ABOUT DEUTERIUM NUCLEAR REACTION RATE IN CONDENSED MATTER

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Abstract

The Coulomb barrier penetrability of two approaching nuclei is computed in the frame of the W.K.B approximation. A simple model for describing the screening effect of the Coulomb nuclear barrier by the high electron concentration in condensed matter is presented. The nuclear reaction rate of the hydrogen isotope nuclei, trapped in a metallic lattice is assessed, both for the unscreened and for the screened Coulomb barrier, averaged by the Maxwell distribution. The model predicts that, in certain circumstances, for porous or grainy samples, which are subject to a negative electric potential and are heavily loaded with deuterium, very low nuclear radiation level might be detected. The results are discussed in connection with some of the very successful experiments like Miley’s metal-coated spheres.

Introduction

The announcement of Drs. Fleischman and Pons, early in March 1989, that nuclear fusion reaction between deuterium nuclei occurred at the room temperature [1] marked the beginning of a long saga. Thousands of experiments, of an overwhelming variety [2], starting with the simple one to reproduce the electrolysis experiment and ending with complex multilayer cathodes, have been performed all over the world, in the effort to understand all the odd aspects of the phenomena, whose existence is no longer questioned [3]. Many articles like [4], [5], [6], [7], point out that nuclear transmutations should be associated with this peculiar behaviour. The possibility of two nuclei to undergo a nuclear reaction in condensed matter is analysed further on.

The Nuclear Reaction Rate

For the beginning the volume nuclear reaction rate of the bare deuterium nuclei trapped in a metallic lattice is assessed, in a simple manner, considering that half of them are incident toward the others /8/:

$$R = \int dR = \frac{n^2{}_d}{4} \cdot s^0 \cdot \int_0^\infty P(v) \cdot P_M(v) \cdot v \cdot dv \quad (1)$$

where P(v) is Coulomb barrier penetration probability, $P_M(v)$ is the Maxwell distribution of the deuterons, v is the velocity, and σ^0 the pre-exponential factor, as described in [8], where:

$$\sigma^0 = 10^{-24}\ cm^2 \text{ for reactions } (a,b)\ and\ \sigma^0 = 10^{-30}\ cm^2 \text{ for } (a,g) \quad (2)$$

The reaction rate has been integrated using a computer programme written for this purpose. A value of the magnitude 10^{-211} reactions $/m^3 \cdot s$ has been found for the bare deuterium nuclei. This cvasi-null reaction rate is obviously not detectable by any of the available procedures; it is considered that the lower detectable limit for a nuclear reaction rate is $10^{-3}\ cm^{-3}.s^{-1}$ [8].

The Effect of the Electron Screening

The approaching deuterium nuclei trapped in a metallic lattice will move towards each other in a rich negative charge environment caused by the cvasi - free electrons in the conduction energy band. A simple model to describe the screening effect of the Coulomb barrier caused by the electrons in a metal is presented.

The Debye length l_D in a plasma is the size of the possible displacement of a layer of electrons which moves aside from the layer of positive ions as the result of a fluctuation and can be assessed by equalling the electric potential energy to the average thermal kinetic energy. It can be found [9] that:

$$l_D = \sqrt{\frac{\varepsilon_0 kT}{n_0 e^2}} \quad (3)$$

where k is the Boltzman’s constant, e the electric charge of the electron, n_0 the “free” electron concentration and ε_0 is the permittivity of the free space.

The potential used for the screened Coulomb barrier, inspired from [10], is plasma - like screening potential, where the screening parameter is the Debye length. The screened Coulomb potential between two approaching deuterons will be:

$$V(r) = \frac{e^2}{4\pi\varepsilon_0 r} \cdot \exp\left(-\frac{r}{l_D}\right) \quad (4)$$

where r is the distance between the nuclei and l_D is the Debye length, given by [9]:

$$l_D = \sqrt{\frac{\varepsilon_0 kT}{n_0 e^2}} \quad (5)$$

where k is the Boltzman’s constant, e the electric charge of the electron, n_0 the “free” electron concentration and ε_0 is the permittivity of the free space. The effect of the increasing the “free” electron concentration is to reduce the Debye length and therefore enhance the screening effect and increase the nuclear reaction rate.

The penetration probability is strongly enhanced from 10^{-500} at thermal kinetic energy for the bare deuteron, to 10^{-38} for a normal concentration of $n_0 = 6{,}25\cdot10^{28}$ $m^{-3,}$ which is the “free” electron concentration in palladium.

It is worth noticing that that when a metal is loaded with hydrogen isotopes to a loading ration of one deuterium atom to one metal atom, as it is reported in many papers on the subject [1], because the sample is electrically neutral, the concentration of “free” electrons is approximately double, so a value of $n_0 = 1{,}25\cdot10^{29}$ m^{-3} should normally be considered in the calculations. Also it should be noted that higher “free” electron concentration zones can exist near the surface of a metal which is the subject of a negative electric potential, due to the capacitor effect, as is presented in [11, 12].

The nuclear reaction rate of the deuterons encountering a screened electric potential in a metal’s lattice, is assessed in the same manner as for the unscreened Coulomb potential, using (1), and the results are presented in table 1.

n, m^{-3}	$6.25\cdot10^{28}$	$8\cdot10^{28}$	$1.\cdot10^{29}$	$1.25\cdot10^{29}$	$2\cdot10^{29}$
R, $m^{-3}\cdot s^{-1}$	$1.64\cdot10^{-6}$	$3.12\cdot10^{-6}$	$2.94\cdot10^{-2}$	2.11	$8.32\cdot10^{3}$

Table 1

Discussions

The computed values of the nuclear reaction rate in condensed matter presented in the table reveal that the rate increases very fast with the “free” electron concentration, actually it increases 10^6 times when the electron concentration doubles it’s value from the normal one. Above all, the nuclear reaction rate predicted by this model can reach high enough values to be detectable, in certain regions where the electron concentration is high enough.

The model strongly overestimates the nuclear reaction rate, because the screening parameter is very small and because it uses an approximation for the low energy reaction cross section, as presented in (2), therefore the results presented here should be considered only as a simple estimation of the reaction rates. With this in mind, it is worth noticing that the nuclear reactions at very low energies, in condensed matter, should be considered in a completely different manner than in free space between heavy ions, and that, in certain circumstances, for porous or grainy samples which are subject to a negative electric potential and are heavily loaded with deuterium, very low nuclear radiation level might be detected [11, 12]. Such regions with high electron concentrations can represent a significant part of the cathode volume in systems like the Miley – Patterson metal coated beads, either simple coated, represented by the layer near the surface where the excess negative electric charge is located in, or the multi-layer beads, where a region with high electron concentration exists at the contact between different metals due to the different Fermi levels [4 – 7].

The very low value of the nuclear reaction rate could stand for the very low tritium and neutron levels detected in some experiments, but not for the excess energy which accompanied the loading of deuterium in palladium or titanium, in many experiments [2].

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