Palladium fission triggered by polyneutrons

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Abstract

Polyneutron theory is applied to experiments of Iwamura *et al.* [1] that show evidence for titanium and for an anomalous iron isotope ratio in palladium cathodes following electrolysis. Theory and experiment are in reasonable agreement. Experiments are suggested for additional testing of the theory.

Iwamura *et al.* have conducted electrolysis experiments in which deuterium was introduced into a palladium cathode [1]. During electrolysis they observed excess heat generation and X-ray emission that they attributed to nuclear reactions. Following electrolysis, investigation of the cathode revealed a significant signal for titanium and an anomalous iron isotope ratio. In subsequent experiments [2] where deuterium was diffused into a palladium diaphragm they confirmed the anomalous iron isotope ratio. Evidence for titanium and for iron suggests that these isotopes may have arisen from fission of palladium in the cathode. Although this interpretation seems at first to be physically impossible, it may be that interactions with polyneutrons can enable fission to occur.

Fission reactions that yield titanium, iron, and other isotopes with mass numbers comparable to half that of palladium are exothermic, but do not occur under normal circumstances. According to the liquid drop model of nuclei the criterion for spontaneous fission is

$$Z^2/\mathrm{A} > 2a_s/a_c \tag{1}$$

where Z is the nuclear charge, A is the nucleon number, a_s is the surface energy coefficient, and a_c is the coulomb energy coefficient [3]. For ordinary nuclei the drop model coefficients are $a_s = 16.8$ MeV and $a_c = 0.72$ MeV and the corresponding criterion for spontaneous fission is $Z^2/\mathrm{A} > 47$. For ^{102}Pd we have $Z^2/\mathrm{A} = 21$, well short of the required 47. An extrapolation to $Z = 46$ based on data for $Z > 89$ suggests a palladium fission half-life of about 10^{60} years. It follows that a significant reduction in surface energy is required if palladium fission is to occur.

Polyneutron theory offers a possibility for the required reduction in surface energy. It has been proposed that polyneutrons bind to ordinary nuclei in reactions responsible for

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nuclear energy production, helium production, palladium transmutation, and other nuclear phenomena [4]. For this binding energy to be the cause of surface energy reduction, the configuration of the polyneutron-nucleus composite must be that of a shell nucleus, with a polyneutron forming a neutron shell around an ordinary nucleus as core. If the energy of the outer surface of the shell plus the interfacial energy between the shell and the core nucleus together amount to less than 45% of the surface energy of a free nucleus, then $Z^2/\mathrm{A} < 21$ and palladium fission is assured. I assume this to be so and consider the consequences.

Fission reactions are of the following form:

$$
\begin{aligned}
{}^{\mathrm{A}}\mathrm{Pd} + {}^{\mathrm{B}}\mathrm{n} \rightarrow ({}^{\mathrm{A}}\mathrm{Pd}^{\mathrm{B}}\mathrm{n}) \rightarrow ({}^{\mathrm{C}}\mathrm{X}^{\mathrm{B}-\alpha}\mathrm{n}) + {}^{\mathrm{D}}\mathrm{Y} + \Delta E_s + \Delta E,\\
\alpha = \mathrm{C} + \mathrm{D} - \mathrm{A}. \qquad (2)
\end{aligned}
$$

In this reaction the symbol $({}^{\mathrm{A}}\mathrm{Pd}^{\mathrm{B}}\mathrm{n})$ stands for a shell nucleus with B neutrons in the shell surrounding ${}^{\mathrm{A}}\mathrm{Pd}$ as core. The nuclei ${}^{\mathrm{C}}\mathrm{X}$ and ${}^{\mathrm{D}}\mathrm{Y}$ are the fission products. The $({}^{\mathrm{C}}\mathrm{X}^{\mathrm{B}-\alpha}\mathrm{n})$ is a shell nucleus with $\mathrm{B} - \alpha$ neutrons in the shell. $\Delta \mathrm{E}_s$ is the net surface energy released on formation of the final composite. ΔE is the remainder of energy released in the reaction. The quantity α is the number of neutrons that are transferred from the polyneutron to the fission products. I assume that the polyneutron halo is attached to a single fission fragment. This is plausible provided that the interfacial energy between shell and core depends on the thickness of the shell and does not reach its minimum value until the shell reaches a thickness of several neutrons. As a consequence, considering the sizes of palladium nuclei and the estimated sizes of free polyneutrons in the reactions under consideration, the energy is a minimum when all neutrons are concentrated in a single shell. I assume that chance decides which fission fragment is free and which is a shell nucleus core.

