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SHORT COMMUNICATION

Further evidence of nuclear reactions in the Pd/D lattice: emission of charged particles

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Abstract Almost two decades ago, Fleischmann and Pons reported excess enthalpy generation in the negatively polarized Pd/D-D_2O system, which they attributed to nuclear reactions. In the months and years that followed, other manifestations of nuclear activities in this system were observed, viz. tritium and helium production and transmutation of elements. In this report, we present additional evidence, namely, the emission of highly energetic charged particles emitted from the Pd/D electrode when this system is placed in either an external electrostatic or magnetostatic field. The density of tracks registered by a CR-39 detector was found to be of a magnitude that provides undisputable evidence of their nuclear origin. The experiments were reproducible. A model based upon electron capture is proposed to explain the reaction products observed in the Pd/D-D_2O system.

Keywords CR-39 · Pd/D Codeposition · Charged particles

Introduction

A physical quantity is defined by prescribing the operations necessary for its production and measurement. One such quantity is the excess enthalpy production during electrolysis of D_2O on Pd electrodes—the Fleischmann–Pons effect. In particular, they reported that during electrolysis, excess enthalpy is generated in the amounts that could not be accounted for by any known physical or chemical process; hence, it must be of a nuclear origin. This indirect evidence was not accepted primarily on two grounds: (1) the absence of nuclear ash and (2) at that time, poor reproducibility. Since then, substantial progress was made in improving reproducibility in generating excess heat and in measuring nuclear ash. (Interested readers are referred to the Proceedings of the International Conference on Cold Fusion—the ICCF series).

Restricting our attention to cells employing cathodes prepared by the Pd/D codeposition, the first indication of nuclear activity was the emission of X-rays with a broad energy distribution and, occasionally, with well identifiable peaks (Szpak et al. 1995). However, the presence of electromagnetic radiation alone cannot be regarded as the proof of nuclear activity. In the search for additional evidence we examined the production of tritium, which was found to be sporadic and often at low rates. Nevertheless, active periods persisting for days, were observed with the tritium production rates of approximately 6×10^3 atoms/s (Szpak et al. 1998). Recently, we reported that by placing an operating cell in an external electrostatic field, "new elements" are produced, among them Al, Si, and Mg (Szpak et al. 2005a,b). In this report, we present a reproducible and, what we believe to be, direct and undisputable evidence of low-energy nuclear reactions in the Pd lattice, namely, the emission of charged particles in amounts far greater than that provided by the background. Furthermore, we propose a model that is based on concepts and methods, common in physical chemistry, to analyze conditions that lead to the nuclear events in the polarized Pd/D-D_2O system.

Materials and methods

The experimental set-up, including cell design and operation, was identical to that described previously (Szpak et al.

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2005a,b), except for the cathode assembly. Here, a Ni screen or a single wire was substituted for the Au foil and, to record the emission of charged particles, a CR-39 detector (Fukuvi) was placed between the polyethylene base and the Ni screen, as shown in Fig. 1. CR-39 is an etch detector commonly used in nuclear physics to detect the emission of charged particles. The use of CR-39 to detect high-energy particles in the Pd/D system has previously been demonstrated by Oriani and Fisher (2002), Lipson et al. (2000), and Miley et al. (2002) The cathode assembly was positioned parallel to the external field. Upon completion of an experimental run, the cathode was disassembled and the CR-39 chip processed using standard procedure (etching in 6.5 N of NaOH for 6–7 h at 65–72°C).

Results

Under normal conditions, i.e., when the cell operation is controlled by the cell current and temperature, the nuclear ash consisted of X- and γ-rays, tritium, and excess enthalpy. However, when an operating cell was placed in an external electric field, reaction products included the formation of "new elements" as well as the emission of charged particles. The emission of charged particles, e.g., p^+ and α^{2+}, constitutes an undisputable evidence of nuclear events. If such events occur in the polarized Pd/D-D_2O system, then, owing to the stopping power of the electrode material, they could be detected only along the electrode edge as illustrated in Fig. 2a. The bright line along the peripheries of a single eyelet is, in fact, an overlap of hundreds of impingement tracks, as shown by magnifying a segment indicated by an arrow (Fig. 2b). Images near the edges of the cathode have a lower density of tracks. As indicated in Fig. 2c, double and triple tracks can be observed. Such tracks are observed from a reaction that emits two or three particles of similar mass and energy (Phillips[1], personal communication).

