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THEORY OF ELECTRON CATALYZED FUSION IN PD LATTICE

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ABSTRACT

When an electron is placed in the center of mass of two deuterons, those being attracted by a negative charge of the electron may reach zero seperation and fuse. The idea which forms in fact the essence of Coulomb barrier tunnelling is applied to interpretation of cold fusion experiments. Theoretical model describing behaviour of hydrogen in Pd-lattice is presented and molecular mechanism of nuclear fusion is described. Accordingly to the formulated theory hydrogen in Pd lattice exists mostly in the form of linear $H_2^+(D_2, DH^+)$ quasimolecules, which during $\alpha \rightarrow \beta$ phase transition may lose stability and may collapse, forming tightly bound nuclear system. Synthesis of tritium from deuterons and protons, accordingly to the scheme $D+e+p \rightarrow T+h\int d\nu$, is, therefore, quite possible. It is a characteristic feature of electron catalyzed nuclear fusion that energy is in principle released in the form of soft X-rays. Arguments are presented that a single-crystal Pd-electrode has to be used to achieve high fusion rates.

INTRODUCTION

During the last few years, there has been gathered quite a lot of experimental material in favour of the hypothesis that hydrogen nuclei can fuse in a condensed matter at room temperatures. Some geological observations, like heat generation in Jupiter and in the earth mantle as well as anomalies in He^3 distribution in various minerals[1], and in particular well documented results on muon catalysis, obtained in very precisely designed experiments (see for instance Brenlich[2]) seem to leave no much room for doubts that cold fusion process does really exist. Why, therefore, the physical community was so strongly shocked by Fleischmann and Pons announcement[3]? Shocking were the numbers presented there. The authors have reported that in a Pd electrode containing deuterium a huge amount of heat, sufficient to melt the electrode, was generated. At the same time the neutron flux, which should accompany fusion D+D reactions at the level of 10^{12} **n/sec**, remained practically undetectable (below 10^4**n/sec**). A remarkable amount of the produced heat as well as the lack of neutrons and γ-rays (the latter should accompany $D + D \rightarrow T + p$ fusion channel) was in evident contradiction with a being developed for six decades theory. Accordingly to quantum-wave calculations, tunnelling through the Coulomb barier at room temperatures should be extremely small - the calculated D-D fusion rate is only about 10^{-70} per D_2 molecule per second. This value is much too small (by the factor 10^{-60}) to explain the heat generation reported by Fleischmann and

Pons, and too small (by factor of 10^{-50}) to explain minute quantities of heat, neutrons, and γ-rays, observed in some other experiments (see for instance DOE report[4] as well as some other papers on the problem[5-9]).

NEW CONCEPTS NEEDED

Traying to understand enigmatic results on cold fusion it is necessary to remind some facts from the early days of nuclear physics. First of all one has to remember that the concept of Coulomb barrier tunnelling was introduced into theory to explain the fact that nuclear transformations are observed at kinetic energies much lower than threshold energy calculated from electrostatic interaction of two nuclei. The controversy between the experiment and a correctly looking interpretation was formally removed by quantum mechanics on the grounds of probabilistic interpretation of the Schroedinger equation. It has been simply assumed that tunnelling effect represents the inherent property of microscopic object for which energy conservation law is inapplicable. Accordingly to quantum-wave philosophy, the Coulomb barier tunnelling is entirely a two-body process, which in principle is independent of the state of the environment. Atomic electrons which in a typical experiment accompany any nuclear collision, play in the quantum theory merely a secondary role (electrons appeare in the theory at a second stage of calculations as a correcting factor). A deep conviction that atomic electrons in nuclear collisions can only play a marginal role, seems to have the origin in the fact that trajectory of heavy particle can not be changed much by an electron in the isolated binary collision. One must remember, however, that two positively charged nuclei and negatively charged electron can form a long-living quasi-molecule. In such a case, the interaction time between electron and nuclei may be much longer than the interaction time in a free binary collision and, therefore, motion of the nuclei may be modified by the electron significantly. A good explanation of the point is an electron situated in the center of mass of two protons. Protons being attracted by a closer situated electron can reach zero separation even at zero initial kinetic energy. In principle two deuterons at presence of electron can fuse in any temperature (a short remark on the point appeared not long ago Nature[10]).

The idea that electrons are responsible for Coulomb barrier tunnelling originates from theoretical research of the author on chemical bonds[11,12]. The author investigating bound-states of the system consisting of two protons and an electron has found that there is a whole class of solutions when the attractive interaction between protons and a negatively charged electron dominates over a repulsive interaction between protons, and two, initially being at rest, nuclei can approach to each other on a very small distance. From this fact the conclusion was drawn that Coulomb barrier tunnelling observed in nuclear collisions is a three body process in which an electron is involved. Not long ago, solving approximately some particular case of a three body

problem, it has been shown that probability of tunnelling in keV energy range has the form of the well known Gamov relation[13].

In the both cases, that is in the case of keV-range fusion described by Gamov formula and in the case of the cold fusion (fusion between nuclei having practically zero kinetic energy), the atomic model, which specifies initial conditions for differential equations describing behaviour of particles in a considered system, plays a key role in tunnelling at normal physical conditions. Free-fall atomic model, which has been succesfully used in atomic collision physics[14-16] and atomic spectroscopy[17], for calculation of atomic and molecular diamagnetism[18], and which seems to open new possibilities in solid state physics[19], will provide a basis of current considerations. A particular value for the actual analysis have recent investigations on slow p+H collisions[20]. Those have shown that hydrogen atom in the field of a slowly moving proton is changing orientation so that the free-fall radial orbit of the atomic electron is all the time directed towards the moving proton and at some distance between protons a linear quasi-molecule, as shown in Fig. 1, can be formed.

