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Research Article

Nuclear Exothermic Reactions in Lattices: A Theoretical Study of D–D Reaction

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Abstract

In this work we try to explain the deuteron–deuteron reactions within palladium lattice by means of the coherence theory of nuclear and condensed matter. The coherence model of condensed matter affirms that within a deuteron-loaded palladium lattice there are three different plasmas: electrons, ions and deuterons plasma. Then, according to the loading percentage x = D/Pd, the ions deuterium can take place on the octahedrical sites or in the tetrahedral in the (1,0,0)-plane. In the coherence theory it is called β-plasma the deuterons plasma in the octahedral site and γ-plasma which in tetrahedral. We propose a general model of effective local time-dependent deuteron–deuteron potential, that takes into account the electrons and ions plasma oscillations. The main features of this potential are extracted by means of many-body theory considering the interaction deuteron–phonon–deuteron. In fact the phonon exchange produces a attractive component between two deuteron within the D_2 molecular. This attractive force is able to reduce the inter-nuclear distance from about 0.7 to 0.16 Å. It means that the lattice strongly modifies the nuclear environment with respect to free space. In this way according to deuterons energy, loading percentage and plasma frequency we are able to predict high o low tunneling probability.

Keywords: Coherence theory, Condensed matter, Dislocations within the ions of the metal, Low energy nuclear reactions

1. Introduction

In a model of lattice a reaction takes place within the Coherence Theory of Condensed Matter and represents a general theoretical framework accepted by most of physicists that work on the cold fusion phenomenon. In the coherence theory of condensed matter [1] it is assumed that the electromagnetic (e.m.) field due to elementary constituents of matter (i.e. ions and electrons) plays a very important role in the dynamic system. In fact, considering the coupling between e.m. equations, due to charged matter, and the Schrödinger equation of field operator, it is possible to demonstrate that in proximity of e.m. frequency ω_0, the matter system is represented by a coherence dynamic system. For this reason it is possible to speak about coherence domains whose length is about $\lambda_{\rm CD} = 2\pi/\omega_0$.

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Of course the simplest model of matter with coherence domain is the plasma system. In the usual plasma theory we must consider the plasma frequency ω_p and the Debey length that measures the coulomb force extension, i.e. the coherence domain length. For a system with N charges Q of m mass within a V volume the plasma frequency can be written as

$$\omega_\mathrm{p} = \frac{Q}{\sqrt{m}}\sqrt{\frac{N}{V}}. \tag{1}$$

This presentation is focused on the "nuclear environment" that is supposed to exist within the palladium lattice D_2-loaded and at room temperature as predicted by the Coherence Theory. In fact, when the palladium lattice is loaded with deuterium gas, according to some people, it is possible to observe traces of nuclear reactions [2–4]. For this reason many physicists speak about Low Energy Reaction Nuclear (LERN). Various experiments prove that in the D_2-loaded palladium lattice the most frequent nuclear reactions are [4,5]:

(1) D+D→ ^{3}H + p + 4.03 MeV,

(2) D+D→ ^{4}He + 23.85 MeV.

The aim of this presentation is to propose a "coherence" model through which it becomes possible to explain the occurrence of reactions (1) and (2) and their probability, according to the most reliable experiments. The starting point of this theoretical study is the analysis of the inner environment of the lattice, i.e. of plasma present within the lattice itself (d-electron, s-electron, Pd-ions and D-ions), using the coherence theory of matter; the following step is based on the effective potential reported in [6,7] by adding the role of lattice perturbations through which the computation of the (D–D) tunneling probability improves.

2. Plasma Present within the Non-loaded Palladium Lattice

According to the Coherence Theory of Condensed Matter, in a Pd lattice at room temperature the electron shells are in a coherent regime within a coherent domain. In fact they oscillate in tune with a coherent e.m. field trapped in the coherent domains. For this reason, in order to describe the lattice environment, we must consider the s-electron and d-electron plasma.

2.1. Plasma of d-electrons

They are formed by palladium d-shell electrons. We can start computing:

$$\omega_\mathrm{d} = \frac{e}{\sqrt{m}}\sqrt{\frac{n_\mathrm{d}N}{V}} \tag{2}$$

as d-electron plasma frequency. But according to the coherence theory of matter the plasma frequency is about 1.38 and this factor is obtained assuming a uniform d-electron charge distribution. But of course the d-electron plasma is localized in a shell of radius R (that is about 1 Å), so the geometrical contribution is

$$\sqrt{\frac{6}{\pi}} = 1.38. \tag{3}$$

From the *renormalized* d-electron plasma frequency, you obtain:

$$\omega_\mathrm{de} = 41.5\ \mathrm{eV}/\hbar \tag{4}$$

and the maximum oscillation amplitude ξ_d is about 0.5 Å.

