On a Mechanism of the Electrochemically Induced Nuclear Fusion II

Hideo KOZIMA, Kunihiko HASEGAWA*, Hideo SUGANUMA*, Sumio ŌE**
Kunio SEKIDO, Masaharu FUJII, Masaharu YASUDA and Takami ONOJIMA

Department of Physics, Radiochemistry Research Laboratory and*
*Department of Chemistry***
Shizuoka University, Shizuoka 422

(Received July 21, 1989)

Synopsis

A numerical estimate of a fusion cross section for the electrochemically induced nuclear fusion is presented according to the mechanism proposed in the previous paper[1] and using the WKB approximation. To fit the data with experimental results, possible factors to enhance the fusion probability are speculated.

1. Introduction

As is explained in the previous paper[1], Jones et al.[2] detected neutrons with an energy 2.5 MeV liberated in a reaction

$$d + d \rightarrow {}^3He + n \tag{1}$$

in a process of D_2O electrolysis with Pd (Ti) cathode. The results are remarkable with extraordinary large fusion cross section and other features explained in I. The low energy fusion cross section between deuterons is expressed as follows[3]:

$$\sigma(E) = E^{-1}S(E)\exp(-31.39E^{-1/2}) \tag{2}$$

where $S(E)$ is an astrophysical factor (in keV-b) and E is the center of mass energy in keV. $S(E)$'s for d-d reactions are expressed as follows: for D (d, n) ^{3}He,

$$S(E) = 49.7 + 0.170E + 2.12 \times 10^{-3}E^2, \tag{3}$$

and for D (d, p) T,

$$S(E) = 52.9 + 0.019E + 1.192 \times 10^{-3}E^2. \tag{4}$$

As is seen from these equations, the cross sections depend very strongly on the mutual energy.

2. Numerical Calculation.

According to a mechanism proposed in I , we will calculate a fusion cross section for deuterons occluded in Pd cathode in the process of D_2O electrolysis.

A probability of the nuclear fusion of two deuterons is considered to be proportional to the probability of coexistence (mutual distance $r = 0$) of the two nuclei. To estimate the relative value of the fusion probability according to the mechanism proposed in I , we calculated a value of the wave function $\psi_{\varkappa,E}(x)$ describing relative behavior of the two deuterons at $x = 0$ using the WKB approximation. Here, E is the relative energy and $\varkappa$ is a parameter defined below. The interaction potential was taken as

$$V(x) = e^2 \exp(-\varkappa x)/x, \tag{5}$$

where $\varkappa$ is a parameter describing an effective screening radius $\lambda = \varkappa^{-1}$ in the metal for an occluded deuteron d* explained in I .

In the calculation, the WKB approximation was used throughout this paper irrespective of the mutual energy. The wave function in this approximation is given as follows ;

$$\psi_{\varkappa,E}(x) = \text{Const.}\,(\Pi(x\,;\varkappa,E))^{-1/2} \exp\left\{ -\int_{x}^{x_0(\varkappa,E)} \Pi(x\,;\varkappa,E)\,dx \right\} \tag{6}$$

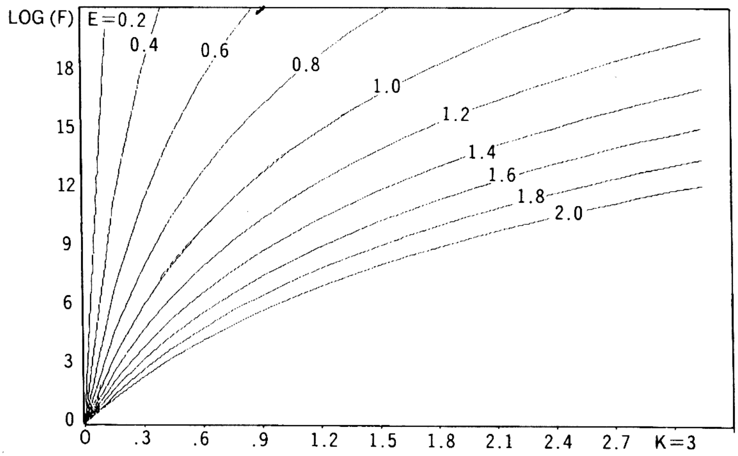
where

$$\Pi(x\,;\varkappa,E) = \left\{ 2\,(m_d/m_e)\,(\exp(-\varkappa x)/x - E) \right\}^{1/2} \tag{7}$$