Reaction energies ΔE are calculated using the standard mass excesses for ordinary nuclei [5], and the formula

$$
\Delta({}^{\mathrm{A}}\mathrm{n}) - \Delta({}^{\mathrm{A}-\alpha}\mathrm{n}) = 1.143\alpha \qquad (3)
$$

for the differences between polyneutron mass excesses [4]. I assume even values for A and α because of the high mass excesses expected for polyneutrons containing an odd neutron.

The following calculations illustrate the method:

$$^{102}\mathrm{Pd} + {}^{\mathrm{A}}\mathrm{n} \longrightarrow {}^{56}\mathrm{Cr} + {}^{52}\mathrm{Ti} + {}^{\mathrm{A}-6}\mathrm{n} + \Delta E_s + \Delta E$$

$$\Delta E = \Delta(^{102}\mathrm{Pd}) - \Delta(^{56}\mathrm{Cr}) - \Delta(^{52}\mathrm{Ti}) + 6(1.143) = 23.679 \text{ MeV}$$

$$^{106}\mathrm{Pd} + {}^{\mathrm{A}}\mathrm{n} \longrightarrow {}^{56}\mathrm{V} + {}^{54}\mathrm{V} + {}^{\mathrm{A}-4}\mathrm{n} + \Delta E_s + \Delta E$$

$$\Delta E = \Delta(^{106}\mathrm{Pd}) - \Delta(^{56}\mathrm{V}) - \Delta(^{54}\mathrm{V}) + 4(1.143) = 10.660 \text{ MeV}. \qquad (4)$$

There are about a thousand such reactions with energies ΔE in the range from zero to 24 MeV. They occur with probabilities that depend on how exothermic they are. I expect that the probability increases exponentially with ΔE and that reactions with small ΔE can be neglected. As a rough approximation I consider only the 94 reactions having $\Delta E > 18$ MeV and I give them equal weight. This assumes that the unknown energy ΔE_s is approximately the same for all fission reactions and that it does not affect their ranking. The 188 fission fragments are classified in the following table.

Mass number	Final product	1.02% ^{102}Pd	11.14% ^{104}Pd	22.33% ^{105}Pd	Weighted totals
42	Ar	3	-	-	3
44	Ca	3	-	-	3
46	Ca	7	-	-	7
47	Ti, K→Ti (8d)	3, 2	-	-	3, 2
48	Ti, Ca	1, 6	0, 4	0, 3	1, 67
49	Ti	5	1	2	61
50	Ti	8	4	1	75
51	V	12	-	1	35
52	Cr	7	2	2	74
53	Cr	12	-	2	57
54	Cr	8	3	-	42
55	Mn	12	-	1	35
56	Fe	6	3	2	84
57	Fe	5	-	1	27
58	Fe	7	1	-	18
59	Fe→Co (44d)	6	-	1	28
60	Fe	6	2	1	51
61	Ni	5	1	1	38
62	Ni	3	2	1	48
63	Ni	3	-	1	25
64	Ni	6	1	-	17
65	Cu	1	-	-	1
66	Zn	4	-	-	4
68	Zn	3	-	-	3
Totals		144	24	20	809

The first column gives the mass number of the fission fragment.

Many fragments are radioactive and undergo one or more beta decays before reaching stability. The second column identifies the isotopes that are present one day after electrolysis, by which time most beta decay has ceased. Except for mass numbers 47 and 59 all tabulated fission products are stable or have half-lives greater than 30 years.

The third column summarizes the fragments expected from fission of ^{102}Pd. The largest signals are for Cr (27 fragments with mass numbers 52-54), for Fe (30 fragments with mass numbers 57-60 declining to 24 fragments after decay of ^{59}Fe), and Ti (17 fragments with mass numbers 47-50 rising to 19 after decay of ^{47}K).