2.2. Plasma of delocalized s-electrons

The s-electrons are the ones that within the lattice structure neutralize the adsorbed deuteron ions. They are delocalized and their plasma frequency depends on loading ratio (D/Pd percentage) shown in the following equation (5):

$$\omega_{\mathrm{se}} = \frac{e}{\sqrt{m}}\sqrt{\frac{N}{V}}\cdot\sqrt{\frac{x}{\lambda_{\mathrm{a}}}}, \tag{5}$$

where

$$\lambda_{\mathrm{a}} = \left[1 - \frac{N}{V}V_{\mathrm{pd}}\right] \tag{6}$$

and V_{pd} is the volume actually occupied by the Pd-atom. As reported in [1]:

$$\omega_{\mathrm{se}} \approx x^{1/2} 15.2 \text{ eV}/\hbar. \tag{7}$$

For example for $x = 0.5$, the ω_{se} is about 10.7 eV/$\hbar$.

2.3. Plasma of Pd-ions

Further, it is important to consider the plasma due to Palladium ions that form the lattice structure. In this case it is possible to demonstrate that the frequency is

$$\omega_{\mathrm{pd}} = 0.1 \text{ eV}. \tag{8}$$

3. Plasma Present within the D_2-Loaded Palladium Lattice

We know that deuterium is adsorbed as soon as it touches the palladium surface. This loading can be enhanced using electrolytic cells or vacuum chambers working at opportune pressure [8,9]. Throughout Preparata's theory of Condensed Matter it is assumed that, according to the ratio x = D/Pd, three phases, concerning the D_2–Pd system, reaction:

(1) phase α for $x < 0.1$,

(2) phase β for $0.1 < x < 0.7$,

(3) phase γ for $x > 0.7$.

In the α phase, the D_2 is in a disordered and not coherent state (D_2 is not charged!). Regarding the other phases, the following ionization reaction takes place on the lattice surface, due to lattice e.m. field:

$$\mathrm{D}_{\mathrm{lattice}} \rightarrow \mathrm{D}^+ + \mathrm{e}^-. \tag{9}$$

Then, according to the loading percentage x = D/Pd, the ions deuterium can release on the octahedrical or in the tetrahedral sites are in the (1,0,0)-plane. In the coherence theory it is called β-plasma the deuterons plasma in the octahedral site and γ-plasma in the tetrahedral site.

Regarding the β-plasma it is possible to affirm that plasma frequency is

$$\omega_{\beta} = \omega_{\beta 0}(x + 0.05)^{1/2}, \tag{10}$$

where

$$\omega_{\beta 0}=\frac{e}{\sqrt{m_{\mathrm{D}}}}\left(\frac{N}{V}\right)^{1/2}\frac{1}{\lambda_{\mathrm{a}}^{1/2}}=\frac{0.15}{\lambda_{\mathrm{a}}^{1/2}}\ \mathrm{eV}/\hbar. \tag{11}$$

For example if we use $\lambda_{\mathrm{a}}=0.4$ and $x=0.5$ you obtain $\omega_{\beta}=0.168$ eV/$\hbar$.

In the tetrahedral sites the D^+ can occupy the thin disk that encompass two sites.

They present to the D^+ ions a barrier. Note that the d-shell electrons oscillate past the equilibrium distance y_0 (about 1.4 Å) thus embedding the ions in a static cloud of negative charge (which can screen the coulomb barrier). So, as reported in have [7]:

$$\omega_{\gamma}=\sqrt{\frac{4Z_{\mathrm{eff}}\alpha}{m_{\mathrm{D}}y_0^2}}\approx 0.65\ \mathrm{eV}/\hbar. \tag{12}$$

Of course this frequency depends also on chemical condition of the palladium lattice (impurities, temperature, etc.)

Due to a large plasma oscillation of d-electrons, in the disk-like tetrahedral region (where the γ-phase D^+'s are located) a high density negative charge condenses giving rise to a screening potential $W(t)$.

We emphasize that the γ-phase depends on x value and that this new phase has been experimentally observed [10].

The new phase γ is very important in the LERN investigation. In fact many "cold fusion physicists" declare the main point of *cold fusion protocol* is that the loading D/Pd ratio must be higher than 0.7, i.e. the deuterium must be placed in the tetrahedral sites.

4. The D–D Potential

In [6], it was shown that the phenomenon of fusion between nuclei of deuterium in the crystalline lattice of a metal is conditioned by the structural characteristics, by the dynamic conditions of the system, and also by the concentration of impurities present in the metal under examination.