in the atomic units ($h/2\pi = e = m_e = 1$). $x_0(\varkappa, E)$ is a value of x where the function Π becomes zero.

The results of numerical calculations are shown in Figs. 1 and 2. In Fig. 1 (a), values of $F(\varkappa, E) \equiv \psi_{\varkappa,E}(0)/\psi_{0,E}(0)$ is plotted as a function of $\varkappa$ with a parameter E (mutual energy). In Fig. 1 (b) F^2/E is plotted as a function of $\varkappa$. From this figure, it is seen that for a value of $\varkappa = 3$ (i. e. $\varkappa = 3/a_H$, where a_H is the Bohr radius of the hydrogen atom) and $E = 1$ (i. e. $E = 27$ eV), the value of $F^2/E \simeq 10^{45}$. This quantity might be taken as a measure of a relative probability of the d-d fusion in a screened Coulomb potential to that in the pure Coulomb potential for a fixed energy E. The latter case (pure Coulomb potential) expresses the situation we meet in the case of plasma fusion of deuterons.

In Fig. 2 (a) , values of $G(\varkappa, E) = \psi_{\varkappa,E}(0)/\psi_{\varkappa,1}(0)$ is plotted as a function of E with a parameter $\varkappa$, $G(0,E)$ is the relative value of the probability amplitude finding two deuterons with energy E interacting through the pure Coulomb potential in the same position. In Fig. 2 (b), G^2/E is plotted as a function of E. This quantity might be taken as a measure of a probability of the d-d fusion with an energy E relative to that with unit energy for a fixed $\varkappa$. From this figure, it is seen that for a value of $\varkappa = 0$ and $E = 3.7$ (100 eV), $G^2/E \simeq 10^{49}$. So, comparing G^2/E and F^2/E we can estimate the effect of



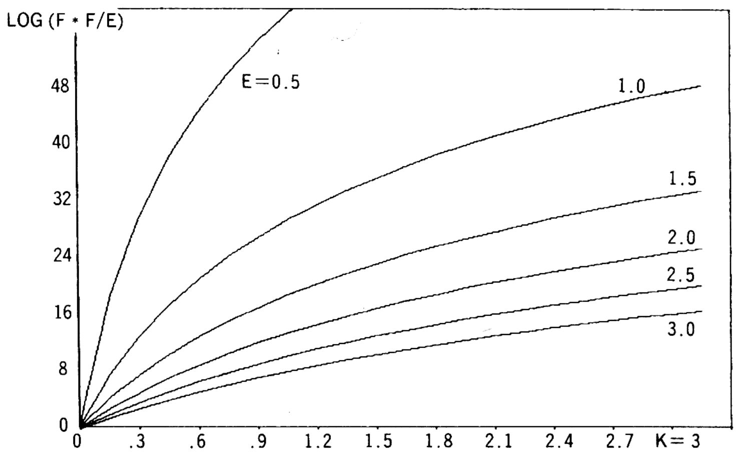
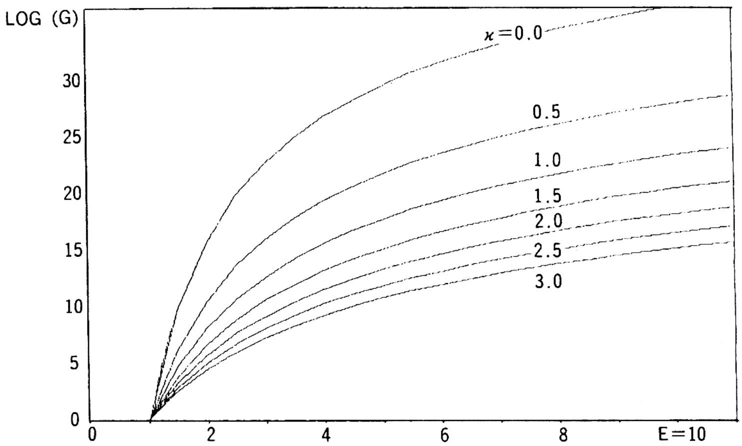


