Toward an Explanation of Transmutation Products on Palladium Cathodes

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Abstract

A lattice model of nuclear structure that is isomorphic with the conventional independent-particle model (IPM) has previously been shown to predict the asymmetrical fragments produced by the thermal fission of the actinides. The same model can be used to predict the transmutation products found on palladium cathodes following electrolysis, as reported by Mizuno [1]. It is concluded that the substructure provided by the lattice may be a crucial addition to conventional nuclear structure theory in order to explain the nuclear transmutations in both thermal fission and "cold fusion".

Introduction

Several decades ago, various nucleon lattice structures were examined theoretically in the search for stable, condensed configurations of nucleons, possibly present in "neutron stars" [2]. Amidst such research, several lattice models of nuclei at normal nuclear densities [e.g., 3, 4] were developed and shown to exhibit the properties that are normally described using the conventional (shell, liquid-drop, cluster, etc.) models of nuclear structure theory. The lattice models have proved most useful in predicting the multifragmentation products of heavy-ion experiments [3, 5, 6] – an area where conventional models are inapplicable. Notable among such theoretical work was the quantitative explanation of the high-energy fragmentation of Xe and Kr nuclei using an FCC lattice [5] and the parameter-free explanation [7, 8] of the ***asymmetrical*** fragments produced in the thermal fission of uranium and plutonium: "the perennial puzzle of nuclear physics" [9].

The present study was undertaken to examine the use of the FCC lattice model for explaining the transmutation products that have been reported in low-energy "cold fusion" experiments. Mizuno [1] found not only deviations from the natural abundance of Pd isotopes on Pd cathodes, but also deposits of various light elements on the cathode surface. Those results are undisputed as empirical studies, but questions remain concerning the physical mechanisms. Here I apply the same lattice-fission technique that explains the asymmetrical fission of uranium [7, 8] to the break-up of the Pd isotopes, again ***without*** the use of model parameters to produce the results.

The Lattice Model

Central to an understanding of the lattice model itself is a mathematical identity between the quantum mechanical description of nuclear quantum states (summarized by the quantum numbers, ***n, j, m, s*** and ***i,*** that are used in the Schrodinger wave-equation) and a specific lattice structure [4, 8]. Specifically, in the conventional description of nuclear states, each nucleon is presumed to be in an energetic state specified by its unique set of quantum numbers. The description of nucleon states is analogous to (although, in detail, somewhat different from) the quantum mechanical states of the electrons in electron orbitals and described by similar quantum numbers. The motivation underlying the lattice model is the fact that a specific lattice structure that reproduces all of the nucleon energy states of the so-called independent-particle (~shell) model. That same lattice (an antiferromagnetic face-centered-cubic [FCC] lattice with isospin layering) has been independently shown to be the lowest-energy condensed state of nuclear matter (N=Z) [11]. The significance of the isomorphism between the lattice and quantum mechanics lies in the fact that, if the conventional IPM structure of a nucleus is known, then the 3D lattice positions of all its nucleons can be deduced directly from Eqs. 1-5 (and vice versa, starting with occupied lattice sites and deducing its IPM state, Eqs. 6-8).

$\boldsymbol{n} = (\lvert x\rvert + \lvert y\rvert + \lvert z\rvert - 3) / 2$	Eq. 1	$\boldsymbol{i} = ((-1)^{(z-1)}) / 2$	Eq. 5
$\boldsymbol{j} = (\lvert x\rvert + \lvert y\rvert - 1) / 2$	Eq. 2	$x = \lvert 2\boldsymbol{m}\rvert(-1)^{(\boldsymbol{m}+1/2)}$	Eq. 6
$\boldsymbol{m} = \lvert x\rvert / 2$	Eq. 3	$y = (2\boldsymbol{j}+1-\lvert x\rvert)(-1)^{(\boldsymbol{i}+\boldsymbol{j}+\boldsymbol{m}+1/2)}$	Eq. 7
$\boldsymbol{s} = ((-1)^{(x-1)}) / 2$	Eq. 4	$z = (2\boldsymbol{n}+3-\lvert x\rvert-\lvert y\rvert)(-1)^{(\boldsymbol{i}+\boldsymbol{n}-\boldsymbol{j}-1)}$	Eq. 8

where x, y and z are all odd-integers defining FCC lattice coordinates. Full details of the lattice structure and its application to the unresolved problems in nuclear theory are available elsewhere [8]. Suffice it to say that the ***n***-shells of the harmonic oscillator are literally shells in the lattice (Fig. 1), and all of the ***j***-, ***m***-, ***s***- and ***i***-subshells of the IPM model are defined in terms of lattice symmetries. It bears emphasis that the occupancies of ***all*** of the shells and subshells in the lattice model are identical to those in the IPM model – from which the shell model is derived. In other words, the FCC lattice is a geometrical analog of the quantal regularities of the Schrodinger equation. It therefore provides a natural inroad to questions concerning nuclear substructure ***without*** the need for ad hoc postulates concerning nucleon-clustering or dynamics (i.e., "model" parameters that are not derived from quantum mechanics).