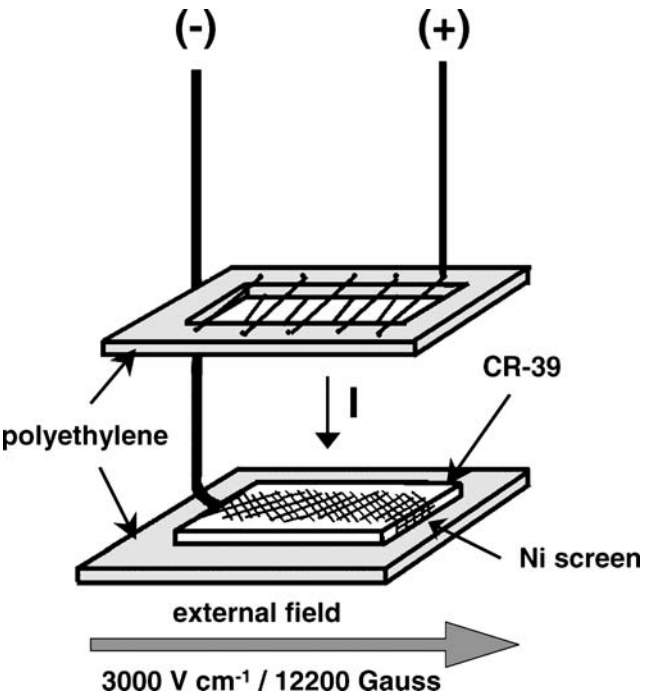

Fig. 1 Cathode assembly used to record emission of charged particles. A single wire can be used in place of the Ni screen. The cathode assembly placed in a rectangular cell. Field direction indicated by an *arrow*

The size, depth of penetration, and shape of the tracks yield information on the identification of particles (e.g., p^+ and α^{2+}) and their energy. Since our interest is in the behavior of an operating system, we are currently concerned with when and how the energetic particles are emitted. Figure 2d shows clusters of tracks recorded after 1 h of exposure, indicating that coherent domains, arising from self-organization, are formed shortly after activation of an external field. The presence of clusters is consistent with an earlier observation of hot spots (Mosier-Boss and Szpak 1999). To reiterate, (1) emission of charged particles occurs shortly after the activation of an external field, (2) reaction sites are localized (Fig. 2d), and (3) the high density of tracks (Fig. 2b) resulting from prolonged exposure is consistent with a random distribution of active sites.

Discussion

The emission of charged particles is a product of transmutations that are governed by the same laws as ordinary chemical reactions (i.e., conservation of mass and charge; Remy 1956). This observation is the starting point that leads to the proposition that pertinent information concerning the mechanism of any reaction can be obtained if the input and output variables are known. A model can be formulated in the context of the following: (1) state of the system, (2) imposed constraints, and (3) the nature of the electron–nucleus reaction.

State of the system

An operating cell is viewed as an open system that is in a nonequilibrium condition. If a complex reaction path exists, with rate constants being a nonlinear function of variables affecting their rate, then the expected behavior is the development of new structures. As a rule, open physico-chemical systems, far from equilibrium, undergo "self-organization," which, in turn, yields structures of spatial domains characterized by bursts of chemical activity

