process in which a layer applied to another material grows with a crystal orientation which is an extension of the crystal orientation in the base material. As a result, the 400Å layer will grow on the small exposed Pd surfaces located between the CaO crystals, thereby transferring this grain structure to the surface.

the transmutation should occur very near the surface. This work is important for characterizing the NAE because a single additive in Pd is shown to make the metal nuclear-active without the normal confusion caused by many impurities.

### III. CONCLUSION

During past attempts to increase the average deuterium concentration in the bulk palladium cathode, considerable effort has been applied to measuring and modifying the surface composition of a P-F cathode, in an attempt to increase the amount of deuterium in the bulk material. The assertion made here is that this effort was doomed to be unproductive because the complex surface layer is the actual site of all nuclear activity. Bulk PdD is inert and is only required to support a high deuterium composition within the impurity layer. If this assertion is correct, platinum becomes better choice of substrate because this metal does not easily absorb deuterium, thereby preventing deuterium from being lost from the deposited layer.

When a thin active palladium layer containing suitable impurities is applied to platinum or silver, anomalous energy is seen immediately upon start of electrolysis. This is in contrast to the long delay needed to achieve energy production when bulk palladium is used. This long delay is proposed to involve slow deposition of suitable impurities, rather than slow loading of bulk material. Because such a surface layer is not easy to control, the effect has been difficult to reproduce.

A submicron size, possibility near 30 nanometers, appears to be required for the NAE to operate. In addition, when Pd is present, the active material is a complex alloy of Pd with an unknown but high D/Pd ratio. If the experience reported by Iwamura et al. [54] is assumed to be universal, the target nucleus would appear to exist as a minor impurity within a uniform lattice of inert material. In a conventional P-F experiment, many impurities are present and these diffuse into the Pd from the electrolyzing surface. Because the surface is very heterogeneous, these impurities are present in a variety of compositions and combinations. Hence a large number of transmutation products would be expected and are detected. Conditions can be imagined in such a surface where Pd is a minor impurity within another inert lattice, whereupon it becomes the target nucleus.

The author realizes these observations have been and can be interpreted in different ways. The purpose of this paper is to focus attention on one more interpretation that might be more useful than past models. Previous models have failed to provide a useful understanding of how to create the NAE, perhaps because they have focused on the wrong material. Perhaps a new approach would be more productive.

#### IV. PROPOSED FUTURE APPROACH

Once the NAE is accepted as being of a small size and made from a complex alloy of various elements, perhaps including palladium, methods required for replicating the effect can be suggested. The most obvious method is to use techniques developed by the microelectronic industry, which can deposit controlled amounts of material onto very small regions. Such methods would allow the particle size to be controlled as well as having the ability to apply known amounts of various elements. Once the range of variables affecting the NAE is understood, a large amount of active material could be easily made. In addition, a correct model for explaining the unique nuclear reactions could be developed based on such knowledge. In the absence of this approach, present efforts are handicapped by having to create the NAE using random processes, which is a very inefficient method. The Iwamura et al. [54] study shows what can be accomplished when suitable tools are applied to the problem.

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