ON THE POSSIBILITY OF DEUTERON DISINTEGRATION IN ELECTROCHEMICALLY COMPRESSED D^+ IN A PALLADIUM CATHODE

COLD FUSION

TECHNICAL NOTE

KEYWORDS: *cold fusion, neutron capture, Oppenheimer-Phillips reaction, disintegration, palladium reaction*

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The possibility of deuteron disintegration due to polarization in the coulomb field of a target nucleus according to an Oppenheimer-Phillips process is discussed within the context of electrochemically compressed D^+ in a palladium cathode. This reaction is possible between deuterons and palladium isotopes, as well as between the deuterons themselves. In the last case, the equivalent of the proton branch of the deuterium-deuterium fusion reaction occurs in preference to the neutron branch. The process provides a possible explanation for the observed energy release, tritium production, and neutron suppression in the Fleischmann and Pons experiment. If such a process can be experimentally verified, analogous processes leading to the disintegration of the ^{9}Be nucleus may be achievable.

INTRODUCTION

The possibility of deuteron disintegration in condensed matter is discussed as a model for the processes occurring in the work on cold fusion reported by Fleischmann and Pons[1] and by Jones et al.[2] Other proposed models for these processes include quantum-mechanical tunneling and quasi-electron formation in the deuterated lattices by Jones et al.,[2] classical oscillations of delocalized species in shallow potential wells by Fleischmann and Pons,[1] and cosmic muon catalysis by Moir.[3]

The suggestion by Fleischmann and Pons[1] that the reactions

$$D + D \rightarrow T + H + 4.03 \text{ MeV} \tag{1}$$

and

$$D + D \rightarrow {}^3He + n + 3.27 \text{ MeV} \tag{2}$$

take place to the extent of 1 to 2×10^4 atom/s (consistent with the measurements of the neutron flux), whereas the data on enthalpy generation would require rates for reactions (1) and (2) in the range 10^{11} to 10^{14} atom/s, leads them to conclude that these reactions " . . . are only a small part of the overall reaction scheme and that other nuclear processes must be involved." They further observe that ". . . the bulk of the energy release is due to an hitherto unknown nuclear process or processes (presumably again due to deuterons)." This technical note discusses the possibility of deuteron disintegration due to its polarization in the coulomb field of a target nucleus as an explanation of their observations.

DISCUSSION

Early in the study of nuclear reactions, it was observed that (D,p) reactions occur at deuteron energies well below the coulomb barrier of a target nucleus. Moreover, the cross sections are considerably larger than those for the corresponding (D,n) reactions.[4] These two observations are at odds with expectations based on the compound nucleus model, which suggests that there should not be reactions below the coulomb barrier and that neutron emission should predominate over proton emission from the compound nuclei formed. Oppenheimer and Phillips[5] explained this apparent anomaly based on the peculiar properties of the deuteron.

The deuteron is a loosely bound nuclear structure with a binding energy of 2.23 MeV only. This value can be calculated from

$$BE = [Z \cdot M(p) + N \cdot M(n) - M'] \times 931.5$$

or

$$BE = [Z \cdot M(\text{H}) + N \cdot M(n) - M] \times 931.5 \ ,$$

where

$M(p)$ = mass of proton

$M(n)$ = mass of neutron

M' = mass of bare nucleus

M = mass of neutral nuclide

$M(\text{H})$ = neutral mass of hydrogen.

Thus, for the deuteron,

$$BE(\text{D}) = \{[M(n) + M(\text{H})] - M(\text{D})\} \times 931.5$$
$$= 2.2246 \text{ MeV} \ ,$$

where[6,7]

$M(\mathrm{D}) = 2.01410179$ amu

$M(n) = 1.00866497$ amu

$M(\mathrm{H}) = 1.00782504$ amu.