The fourth and fifth columns summarize the fragments expected from fission of ^{104}Pd and ^{105}Pd. There are no fission reactions with $\Delta E > 18$ for isotopes ^{106}Pd, ^{108}Pd, or ^{110}Pd.

The last column gives the totals from all Pd isotopes, weighted by their natural abundance percentages. From these values I abstract the quantities of relevance for comparison with the experiments of Iwamura *et al.*

1. Abundance ratio of ^{57}Fe to ^{56}Fe:
    Natural abundance ratio is $^{57}\text{Fe}/^{56}\text{Fe} = 0.023$
    Theory: $^{57}\text{Fe}/^{56}\text{Fe} = 27/84 = 0.32$
    Experiment: $^{57}\text{Fe}/^{56}\text{Fe} = 0.036, 0.038, 0.065, 0.24, 0.66,$
    $0.26, 0.22, 0.29, 0.45, 0.37, 0.66, 0.097, 0.03, 0.03$
    (range 0.03-0.66, mean 0.25; SIMS[1])
    $^{57}\text{Fe}/^{56}\text{Fe} = 0.31$ (TOF-SIMS[2])
    The theoretical value 0.32 and the experimental values 0.25 and 0.31 are in reasonable agreement.
2. Abundance ratio of mass-58 to mass-56:
    Natural abundance ratio of iron isotopes is $^{58}\text{Fe}/^{56}\text{Fe} = 0.003$
    Theory: $^{58}\text{Fe}/^{56}\text{Fe} = 18/84 = 0.21$
    Experiment: mass-58/mass-56 $= 0.02$ (min) to 0.30 (max).
    The theoretical value 0.21 and the mean experimental value 0.16 are in reasonable agreement.

3. Presence of titanium:

   Theory: Ti fission fragments amount to 17% of total

   Experiment: Strong EDX signal for Ti

   Theory and experiment are compatable.

The tabulated data suggest additional measurements that can further test the theory:

A. Abundance ratio of ^{54}Cr to ^{52}Cr:

   Natural abundance ratio is ${}^{54}\mathrm{Cr}/{}^{52}\mathrm{Cr} = 0.028$

   Theory: ${}^{54}\mathrm{Cr}/{}^{52}\mathrm{Cr} = 42/84 = 0.57$

B. Abundance ratio of ^{60}Fe to ^{56}Fe:

   Natural abundance ratio is ${}^{60}\mathrm{Fe}/{}^{56}\mathrm{Fe} = 0$

   Theory: ${}^{60}\mathrm{Fe}/{}^{56}\mathrm{Fe} = 51/84 = 0.61$

C. Gamma radiation from decay of ^{60}Co:

   Theory: The ^{60}Fe fission fragments decay to ^{60}Co with a half life of 1.5 million years. Decay of the resulting ^{60}Co emits characteristic gamma radiation.

Overall the agreement between theory and experiment is consistent with the concept of palladium fission. Confirmation of the ${}^{57}\mathrm{Fe}/{}^{56}\mathrm{Fe}$ and ${}^{58}\mathrm{Fe}/{}^{56}\mathrm{Fe}$ ratios and of the presence of Ti are possible by testing palladium cathodes from earlier experiments. Measurements of ${}^{54}\mathrm{Cr}/{}^{52}\mathrm{Cr}$ and ${}^{60}\mathrm{Fe}/{}^{56}\mathrm{Fe}$ offer possibilities for extending the evidence for fission.

Detection of gamma radiation from ^{60}Co decay would provide the most compelling evidence. The ^{60}Fe fission fragments predicted by the theory have a 1.5 million year half-life, decaying to ^{60}Co. Subsequently ^{60}Co decays to ^{60}Ni with a 1900 day half-life, emitting characteristic gamma rays. Iwamura *et al.* found about 10^{17} atoms of Ti in the surface layers of their cathode. If Ti and Fe isotopes have proportional molar concentrations we can expect about $4(10)^{16}$ atoms of ^{60}Fe. The rate of ^{60}Fe decay would be about 10^3/sec, and after a few years the decay rate of the Co^{60} product would rise to equal it. This level of radioactivity is measurable and a positive result would provide irrefutable proof of nuclear reaction, free of the doubts that invariably plague calorimetric measurements.

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