Mechanism of Cold Nuclear Fusion in Palladium

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Abstract

A new interpretation of cold nuclear fusion at the center of the boson cluster was given by R.T.Bush et al. The modified theory is given in this paper by adding the effect of screened d-d repulsion. Tunneling probability and power density of cold nuclear fusion in palladium are obtained, and the role of screening effect is found to be very important.

1. Introduction

In 1989, Fleishman and Pons et al [1] reported experimental results suggesting a cold nuclear fusion in palladium. And also in 1989, Jones et al [2] reported similar results. In 1991, we have pointed out the importance of electronic screening around deuteron (d) and obtained d-d pair potential with taking into account the non-linear screening effects [3]. Bush et al [4] have given another approach in 1990 by using the concept of symmetry force for boson cluster, and obtained the transmissivity of tunneling and power density generated from d-d nuclear reaction at the center of the cluster. According to their theory, attractive symmetry force supplies kinetic energy to d and this raises the transmissivity of tunneling through the Coulomb barrier. In the present work, we consider that two forces are effective to d. One is symmetry force and the other is d-d repulsive force. This means that repulsive potential reduces the tunneling effect, however electronic screening around d seems to decrease this reduction. Therefore, linear screened, i.e. Thomas-Fermi, and non-linear screened [3] potentials are tried to use for the calculation of transmissivity and power density as a function of the number of d's in a cluster.

2. Kinetic Energy

As in ref.[4], d's in metals perform as identical bosons and tend to make clusters. The attractive force effective to them is called symmetry force, and it is written as

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$$F_s(R) = -\Omega R^3 , \quad (1)$$

where Ω is a coupling constant and R is a radius of the N boson cluster, which is determined by using degenerate radius r_0 as

$$\frac{4}{3}\pi R^3 = N\frac{4}{3}\pi r_0^3 . \quad (2)$$

The coupling constant is given by assuming that attractive symmetry force and repulsive force between two bosons are balanced when the distance between them is r_0 as

$$\Omega R_0^3 = -[\frac{d}{dr}V(r)]_{r=r_0} , \quad (3)$$

where R_0 is the radius of two boson cluster and $V(r)$ is the repulsive potential. The value of degenerate radius r_0 is given in ref.[4] as r_0=0.23A.

When a d moves towards the center of the cluster under the effects of force f, kinetic energy E_k is supplied, which is expressed as

$$E_k = \int_R^0 f(R)dR . \quad (4)$$

In eq.(4), Bush et al [4] assumed that only symmetry force is effective and f was written as

$$f(R) = F_s(R) , \quad (5)$$

which gave

$$E_k = \frac{1}{4}\Omega R^4 . \quad (6)$$

In our treatment, we assume that not only symmetry but also repulsive forces are effective, therefore f is expressed as

$$f(R) = F_s(R) + \frac{d}{dR}(NV(R)) , \quad (7)$$

which gives

$$E_k = \frac{1}{4}\Omega R^4 - NV(R) . \quad (8)$$

If Coulomb repulsion is chosen as V, the second term of eq.(8) is so large that E_k is always negative. However, if screened repulsion is chosen, E_k becomes positive for large N, and the tunneling effect is catalyzed.

3. Transmissivity and Power Density

If a d with kinetic energy E_k penetrates the repulsive barrier ($r_n < r < r_1$) and reachs the nuclear force region ($r < r_n$), the tunneling point r_1 depends on the shape of the repulsive potential and the values of the kinetic energy and taransmissivity of this tunneling are written as

$$E_k = V(r_1) , \quad (9)$$

and

$$T = exp(-2G) , \quad (10)$$

where the formula of G is well known [5] as

$$G = \frac{\sqrt{2m}}{h}\int_{r_n}^{r_1}(V(r) - E_k)^{1/2}dr \ . \tag{11}$$

In the nuclear force region, the d-d nuclear reaction to produce He^4 is catalyzed, and the power generated from this reaction can be calculated by using the transmissivity T. This gives the power density p as

$$p = \frac{\nu n N T E_1}{2V_a} , \tag{12}$$

where ν, n, E_1, and V_a mean frequency factor, average number of d's injected per interstitial site, released energy from this nuclear reaction and volume of a unit cell of fcc palladium, respectively, and the values of them are given in ref.[4] as $\nu=10^{14}s^{-1}$, $n=1.2$ and $E_1=38.4\text{x}10^{-13}J$. The value of lattice constant of fcc palladium is $a=3.89A$, and this gives $V_a=a^3/4$. We regard the radius r_n of nuclear force region as $10^{-5}A$.