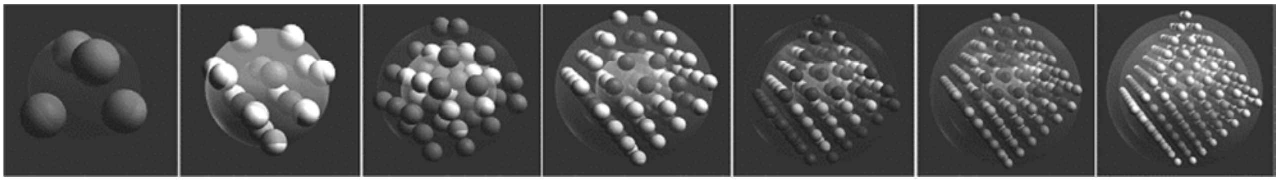

Figure 1. The n-shells in the lattice built from a central tetrahedron show the same occupancy as the harmonic oscillator [4, 9]: $_{2}He^{4}$, $_{8}O^{16}$, $_{20}Ca^{40}$, $_{40}Zr^{80}$, $_{70}Yt^{140}$, $_{112}Xx^{224}$, $_{168}Xx^{336}$.

Given the well-established validity of the IPM (~shell model) description of nucleon states, a unique lattice structure for any combination of N and Z is implied (Eqs. 1~8) – so that the lattice structure itself can be examined in terms of its fragmentation dynamics.

Fission of the Actinides

The break-up of a mini-lattice (A~240) is favored along those lattice planes where the number of interfragment 2-body interactions is low and simultaneously the interfragment Coulomb effect is high [7]. These are competing tendencies: ***asymmetrical*** fission is favored by the small number of nucleon-nucleon interactions binding small fragments to the larger parent nucleus, whereas the ***symmetrical*** (~1:1) split of the parent nucleus is favored when equal numbers of proton charges are in both daughter fragments. Note that the prediction of ***symmetrical*** fission fragments is the classic deficiency of the liquid-drop model (LDM) explanation of thermal fission. Without an "asymmetry parameter" – introduced explicitly to enhance asymmetrical fragmentation, the presumed liquid-like interior of large nuclei in the LDM inevitably predicts ***symmetrical*** fission – contrary to all findings on low-energy fission of the actinides. Shell model theorists have sought to introduce nuclear substructure (i.e., asymmetry) via the stability of "magic" numbers of protons and neutrons – and that view is the qualitative explanation of asymmetrical fission in most textbooks today. To the contrary, however, Strutinsky et al., who worked explicitly on this problem, have noted that the manipulations of the nuclear potential well needed to produce asymmetric fission have "little to do with the magicity of spherical fragments" [11] and the magic numbers 28 and 50 among the final fragments do not explain – qualitatively or quantitatively – the known fragment asymmetries. In contrast, the lattice model contains substructure inherent to the lattice itself. Using the default FCC structures for the uranium and plutonium isotopes, calculation of the interfragment binding along lattice planes, together with interfragment Coulomb effects, already shows the predominance of ***asymmetrical*** fission fragments (~3:2) (Fig. 2).