This is actually determined experimentally from the threshold for the photodisintegration reaction of the deuteron into a proton and a neutron,

$$\gamma + \mathrm{D} \rightarrow p + n \ ,$$

and combined with the mass-spectrograph masses of hydrogen and deuterium to determine the neutron mass, since no accurate method for a direct measurement of the neutron mass is known.[8,9]

The deuteron binding energy is low compared with that of other nuclei: 8.48 for the triton, 7.72 for ^{3}He, 28.3 MeV for the alpha particle, 32.0 for ^{6}Li, 39.2 for ^{7}Li, and 7 or 8 MeV for the average particle in a nucleus. Table I compares this value of the deuteron binding energy to that of other nuclei.[9]

The deuteron is the only known two-body nuclear-bound system. There are no excited states of the deuteron that are stable with respect to decomposition. The absence of excited states of the deuteron, its low binding energy, and its large size (the neutron and the proton spend about one-half the time outside the range of the nuclear force) results from the weakness of the nuclear force when viewed in the context of its small range. Moreover, the charge distribution of the deuteron is very unsymmetric. Its center of mass and its center of charge do not coincide as they do in the alpha particle. A large separation of $\sim 4 \times 10^{-13}$ cm exists between the constituent proton and neutron, which actually spend most of their time outside the range of their attractive mutual force.[9]

DEUTERON INTERACTIONS

Because of the finite distance between the proton and neutron in the deuteron, when compressed in a metal lattice, one of these particles may reach the nuclear surface before the other. The nuclear interaction energies or the average binding energies per nucleon in the nucleus are much higher than the binding energy of the deuteron. As a result, the constituent of the deuteron that arrives at the nuclear surface first is quickly separated from its partner.

TABLE I

Binding Energy of Typical Nuclei

Nuclide	Binding Energy (MeV)
^{2}D	2.23
^{3}T	8.48
^{3}He	7.72
^{4}He	28.30
^{6}Li	32.00
^{7}Li	39.20
^{9}Be	1.60
Average per nucleon	7 to 8

In an Oppenheimer-Phillips process,[5] the coulomb field of the nucleus polarizes the deuteron. As the deuteron approaches the nucleus, its neutron end is turned toward the nucleus, the proton end being repelled by the coulomb force. Because of the relatively large neutron-to-proton distance in the deuteron, the neutron would reach the surface of the nucleus while the proton is still outside most of the coulomb barrier. Because of the low binding energy of the deuteron (2.23 MeV), the action of the nuclear force on the neutron tends to break up the deuteron, leaving the proton outside the potential barrier, according to the "highly exothermic[5]" reaction:

$$X(Z,A) + \mathrm{D} \rightarrow [C(Z,A+1)] + p \ , \qquad (3)$$

where the compound nucleus $[C(Z,A+1)]$ may be stable or could decay by the emission of some other particle or by gamma emission. Nucleus X could be a palladium isotope, an isotope of lithium from the electrolytic solution, or another deuteron confined in the palladium lattice. If nucleus X is a deuteron, we obtain Eq. (1), with tritium as a product nucleus in addition to hydrogen. However, from the perspective of this process, what is happening can be characterized as disintegration of the deuteron rather than a fusion of the two deuterons. Interestingly, it would be closer to a fission process than a fusion process. It could also be regarded as a neutron capture process. Moreover, since it is expected to occur under nonequilibrium conditions, it may be closer to localized hot fusion than to cold fusion.

If the proton penetrates the coulomb barrier and hits the target nucleus first, the ensuing reaction would be

$$X(Z,A) + \mathrm{D} \rightarrow [C'(Z+1, A+1)] + n \ . \qquad (4)$$

Again, if nucleus X is a deuteron, then reaction (2) would ensue with a neutron and a ^{3}He nucleus as a result.

At relatively low energies, the neutron capture reaction of Eq. (3) is preferred to the proton capture reaction of Eq. (4). If nucleus X is a deuteron, the charged-particle reaction of Eq. (1) is favored over the neutron reaction in Eq. (2). As a consequence, one would expect more heat generation and less neutron emission than a model assuming fusion reactions where the deuterium-deuterium (D-D) fusion reaction would have a 50% branching ratio to the proton and the neutron branches. A model of deuteron disintegration instead of D-D fusion would effectively favor the proton branch over the neutron branch and explain part of the experimental observations.