4. Results

For the case of using the Thomas-Fermi screening potential as a repulsion, we obtain

$$\Omega = \frac{(kr_0+1)e^2}{2r_0^5}exp(-kr_0) , \tag{13}$$

and

$$\frac{e^2}{r_1}exp(-kr_1) = \frac{(kr_0+1)e^2}{8r_0}exp(-kr_0)N^{4/3} - \frac{e^2}{r_0}exp(-kr_0N^{1/3})N^{2/3} , \tag{14}$$

where k is a screening constant and the value is given in ref.[3] as $k=1.71A^{-1}$. The value of r_1 is obtained by solving eq.(14) numerically. The results for Transmissivity T and power density p are shown in Table 1. In this case, it is found that E_k is negative for $N<8$ and p is small even for large N.

Table 1. Transmissivity T and power density p as a function of N by using Thomas-Fermi screening potential.

N	$r_1(A)$	$E_k(Ryd.)$	T	$p(W/cm^3)$
8	0.85	0.3	$8.3\text{x}10^{-136}$	$1.0\text{x}10^{-110}$
10	0.27	2.5	$6.6\text{x}10^{-82}$	$1.0\text{x}10^{-55}$
12	0.16	5.0	$8.6\text{x}10^{-64}$	$1.6\text{x}10^{-36}$
13	0.13	6.4	$4.9\text{x}10^{-58}$	$9.9\text{x}10^{-32}$
14	0.11	7.8	$1.9\text{x}10^{-53}$	$4.1\text{x}10^{-27}$
15	0.095	9.3	$1.1\text{x}10^{-49}$	$2.5\text{x}10^{-23}$
16	0.084	10.8	$1.5\text{x}10^{-46}$	$3.8\text{x}10^{-20}$
17	0.074	12.4	$7.3\text{x}10^{-44}$	$1.9\text{x}10^{-17}$
18	0.066	14.1	$1.5\text{x}10^{-41}$	$4.4\text{x}10^{-15}$
19	0.060	15.8	$1.7\text{x}10^{-39}$	$5.0\text{x}10^{-13}$
20	0.054	17.5	$1.1\text{x}10^{-37}$	$3.4\text{x}10^{-10}$

For the case of using non-linear screened d-d pair potential [3], Ω, r_1 and G are obtained through numerical differentiations and integrations. The results for T

and p are shown in Table 2. In this case, E_k is always positive and p is large enough for N>16.

Table 2. Transmissivity T and power density p as a function of N by using non-linear screened d-d pair potential [3].

N	$r_1(A)$	$E_k(Ryd.)$	T	$p(W/cm^3)$
2	0.26	0.7	$1.0x10^{-80}$	$5.6x10^{-51}$
4	0.16	3.9	$5.6x10^{-60}$	$3.5x10^{-34}$
6	0.090	7.7	$4.5x10^{-49}$	$4.3x10^{-23}$
8	0.064	11.6	$1.9x10^{-42}$	$2.4x10^{-16}$
10	0.053	15.6	$1.7x10^{-38}$	$2.7x10^{-12}$
11	0.049	17.7	$8.6x10^{-37}$	$1.5x10^{-10}$
12	0.046	19.7	$2.5x10^{-35}$	$4.6x10^{-9}$
13	0.043	21.9	$7.3x10^{-34}$	$1.5x10^{-7}$
14	0.040	24.1	$1.7x10^{-32}$	$3.7x10^{-6}$
15	0.038	26.1	$2.6x10^{-30}$	$6.0x10^{-5}$
16	0.035	28.3	$4.4x10^{-30}$	$1.1x10^{-3}$
17	0.033	30.6	$6.1x10^{-29}$	$1.6x10^{-2}$
18	0.030	32.8	$6.5x10^{-28}$	$1.8x10^{-1}$
19	0.027	34.9	$5.0x10^{-27}$	1.5
20	0.026	36.7	$2.3x10^{-26}$	7.2

5. Conclusions

Bush et al [4] pointed out the tendency of identical bosons to clump and derived the attractive symmetry force. In our work, we modified their theory by adding the effect of d-d repulsion. And it is found that screening effect is very important, because symmetry force can not catalyze the tunneling effect for the case of using direct Coulomb repulsion in eq.(8). Our results for the case of using non-linear screening in Table 2 show that power density p is large enough to measure for N>16. We think that the candidate for the site of such a big cluster is lattice defects in palladium.

Acknowledgements

The authors wish to thank Professors S.Haruyama and S.Masaki for encouragements, suggestions and discussions.

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