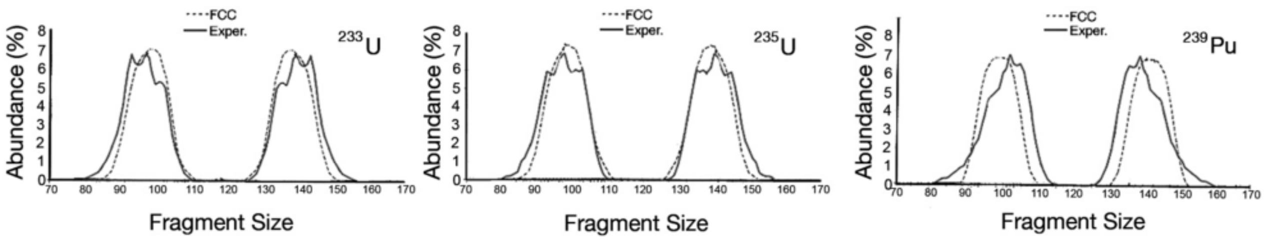

Figure 2. The parameter-less prediction of asymmetrical fragments in the thermal fission of the actinides using the lattice model [7, 8]. The experimental data are shown by the solid lines (experimental error lies within the width of the lines). Not only is the asymmetry of the fragments unexplained in conventional theory (known since 1938), but there is real substructure in the fragments that survives the fission process and cannot be explained by the LDM or shell model.

Transmutation of Palladium

Among the most dramatic results on the transmutation of deuterium-loaded palladium are those reported by Mizuno [1]. As experimentalists, they have been concerned chiefly with the measurement of heat and reaction products, and have reported not only changes in the abundance of various Pd isotopes, but also the deposition of various light- and medium-size elements on the surface of the Pd cathodes. They found that: (i) Prior to the experiment, the measured abundances of Pd isotopes were virtually identical to the known natural abundances (Table 1, Column B). (ii) Subsequent to electrolysis, there were significant changes in the relative abundances (Column C), suggestive of nuclear transmutation at the surface of the electrode, with (iii) gradually smaller changes in the natural abundances as measurements proceeded from the surface to 30,000 Angstroms into the depth of the cathode. Issues of heat production aside, these are profoundly interesting experimental findings.

Table 1: Experimental and Theoretical Changes in Palladium Isotopes Following Electrolysis

	EXPERIMENT			SIMULATION				
Isotope	% Abundance	Mizuno Data	% Change	Initial No.	Loss	Final No.	% Loss	% Abundance
Pd^{102}	1.0%	4%	+3.0%	1,000	600	400	60%	3.8%
Pd^{104}	11.0%	17%	+6.0%	11,000	9,190	1,810	84%	17.1%
Pd^{105}	22.2%	20%	-2.2%	22,200	20,080	2,120	90%	20.0%
Pd^{106}	27.3%	21%	-6.3%	27,300	25,070	2,230	92%	21.0%
Pd^{108}	26.7%	21%	-5.7%	26,700	24,470	2,230	92%	21.0%
Pd^{110}	11.8%	17%	+5.2%	11,800	9,990	1,810	85%	17.1%
Total	100.0%	100%	0.0%	100,000	89,400	10,600	89%	100.0%
A	B	C	D	E	F	G	H	I

The percentage changes in the abundance of Pd isotopes (Column D) do not suggest any obvious regularity in the transmutation process, but a simple simulation indicates that essentially all of the Pd isotopes were equally involved in the transmutation process. That is, assuming that measurements of the cathode surface were made on, say, 100,000 Pd nuclei (Column E), the "loss" of 600, 9190, 20080, 25070, 24470 and 9990 of, respectively, the Pd^{102}, Pd^{104}, Pd^{105}, Pd^{106}, Pd^{108} and Pd^{110} isotopes results in percentages (Column I) virtually identical to those reported by Mizuno (Column C). What is of interest about these values is that they indicate that (with the exception of Pd^{102}, that accounts for only 1% of the natural abundance) ***all*** of the Pd isotopes were involved in nuclear reactions at approximately equal rates (84~92%, Column H). In other words, if transmutation of Pd is the source of heat energy in cold fusion experiments, then it is ***not*** the case that one or a few unusual isotopes are responsible for the effects, in so far as similar percentage decreases of all isotopes were involved. Clearly, this simulation does not indicate how deuterium is able to overcome the Coulomb barrier and enter the Pd nucleus [12], but it does show that, if some such mechanism is at work, the seemingly irregular changes in Pd isotopic abundances (Column D) are a consequence of similar percentage depletions in all isotopes (Column H).

The next question is, therefore, if a constant percentage of surface Pd isotopes were transmuted, what were they transmuted to?

