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Research Article

Theoretical Study of the Transmutation Reactions

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Abstract

Transmutation reactions are studied from a theoretical point of view. An idea is proposed to explain the variations in the transmutation ability of different elements, especially the relative inertness of palladium compared to the other elements. Proposals are made in order to verify experimentally this explanation and to enhance the transmutation signal.

Keywords: LENR, Surface, Theory, Transmutation, WKB approximation

The Condensed Matter Nuclear Science has been studied for the last 26 years since the original work by Fleischmann and Pons [1]. While the cold fusion of two deuterium atom may be more important from the technological point of view, the transmutation reactions are scientifically more interesting. The existence of low energy transmutation reactions is intrinsically even more surprising than the cold (low energy) deuterium fusion, because the low tunneling probability (the Gamow factor) is supposed to suppress very effectively the transition rate with the increasing nuclear charge.

In this note, transmutation reactions will be studied theoretically. In what follows we shall assume that there is some kind of mechanism, which greatly enhances the apparently small tunneling probability. We will not make any restrictive assumptions about the actual mechanism, except just assuming that the mechanism *itself* is independent of the nuclear charge Z.

The reported experiments show a very large variety in the transmutation products [2,3]. Not only the products, but also the methods and materials by which transmutation had been found, have a large variety [4,5]. Among all the published transmutation studies the most prominent are those by Iwamura et al. [6,7]. The interpretation of the experimental results allowed them to propose the existence of the following reactions:

$$4\,\mathrm{D} + {}^{133}_{55}\mathrm{Cs} \rightarrow {}^{141}_{59}\mathrm{Pr} + \ 50.49\ \mathrm{MeV} \tag{1}$$

and

$$6\,\mathrm{D} + {}^{138}_{56}\mathrm{Ba} \rightarrow {}^{150}_{62}\mathrm{Sm} + \ 67.61\ \mathrm{MeV}. \tag{2}$$

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It is worth noting that the corresponding reaction of palladium (e.g. ${}^{108}_{46}\mathrm{Pd}$)

$$4\,\mathrm{D} + {}^{108}_{46}\mathrm{Pd} \rightarrow {}^{116}_{50}\mathrm{Sn} + 54.55\ \ \mathrm{MeV} \tag{3}$$

has not been found, although palladium is present far more extensively than the small amount of the deposited cesium or barium. In some other transmutation studies evidence has been found also of transmutation reactions of palladium itself. However, it can be taken granted that the transition rates for the transmutation reactions of palladium are several orders of magnitude smaller than those of cesium or barium.

Intrinsically one may assume that the rates of the transmutation reactions depend prominently on the nuclear charge Z (through the tunneling probability) and the energy released Q. In both of these respects the palladium reaction should be more copious than for example the corresponding cesium reaction.

If we consider a bare nucleus, the transition rate of the deuterium absorption can be obtained by the semi-classical WKB approximation, giving the leading behavior of the probability:

$$P_1 \sim \mathrm{e}^{-\int_0^r 2\sqrt{\frac{2\alpha\mu c Z}{\hbar x}}\mathrm{d}x} \sim \mathrm{e}^{-4\sqrt{2\alpha\mu c Z r/\hbar}}, \tag{4}$$

where r is the equilibrium distance of the deuteron from the nucleus, μ is the reduced mass of the deuteron and the heavy nucleus, and α is the electromagnetic fine structure constant ($\approx 1/137$). Equation (4) is the static counterpart of the Gamow factor that corresponds to a collision of a charged deuterium projectile and a target nucleus. If we consider a transition, where four deuterons are absorbed simultaneously, Eq. (4) is replaced by

$$P_4 \sim \ \mathrm{e}^{-16\sqrt{2\alpha\mu c Z r/\hbar}}. \tag{5}$$

Taking into account the modification caused by the electron screening, Eq. (5) is replaced by

$$P_4 \sim \mathrm{e}^{-8\int_0^r \sqrt{2\mu V(x)/\hbar^2}\mathrm{d}x} \ \sim \mathrm{e}^{-8\int_0^r \sqrt{\frac{2\alpha\mu c}{\hbar}\times\frac{\mathrm{Z}-\frac{4\pi x^3}{3}\rho_0-\sum_i\int_0^x \mathrm{d}^3x\,\rho_{\mathrm{i}}(x)}{x}}\mathrm{d}x}, \tag{6}$$

where ρ_0 is the number density of the free electron gas in metal (including the electrons of the loaded deuterium atoms). $\rho_{\mathrm{i}}(x)$ are the electron probability functions that in the first approximation can be assumed to be the electron probability functions of the hydrogen atom with the appropriate effective nuclear charge for different energy levels [8,9]. The inclusion of the charge screening by the electrons does not change the fact that the transition probability depends very effectively (i.e. exponentially) on the distance of the deuterons from the nucleus.

These tunneling probabilities shown in Eqs. (5) and (6) are of course incredible small numbers. However, we shall assume that there is some kind of yet unknown CMNS mechanism enhancing these extremely small numbers, and we shall explore here the differences between different elements.

Actually the dependence on the distance r is more important than the dependence on the nuclear charge in Eq. (6). If in some configuration the deuteron is lying (or be pushed) more close to the nucleus, the transition rate increases substantially, which may then allow the enhancing mechanism to compensate the extremely low tunneling probability. These shorter distances can be achieved if there are atoms or molecules, which are either neutral or have the effective charge less than the elementary charge, in the surface region. There is a simple situation, where one can assume this to occur. While the palladium atoms in the lattice are ions as they have given an electron in the surrounding electrons gas, the base metal atoms deposited on the surface can be assumed to be mostly oxidated, and are then part of neutral entities. Especially this is true for alkali metals or alkaline earth metals. Hence the deuterons lie more close to those base metal atoms than the palladium atoms and therefore the base metal atoms transmute more easily.

Few percent reduction of the distance in Eq. (6) increases the probability factor by many orders of magnitude. Of course, these probability factors remain still extremely small numbers, because it is not possible reduce the distances between the deuterons and the absorbing nucleus by chemical means enough to cause the nuclear reaction directly.

However, the increase of the probability factor by the reduction of the distance may be enough that the enhancing mechanism can compensate that small factor.

Of course, the oxidation and the whole surface chemistry are far more complicated than the oversimplified picture above. However, the above idea may give a reasonable picture on the relative transmutation ability of different elements qualitatively.

If this idea is correct, one can assume sodium to be an element that can be transmuted more easily than cesium or barium for three reasons. Firstly the energy released in the corresponding reaction

$$4\,\mathrm{D} + {}^{23}_{11}\mathrm{Na} \rightarrow {}^{31}_{15}\mathrm{P} + 67.45\ \mathrm{MeV} \tag{7}$$

is larger compared to Eq. (1). Also the nuclear charge of the sodium is very much smaller. Sodium is also chemically very active and will be oxidated very rapidly when exposed to the air. Therefore, it would be profitable to check experimentally, whether sodium will be transmuted in the gas permeation experiment along Eq. (7), or by some other (more rapid) transmutation reaction.

Another application of this idea is to embed just below the surface some nonmetal element, which will stay as neutral (or almost neutral) atoms in the palladium lattice. Experiments should be done to see whether transmutation signal can be increased in such a manner. However, one has to ensure that the concentration of the deposited or embedded element remain rather low so that those impurities do not prevent the concentration of the deuterium in the nuclear active environment (NAE) to exceed the critical value needed.

The proposed experiments would give more insight for the further theoretical studies and they can be used to restrict possible theoretical explanations (mechanism and NAE).

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