PALLADIUM INTERACTIONS

When nuclide X in Eq. (3) is an isotope of palladium, one must consider the different palladium isotopes. Table II shows the different palladium isotopes, their mass excess, their dominant radioactive decay modes, and their natural abundances. The atomic masses for all the isotopes, including the radioactive ones, are calculated from

$$M(\mathrm{amu}) = A + \Delta/931.481 \ ,$$

where Δ = mass excess = $M - A$ (MeV).

Figure 1 shows that the ^{106}Pd isotope has the lowest mass excess value and is correspondingly the most stable isotope with a natural abundance of 27.3 at.%. If we consider that the energetics of the neutron capture reaction are analogous to the (d,p) stripping reaction, then according to

TABLE II

Atomic Masses of Palladium Isotopes and Their Natural Abundances

Mass Excess, Δ (MeV)	Isotope	Atomic Mass (amu)	Natural Abundance, Decay Mode (at.%)	Q (MeV) (d,p)
−85.4281	^{101}Pd	100.90829	Electron capture	
−87.9259	^{102}Pd	101.90561	1.0	8.34
−87.4789	^{103}Pd	102.90609	Electron capture	5.40
−89.4005	^{104}Pd	103.90402	11.0	7.77
−88.4225	^{105}Pd	104.90507	22.2	4.87
−89.9135	^{106}Pd	105.90347	27.3	7.33
−88.3716	^{107}Pd	106.90513	β^-	4.30
−88.1566	^{107m}Pd	106.09536	Internal conversion	7.00
−89.5235	^{108}Pd	107.90389	26.7	7.21
−87.6065	^{109}Pd	108.90595	β^-	3.92
−87.4175	^{109m}Pd	108.90615	Internal conversion	6.58
−88.3352	^{110}Pd	109.90517	11.8	6.76
−86.0350	^{111}Pd	110.90782	β^-	3.37
−85.8650	^{111m}Pd	110.90764	Internal conversion	---

Evans[9]: " . . . the energetics of the stripping reaction are indistinguishable from those in which a compound nucleus is formed and subsequently dissociates." On this basis, we calculate the Q values of the neutron capture reaction in the palladium isotopes, as shown in Fig. 2. Note that all the values are positive, corresponding to exothermic reactions, and range from 3.37 to 8.34 MeV. This is to be compared to the value of 4.03 MeV for the neutron capture D-D reaction of Eq. (1). If the natural abundances of the stable palladium isotopes are accounted for, a weighted value for Q of 4.84 MeV can be estimated. This demonstrates that if the proposed model applies, one can expect further heat generation from neutron capture in the palladium isotopes. One would also expect the generation of some radioactive species in proportion to the ratio of neutron capture reactions in palladium to those occurring among the deuteron nuclei. The actuated palladium isotopes would create silver and then cadmium isotopes through decay by β^- emission. They could also decay to rhodium isotopes through β^+ emission.

OTHER REACTIONS

The proposed mechanism can also be applied to a nucleus that is capable of being polarized in the same way as a deuteron. Such a nucleus is the ^{3}He nucleus, which contains two protons and one neutron. On interaction with a deuteron, the following reaction could occur:

$$X(Z,A) + {}^3\text{He} \rightarrow [C''(Z+1, A+2)] + p \ . \qquad (5)$$

If we consider nucleus X to be a deuteron, we can write the equation as

$$\text{D} + {}^3\text{He} \rightarrow {}^4\text{He} + p \ . \qquad (6)$$

In fact, any ^{3}He generated by Eq. (2) would interact with the deuterium to produce ^{4}He, which is expected to be present in the discussed experiments to the extent of the occurrence of reaction (2). This deuteron disintegration reaction is equivalent to the D-^{3}He advanced fuel fusion cycle.[10,11] In a palladium lattice, it would be a neutronless, charged-particle reaction that would lead to the generation of heat, a favorable characteristic if such deuteron disintegration processes are further developed for power production.