Fig. 1 (a) Relative value of the coincidence probability F of two deuterons interacting with a screened Coulomb potential is plotted as a function of the screening constant κ with a parameter E (mutual energy). The standard is taken at $\kappa=0$. The WKB approximation is used in the calculation.

(b) Relative value of the fusion probability F^2/E is plotted as a function of κ with a parameter E.



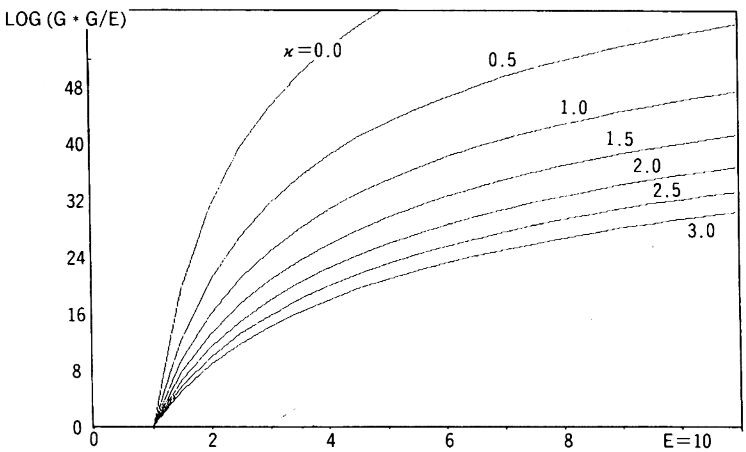


Fig. 2 (a) Relative value of the coincidence probability of two deuterons interacting with a screened Coulomb potential G is plotted as a function of the mutual energy E with a paramethr $\varkappa$. The standard is taken at $E=1$ (in a. u.).
(b) Relative value of the fusion probability G^2/E is plotted as a function of E with a parameter $\varkappa$.

the screening potential in terms of the effect of the mutual energy.

The fusion probability depends also on the number of deuteron encounters in a unit time. In the case of the electrochemically induced fusion, the number of encounters per unit time and volume is αnN, where α is an enhancement factor accounting the 'channel' effect for the deuteron motion in the metal. N is the density of deuterons in the metal and n is the density of deuterons flowing into the metal per unit time and unit area.

In the case of the plasma fusion, number of encounters is $v\nu^2$, where ν is the deuteron density in the plasma and v is the average mutual velocity of deuterons. Therefore, $v\nu^2 G^2/E = (2/m_d)^{1/2}\nu^2 G^2/E^{1/2} = 43\nu^2 G^2/E^{1/2}$ (in a. u.) $= 10^{79}$ for a plasma with $\nu = 10^{16}\text{cm}^{-3}$ and $E = 3.7$.

On the other hand, the fusion cross-section σ_{d-d} at mutual energy of 100 eV (1 keV) is estimated to be about 10^{-41} (10^{-12}) barns by an empirical formula for the low-energy fusion cross section[3]. Therefore, for the plasma fusion, the nuclear reaction occurs about $7 \times 10^{-3}\text{cm}^{-3}\text{s}^{-1}$ at a mutual energy of 100 eV. This estimation shows extremely strong dependence of the fusion cross section on the mutual energy. So, if we can imagine some mechanisms to accelerate deuterons in the metals, we can get easily reasonable values of fusion probabilities to fit experimental data.