In fact, studying the interaction between deuterons (including the deuteron–plasmon contribution) in the case of three typical metals (Pd, Pt and Ti), a three-dimensional model showed that the height of the Coulomb barrier decreases upon the variance of the total energy and the concentration of impurities within the metal itself.

The starting potential that links Morse-like attraction and Coulomb-like repulsion can be written in this way [6,7]:

$$V(r)=k_0\frac{q^2}{r}\cdot\left(V\left(r\right)_{\mathrm{M}}\frac{A}{r}\right) \tag{13}$$

In (13), $V\left(r\right)_{\mathrm{M}}$ is a Morse-like potential, and is given by:

$$V\left(r\right)_{\mathrm{M}}=B\left\{\exp\left(-2\varphi\left(r-r_0\right)\right)-2\exp\left(-\varphi\left(r-r_0\right)\right)\right\} \tag{14}$$

Here the parameters A, B, φ and r_0 depend on the lattice.

In fact the D–D potential (13) is an effective potential whose reliability is shown by its own ability to fit the Coulomb potential for $r\to 0$ and the Morse potential in the attractive zone. Moreover, Siclen and Jones [11] defined ρ the point where the Coulomb potential is linked by the Morse trend, r_0' the equilibrium distance and D' the well. Certainly, within the free space for a D_2 molecule, ρ is about 0.3 Å , r_0' is about 0.7 Å and D' is –4.6 eV. But within the lattice the screening effect and the deuteron–deuteron interaction due to phonon exchange modify noticeably these parameter values.

Considering the role of coupling between deuterons and plasmons, in [12] the authors have numerically evaluated a D–D potential having the features of potential (13) with $D' = -50$ eV and $r'_0 = 0.5$ Å and $\rho = 0.2$ Å (in [12] the authors consider only two plasmon excitations at 7.5 and 26.5 eV).

4.1. The features of potential (14)

Since the screening effect can be modulated by donor atoms the role of impurities becomes considerable (as shown in [6,7]) and has been proven that

$$A = JKTR \tag{15}$$

and

$$B = J/\zeta. \tag{16}$$

Here J is the impurities concentration, *KT* is the lattice temperature, R the nuclear radius and ζ a parameter to evaluate by fitting.

Finally the actual d–d potential can be written as

$$V(r) = k_0 \frac{q^2}{r} \cdot \left(V\,(r)_{\mathrm{M}} - \frac{JKTR}{r} \right). \tag{17}$$

In this presentation, according to the coherence theory of condensed matter, it is emphasized the role of potential (17) in the three different phases : α, β and γ.

So in this theoretical framework aims to clarify:

(1) what is *KT?*
(2) what is the role of electrons and ions plasma?

About the first point, according to the different deuteron–lattice configurations, *KT* can be:

(i) the loaded lattice temperature considering the deuterons in the α-phase,
(ii) ω_β considering the deuterons in β-phase,
(iii) ω_γ considering the deuterons in the γ-phase.

Whereas regarding the second point, the question is trickier.

In fact the lattice environment is a mix of coherent plasmas (ion Pd, electron and deuterons plasma) at different temperature, due to different masses, thus describing an emerging potential becomes a very hard task. The method proposed in this presentation considers the total screening contribution of lattice environment in a D–D interaction (i.e. V_{tot}) as random potential $Q(t)$. So this model can be written as

$$V_{\mathrm{tot}}(t) = V(r) + Q(t). \tag{18}$$

And assuming that

$$\langle Q(t) \rangle_{\mathrm{t}} \neq 0 \tag{19}$$

that is, $Q(t)$ is now supposed to be (as a second order potential contribution) a periodic potential (the frequency will be labeled by ω_Q) that oscillates between the maximum value $Q_{\max}$ and 0.

Further specifically, the charge oscillations of d-shell electrons produce a screening potential having harmonic features:

$$eV(r) = -Z_d \frac{ke^2}{2a_0} r^2. \tag{20}$$

In [1] putting $Z_{\mathrm{d}} = 10/3$ and $a_0 = 0.7$ Å , it is evaluated a screening potential V_0 of about 85 eV. Computing this way you get $\rho g V_0/26.9$ and, at least, $\rho = 0.165$ Å.

According to the loading ratio, within a palladium lattice the following cases occur.

(1) α-phase

In the phase α the deuterons are in a molecular state and the thermal motion is about
0.02 eV $< \hbar\omega_\alpha <$ 0.1 eV.
This phase takes places when x is less than 0.1, and since $W(t)$ is zero, the
D–D potential is

$$V(r) = k\frac{q^2}{r} \cdot \left(V_{\mathrm{M}}(r) - \frac{J\hbar\omega_\alpha R}{r}\right). \tag{21}$$

Equation (21) has been partially evaluated in a previous page [6] but only considering the dependence of tunneling probability on impurities present within lattice.