[1] Phillips, G. Consultant, JWK International

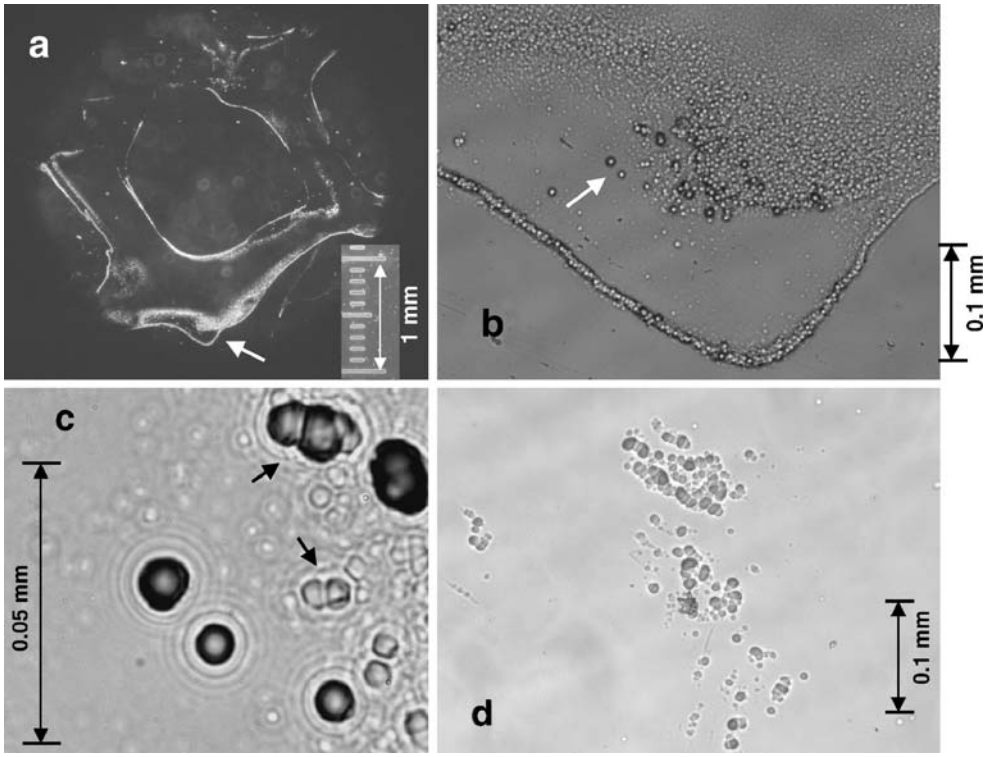

Fig. 2 Emission of high-energy charged particles from a polarized Pd/D-D_2O system exposed to an external field. **a** Tracks observed around a single eyelet of the Ni screen; *bright lines* and *spots* along the peripheries represent hundreds of overlapping impingement tracks. **b** Expanded area indicated by *arrow* in subpanel **a**. **c** Expanded area indicated by an *arrow* in subpanel **b**. *Arrows* indicate double and triple tracks. **d** Impingement tracks of particles emitted from Pd deposited on a single Ag wire. Clusters observed within an hour after activation of an external field. **a**–**c** Magnetostatic field 12,200 Gauss, in field for several days. **c** electrostatic field 3,000 Vcm^{-1}, an hour in field. Solution composition 0.03 M $PdCl_2$+0.3 M LiCl in D_2O. Cathodic cell current profile (in milliampere per square centimeter): i=1.0 for 2 h, i=3.0 for the period necessary to reduce all Pd^{2+} ions, i=30.0–50.0 for 2–3 h, and i=100.0 after placement in an external field

appearing as hot spots (Mosier-Boss and Szpak 1999) or, as in the present case, in the emission of charged particles as shown in Fig. 2. The reaction volume, located within the interphase, is the seat for the set of consecutive and/or parallel reactions terminating with the occurrence of a nuclear event. It is convenient to separate these processes into two groups occupying the same volume, namely, processes undergoing self-organization and subject to the laws of physicochemistry and transmutations and other nuclear activities governed by the applicable laws of nuclear physics.