Another interesting application, if the discussed process is experimentally verified, is the possibility of using ^{9}Be as a nucleus that possesses a relatively loose last neutron. In fact, the binding energy of the last neutron in the ^{9}Be nucleus is just 1.6 MeV. This can be calculated as follows:

$$\begin{aligned} BE({}^9\text{Be}) &= \{[M({}^4\text{He}) + M({}^4\text{He}) + M(n)] \\ &\quad - M({}^9\text{Be})\} \times 931.5 \\ &= 1.5734 \text{ MeV} \ , \end{aligned}$$

where[6,7]

$$M({}^4\text{He}) = 4.00260330 \text{ amu}$$

$$M({}^9\text{Be}) = 9.01218250 \text{ amu.}$$

This equation corresponds to the beryllium photodisintegration reaction:

$${}^9\text{Be} + \gamma \rightarrow {}^4\text{He} + {}^4\text{He} + n \ .$$

With the exception of deuterium and beryllium, the binding energy of the last neutron for other nuclei lies between 5 and 13 MeV (Ref. 9). If ^{9}Be is used, we can write a neutron capture reaction:

$$X(Z,A) + {}^9\text{Be} \rightarrow [C'''(Z,A+1)] + {}^4\text{He} + {}^4\text{He} \ . \qquad (7)$$

If deuterium is the target nucleus, which would occur with an experiment similar to the discussed experiment using a ^{9}Be electrode, the following reaction could occur:

$$\text{D} + {}^9\text{Be} \rightarrow \text{T} + {}^4\text{He} + {}^4\text{He} \ , \qquad (8)$$

which is a charged-particle neutronless reaction. We can even consider the possibility of using light water electrolysis instead of heavy water, leading to the reaction,

$$\text{H} + {}^9\text{Be} \rightarrow \text{D} + {}^4\text{He} + {}^4\text{He} \ , \qquad (9)$$

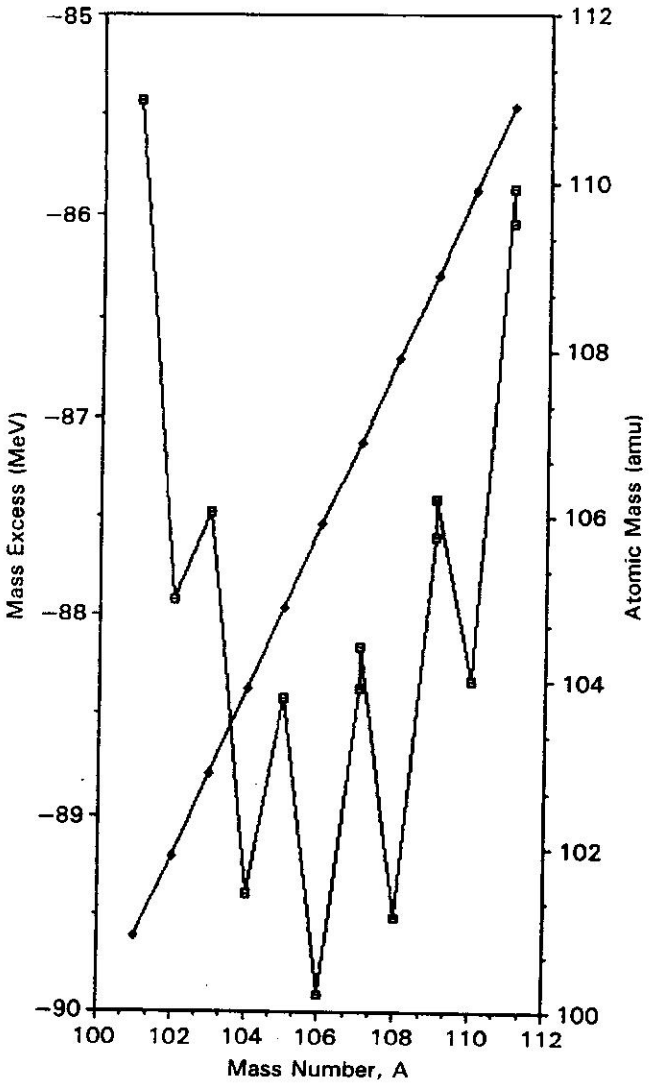

Fig. 1. Mass excess and atomic masses of the palladium isotopes.