(2) β-phase

When x is bigger than 0.1 but less then 0.7, phase β occurs. The interaction takes place between deuteron ions that oscillate within the following energy values:
0.1 eV $< \hbar\omega_\beta <$ 0.2 eV.
In this case $W(t)$ is zero, so the potential is given by Eq. (22):

$$V(r) = k\frac{q^2}{r} \cdot \left(V_{\mathrm{M}}(r) - \frac{J\hbar\omega_\beta R}{r}\right). \tag{22}$$

Comparing Eqs. (21) and (22), it seems quite obvious that the weight of impurities is more important in the β-phase.

The role of temperature on tunneling effect has yielded to such conclusion according to the previous Refs. [6,7].

(3) γ-phase

Finally when the loading ratio is higher than 0.7, the deuteron–palladium system is in the phase γ.

This is the more interesting case. The deuterons undergo the screening due to d-shell electrons, therefore the D–D potential must be calculated assuming that the wall present in potential (13), due to Morse contribution, disappears. In fact if we use a classic plasma model where the D^+ ions are the positive charges and the d-electrons the negative, it is very reasonable to suppose that the following potential must be used:

$$V(r,t) = k\frac{q^2}{r} \cdot \left(V_{\mathrm{M}}(r) - \frac{J\hbar\omega_\gamma R}{r}\right) + Q(t). \tag{23}$$

We emphasize that $Q(t)$ is an unknown perturbative potential. It should be pointed out that

$$\langle Q(t)\rangle_{\mathrm{t}} \approx \frac{W_{\max}}{\sqrt{2}}. \tag{24}$$

As previously said, the screening potential, due to d-electrons is supposed to reduce the repulsive barrier, i.e. ρ and r_0'.

$$\langle Q(t)\rangle_{\mathrm{t}} \approx 85 \text{ eV}. \tag{25}$$

5. Results and Discussions

This presentation shows the D–D fusion probability renormalized to number of events per second regarding the D–D interaction in each different phase. More specifically, fusion probabilities in the phase α, β and γ are compared at varying states of energy between –50 and 50 eV. It is also important to consider the role of d-shell electron screening as perturbative lattice potential. This treatment, which considers only the case where $Q(t)$ is different by zero, involves a change of value of certain points in the x-axes where the coulomb barrier is represented and, in this case, the final result is the screening enhancement of fusion probability. In order to evaluate the fusion rate (Λ) this equation was required:

$$\Lambda = A\Gamma, \tag{26}$$

where Γ is the Gamow factor and A is the nuclear reaction constant obtained from the measured cross sections (value used was $10^{22}\mathrm{s}^{-1}$).

From an experimental point of view, in the cold fusion phenomenon it is possible to affirm that there are three types of experiment [13]:

(1) those that give negative results,
(2) those that give some results (little detection signs are measured in contrast with the background, therefore fusion probability is found to be about 10^{-23} using a very high loading ratio),
(3) those that give clear positive results as Fleischmann and Pons experiments.

Nevertheless, experiments of the third type are less accurate from an experimental point of view. For this reason it is possible to explain only the experiments of the first and second type throughout a physical and mathematical theoretical model of controversial phenomenon of cold fusion. In this case the role of loading ratio needs to be considered on the experimental results.

Starting from α-phase:

In this case the theoretical fusion probability is very small, less than 10^{-74}. It is possible to affirm that if the deuterium is loaded with a percentage $x < 0.2$ no fusion event occurs. The same absence of nuclear phenomenon is compatible for a loading ratio of about 0.7 since, in this case, the predicted fusion probability is less than 10^{-42}. These predictions, of course, agree to the experimental results. But for $x > 0.7$ a set of valid experiments on cold fusion report some background spikes (e.g. see [14]). The remarkable result of such model is that in the γ-phase, some background fluctuations are evident, since the theoretical predictions yielded to a fusion probability of about 10^{-22} due to a very high loading ratio. This represents a new result according to [6,7] since, in those cases, the fusion probability was independent by the loading ratio.

Moreover, the model proposed in this work (which unifies nuclear physics with condensed matter) can explain some anomaly nuclear traces found in the solids. In order to explain the occurrence of a very high fusion rate concerning the experiments of the third type, other contribution as micro-deformation would be required as long as the experiment itself could be possible. The role of micro-crack and impurities associated with the loading ratio will be explored in other speculative works. Hopefully *the nuclear physics within condensed matter* will be a new and highly productive scientific topic.

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