Imposed constraints

The imposed constraints on an operating cell are the cell current and either an external electrostatic or magnetostatic fields. The first determines the rate of relevant electrochemistry through electrochemical potentials while an external field influences the set of events by affecting both the driving forces (electrochemical potentials) as well as the activity within the reaction volume. If a particle interacts with an internal or external field associated with the change in the number of particles, then its energy must be included, and the chemical potential takes on a form $\overline{\mu} = \mu + u(x,y,z)$, where $u(x,y,z)$ is the interaction energy. By application of an external electrostatic or magnetostatic field a new situation is created. Significant morphological and structural changes take place in the cathode, which, in turn, generate Pd lattice defects and changes in the magnitude of driving forces—the chemical/electrochemical potentials, which in effect produce new elements and the emission of charged particles.

The electron–nucleus reaction

Emission of soft X-rays has been reported by Miles et al. (1994), Violante et al. (2002), and Szpak et al. (1995). This emission suggests that electron capture is occurring. Within the reaction volume, the concentration of energetic electrons with the ratio $[e^-]/[D^+]$ is sufficiently large so that the X (where X may be D^+, D_2^+, Li^+, etc.) is surrounded by electrons. Under these conditions, electron capture can be described as a chemical reaction:

$$z(X)^A + e^- \rightarrow_{Z-1} Y^A + \nu \quad (1)$$

with the neutrino escaping the reaction volume. For this

reaction to occur, the product: affinity, A_f, times velocity, v, must be positive $[A_f \times v > 0]$. Taking v>0 for the forward direction, the condition for the electron capture is the inequality $\mu(ne^-) > \mu_{z-1} - \mu_z$ or $\mu(ne^-) > \varepsilon_Z - \varepsilon_{Z-1}$, where ε is the negative binding energy (Landau and Lifshitz 1980).

An example of such a reaction is the reverse of the well-known neutron decay reaction: $n \rightarrow p^+ + e^- + v$. This reaction proceeds spontaneously from left to right while the reverse requires that the chemical potential of free electrons be not less than μ>0.8 MeV (Orear et al. 1949). Similarly, applying Eq. 1 to the D^+ species, we have $e^- + D^+ \rightarrow n_2$ followed by an instantaneous decomposition $n_2 \rightarrow 2n$. For this reaction to occur, the electrochemical potential of free electrons must be roughly 25 times greater than that involving a proton, which is small for electrons interacting with electric fields of 10^8–10^9 Vcm^{-1}.

The reaction $e^- + D^+ \rightarrow 2n$ is the source of low energy neutrons (Szpak, unpublished data), which are the product of the energetically weak reaction (with the heat of reaction on the electron volt level) and reactants for the highly energetic nuclear reaction $n+X \rightarrow Y$. This model states that (1) the imposed constraints are responsible for the frequency of the formation of coherent domains while transmutation reactions, $X(n,r)Y$, determine the excess power and (2) it specifies the mechanism by which a chemical reaction can trigger a nuclear response.

In a short hand notation, the transmutation reaction is written as $X(n,r)Y+Q$ with Q>0 for exothermic and Q<0 for endothermic reactions and where r stands for p^+, α^{2+}, X-ray, γ-ray, or β^-. In the present case, X denotes any specie within the reaction volume, e.g., D^+, D_2^+, Pd, Li, Cl, or O, and Y represents the "new elements", the emitted particles and the electromagnetic radiation. Considering the number of elements within the reaction volume, i.e., the number of different nuclei that can absorb a neutron, the number of possible reaction paths and, therefore, reaction products is expected to be large. The CR-39 detector is capable of recording the type and energy of emitted particles, i.e., it provides limited, but nevertheless significant information about the nuclear activities occurring in the polarized Pd/D-D_2O system.

In conclusion, using procedures that are commonly used in the area of nuclear physics, we have detected the emission of energetic particles during the electrolysis of heavy water on Pd electrodes prepared by codeposition in cells placed in either an external electric or magnetic field. Such energetic particles can only originate from nuclear reactions. A model from a chemist's perspective that is consistent with the state of the system, imposed constraints and the nature of the electron—nucleus reaction rather than on arbitrarily assumed set of approximations, is proposed. However, from a physicist's point of view, the theoretical arguments offered in this communication are pure speculation. It is hoped that future investigations will undoubtedly provide a clearer picture of the nuclear events taking place in the polarized Pd/D-D_2O system.

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