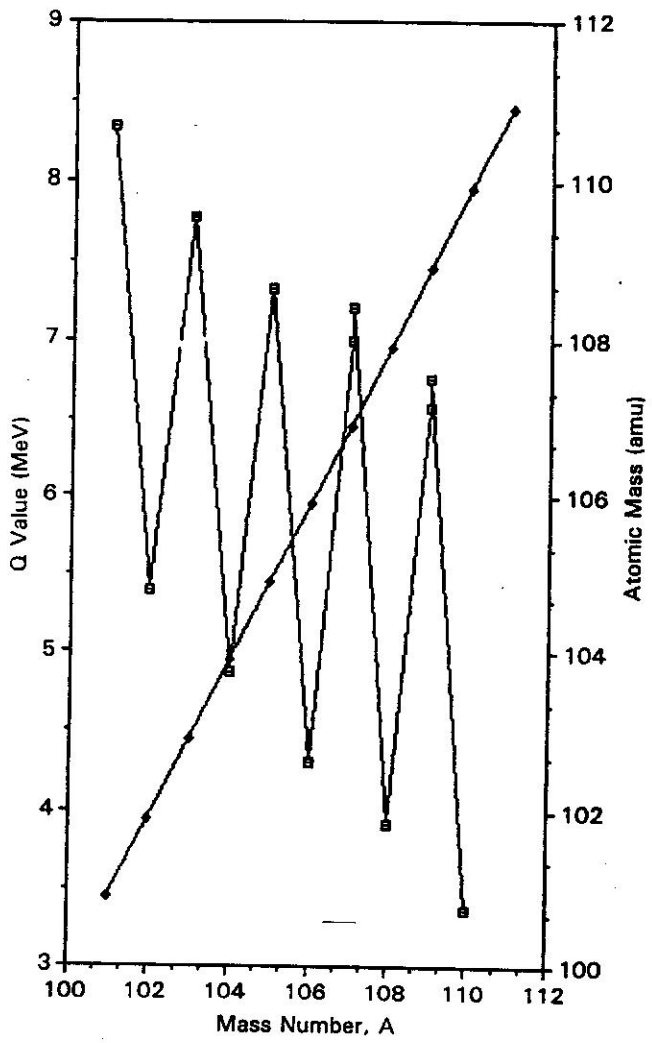

Fig. 2. Values of Q for the neutron capture reaction in palladium isotopes.

which is also a charged-particle reaction with deuterium as a product nucleus. Starting with the reaction in Eq. (9), the hydrogen isotope is gradually turned into a deuterium isotope, then eventually into a tritium isotope, while ^{4}He is produced.

CONCLUSIONS

A model based on deuteron disintegration due to its polarization in the coulomb field of a target nucleus, if verified experimentally, would favor charged-particle production over neutron production and provide an explanation of the reported energy release from electrochemically compressed deuterium in condensed matter.

Experimental verification of the occurrence of reaction (1) would concentrate on the detection of the product tritium and hydrogen nuclei. The production of neutrons would be expected to be suppressed to the level of the ratio of the occurrence of the proton capture reaction (2) to the neutron capture reaction (1). The verification of the possible occurrence of reaction (3) would depend on the detection of the ensuing radioactive species of the palladium isotopes. The presence of tritium in volcanic eruptions[2] would be construed as resulting from the deuteron disintegration reaction (1). On the other hand, the presence of ^{3}He in metals[2] would result predominantly from the decay of the tritium produced from reaction (1) rather than from ^{3}He produced from reaction (2), according to the present model.

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Author's Note: After preparation of this technical note, it was brought to our attention that Peroni Paolo independently commented on the Oppenheimer-Philipps process as an explanation for the Fleischmann and Pons experiment in a note in *Nature*, **338**, 711 (Apr. 27, 1989).