Palladium Fission Fragments

Simulation of the fission of palladium was carried out on each of the six stable Pd isotopes using the lattice model [4, 7, 8,]. The nucleon build-up process in the model is given by Eqs. 1~4, with the assignment of equivalent "valence" nucleon positions determined solely by the maximization of nearest-neighbor interactions. In other words, 46 protons and 56~64 neutrons were placed at lattice sites, such that the final nucleus had (i) maximal nearest-neighbor binding, (ii) minimal Coulomb repulsion, and (iii) a total ***J***-value (calculated from the sum of nucleon ***j***-values) as experimentally known. A deuteron was then added at random to surface lattice sites of each nucleus. Finally, scission of the Z=47, N=57~65 system was simulated along 17 lattice planes cutting through or parallel to the origin of the coordinate system, and statistics collected. For each fissioning nucleus, the total number of "bonds" crossing the fission-plane was counted and the total Coulomb repulsion between the fragments calculated. Assuming an average nearest-neighbor binding energy of ~2.77 MeV (giving a total binding energy of the Pd isotopes within 1% of experimental values) and subtracting the Coulomb effect between the fragments, the four lowest-energy fission events per nucleus were calculated. The final steps in the simulation were (i) adjustment of the percentages of fragments using the natural abundances of Pd isotopes and then (ii) collation of the fission fragments per Pd isotope. The entire fission simulation is similar to that already reported concerning the actinides [7, 8], and can be easily reproduced using the NVS freeware (Windows and Mac versions) available at: www.res.kutc.kansai-u.ac.jp/~cook.

Results

The binding energy of the Pd isotopes was calculated from the total number of nearest-neighbor "bonds" in the lattice structure for a given number of Z and N, assuming a binding energy of 2.77 MeV/bond (ignoring spin and isospin effects) minus the Coulomb effect. By then calculating the total binding energy across each scission plane minus the Coulomb repulsion between the protons in each fragment, the energy required to induce fission was found to be 3.12~8.66 MeV, depending on the isotope. The fragments produced by splitting the Pd isotope along the low-energy planes contained 46~60 nucleons and 22~26 protons. In other words, fission of the Z=47, N=57~65 system was essentially ***symmetrical*** with two daughter fragments of approximately the same mass. Generally, only a few scission planes per isotope had fission energies below 10 MeV, but if fission events requiring up to 15 MeV are also included, then fragments with atomic number 14~33 and mass number 34~73 were found. Typical fission lattice-planes through a Pd isotope are illustrated in Figure 3. Qualitatively, the approximate spectrum of deposits on the Pd cathode reported by Mizuno [1] was reproduced by the lattice model. A quantitative study is in progress.

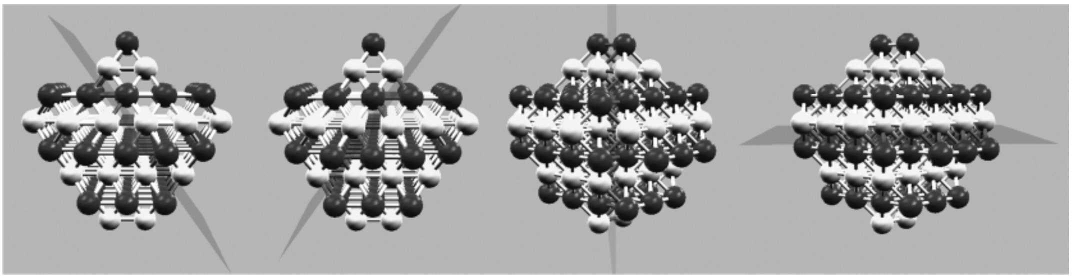

Figure 3. Examples of high (left) and low (right) probability lattice scission planes in Pd110. Note that the FCC lattice structures represent individual nuclei (protons are light spheres, neutrons are dark spheres), totally unrelated to the FCC (atomic) structure of the palladium cathode itself.

Conclusion

Conventional nuclear structure theorists are understandably reluctant to postulate new physical mechanisms to account for the transmutation results reported by Mizuno and others. Nevertheless, the excess heat found in many experimental "cold fusion" set-ups is strongly suggestive of a nuclear origin – and that suggestion alone implies that there are yet imperfectly understood nuclear phenomena at work. In fact, the ***asymmetrical*** fragmentation of U^{235} and all of the other actinides that undergo thermal fission is one of the oldest "mysteries" in nuclear physics. I suggest that both the mystery of asymmetric fission of uranium and the mystery of deuterium-induced transmutation of Pd can be solved by regarding the nucleus itself as a mini-lattice. Assuming a yet-uncertain mechanism for inducing the fission of Pd nuclei [12], the substructure implicit to the FCC lattice representation of nuclear quantal symmetries may explain transmutation results essentially without any modification to the conventional independent-particle (~shell) model of nuclear structure.

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