In the case of the electrochemically induced fusion for the density N of 4×10^{22} (maximum density of occluded deuterons in Pd) and n of $6 \times 10^{16}/\text{s}\cdot\text{cm}^2$ (a current of 1 mA/cm^2) with energy of 27 eV, $\alpha nNF^2/E \simeq 10^{79}$ ($\simeq 10^{-2}\text{cm}^{-3}\text{s}^{-1}$ fusions) with $\alpha = 4 \times 10^5$ and $\kappa = 3.0$. (This value of α corresponds to a channel of the radius r_0 at the center of four Pd ions in the fcc lattice where r_0 is the range of the nuclear force and is assumed as 2.8×10^{-13} cm.) Thus, according to our model, the electrochemically induced fusion with above parameters occurs with the same probability to the plasma fusion with the above condition. This is a remarkable result.

3. Discussion

We have not discussed an effect of the metal surface at all. In the process of the occlusion of deuterons, surface condition must play very important role. In the surface region and around defects, the density of d* particle will be very large above the average value. So, the surface and the defects on the surface and in the body will play important role in the fusion process. Those factors will work favorably to the fusion reaction. Once a fusion reaction occurs, it will start the avalanche of the fusion in the concentrated region. This situation differs from that in the plasma. Not considering those effects, possibility and difficulty of the control of the fusion process and the detection of neutrons liberated in the electrochemically induced fusion (1) are understood from the above estimation.

Though the consideration has confined on the fusion induced in the electrochemical process, it is possible to occur the fusion in other situations. For instance, if a process occurs by chance (due to an accidental strong field or the muon catalyzed mechanism) in or on a metal saturated with occluded deuteron, the energy liberated by the process stirs d* particles and many fusion reactions will occur almost at the same time. Really, some news had reported neutron burst in the deuteron occluded titanium powder. Though we do not have details of the experiments, those events might be explained with the mechanism proposed in this paper.

We have to remember limitations of our treatment. The assumptions that the fusion probability is proportional to $|\psi(0)|^2$ and is inversely proportional to the initial energy are not exact. Though we made those somewhat ambiguous assumptions for simplicity, the estimate given here suggest that the electrochemically induced nuclear fusion is a probable one and should not be denied without thorough investigation.

The most controversial point of our treatment will be the assumption of the mutual potential (5) with a large value of κ and the introduction of enhancement factor α. These assumptions depend on the electronic structure of an isotopic hydrogen nucleus in the palladium (and similar) metal. It is not well known about the electronic structure of an unstable deuteron in those metals. So, it might be permissible to assume the mutual interaction potential of two deuterons in Pd as that given in (5). The value of κ, however, is rather arbitrary. $\kappa = 1$ is a reasonable value for a pair of deuterons almost at rest. $\kappa = 3$ or larger value will be expected for a pair of mutually moving d* particles due to effects of many-electron interaction and also of lattice vibration which we did not consider here. A microscopic justification of these assumptions are problems of the future work.

Acknowledgements

The authors would like to express their thanks to Profs. T. SUZUKI of Shizuoka University and Y. FUKAI of Chuo University for their valuable discussions during this work.

References

1) KOZIMA, H. (1990) On a Mechanism of the Electrochemically Induced Nuclear Fusion, *Rep. Fac. Science. Shizuoka Univ.*, **24**, 19-21 (1990). This paper will be referred as I hereafter.

2) JONES, S. E., PALMER, E. P., CZIRR, J. B., DECKER, D. L., JENSEN, G. L., THORNE, J. M., TAYLOR, S. F. and RAFELSKI, J. (1989) Observation of Cold Nuclear Fusion in Condensed Matter, *Nature,* **338**, 737-740.

3) KRAUSS, A., BECKER, H. W., TRAUTUETTER, H. P. and ROLFS, C. (1987) Low-Energy Fusion Cross Sections of D+D and D+^{3}He Reactions, *Nuclear Phys.*, **A465**, 150-172.