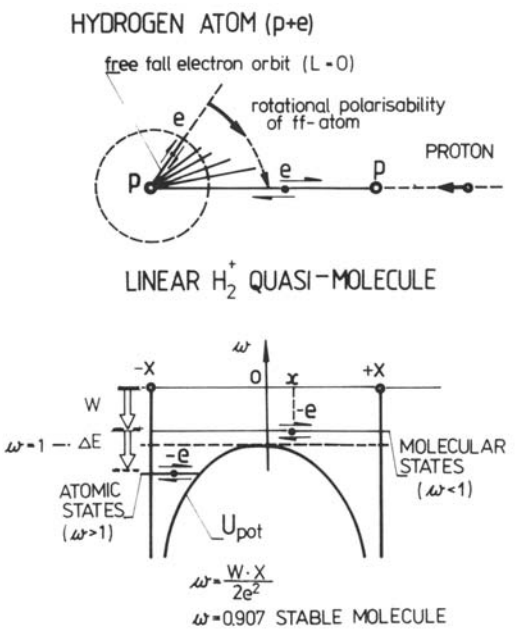


Fig. 1. System of two protons (deuterons) and an electron moving between them may remain in dynamic equilibrium and form a linear $H_2^+(D_2^+)$ quasi-molecule. A rapid change of the binding energy of the electron by ΔE, in a collision with a free electron for instance, may result in splitting of the quasi-molecule into two fragments: a bare proton and a tightly bound quasiatomic system. As a result of charge-electric dipole interaction these two fragments may reach quite high energy. The accelerated nuclei being still screened by the negative charge of the electron may come closely to each other and may form a stable nuclear system.

Not long ago we have shown that in Pd-crystal such needle-like D_2^+ quasi-molecules do really exist[19,21]. Now, we will consider circumstances at which a normally stable D_2^+ quasi-molecule may collapse to the nuclear size and a new nuclear system may be formed (some aspects of the problem have been already published in Polish Journal "Kwartalnik Elektrotechniki i Telekomunikacji" - see ref. 21).

D_2^+ QUASI-MOLECULE - COLD FUSION FUEL

As we have shown previously, see M.Gryziński: INR Report 810/XVIII/1967 and ref.12, main elements of the molecular dynamics may be, in view of the large difference between the mass of the nucleus and the electron, derived from the well known solution of the two fixed-centers problem. If two bare nuclei and an electron form a linear D_2^+ quasi-molecule, analysis is very simple, and the whole problem can be investigated analytically. In fact, it can be reduced to two differential equations: the one, describing fast oscillatory motion of the electron between two fixed centers of force

$$\frac{mv^2}{2} - \frac{Ze^2}{x-\bar{X}} - \frac{Ze^2}{x+\bar{X}} = \text{const} = -W \,, \qquad (1)$$

where $\mp\bar{X}$ are coordinates of the centers, x is the coordinate of the electron, v is the electron velocity and W is the binding energy of the electron, and the other, describing relatively slow translations of heavy centers

$$M \frac{d^2\bar{X}}{dt^2} = \left[\frac{Ze}{2\bar{X}}\right]^2 - \bar{F}(X) \,, \qquad (2)$$

where M is the mass of the center and $\bar{F}(X)$ is the mean value of the interaction force between the electron and the center. Calculation of $\bar{F}(X)$ presents any difficulty and equation describing time evolution of the quasi-molecule assumes the form:

$$M \frac{d^2\bar{X}}{dt^2} = \left[\frac{Ze}{2\bar{X}}\right]^2 \left\{ 1 - \left[\frac{4}{Z}\right] w \left[\frac{K(\sqrt{w}) - 2E(\sqrt{w})}{K(\sqrt{w}) - E(\sqrt{w})} \right] \right\} , \qquad (3)$$

where K and E are elliptic integrals of the first and the second kind, and w is given by:

$$w = \frac{W\bar{X}}{2Ze^2} \,. \qquad (4)$$

If nuclei are not at rest, than there is an exchange of energy between the electron and the moving nuclei, and W is not a constant

quantity. Until velocities of nuclei are very small, that is until $X<<\dot{X}/T(X)$, where T is period of motion of the electron calculated at X = const., the change of W with the travelled distance X can be derived from the adiabatic theorem. Thus:

$$\int_{-X}^{X} m\dot{x}dx = \text{const} = 2(mZe^2X)^{1/2}E(w^{1/2}). \qquad (5)$$

Inspecting the right-hand side of Eq.(3), one finds that it may have, depending upon the value of the parameter w, either positive or negative value. When the repulsive interaction of the two nuclei and the gaso-kinetic pressure of the electron moving between them are less than the mean value of the attractive force between the electron and the nucleus, the net force is negative, and the nuclei, being initially at rest, start to move towards the center. When the net force is positive, the quasi-molecule starts to expand. At some value of w ($w = w_o \approx 0.907$) the net force is zero, and the system of two nuclei and electron remains in dynamical equilibrium.

Considering real atomic (molecular) systems one must have in view that in general periodically moving electron emits electromagnetic radiation. At presence of radiation electron looses kinetic energy and there is a slow increase of W in time ($w \longrightarrow 1$). Radiative cooling, which lowers gaso-kinetic pressure of the electron moving in the potential well of the two nuclei, results in a slow decrease of the dimension of the system. Radiative collapse of the system may stop if motion of the electron between nuclei will satisfy some requirements. These requirements, which have origin in spin properties of the electron[22] have the form of quantisation rules. In the considered case, therefore, the radiationless motion of the electron is determined by:

$$\int_{-X}^{+X} m\dot{x}dx = nh \quad (n = 1, 2, 3, \ldots),$$

where h is Planck's constant.

The above equations form a complete set of relations defining parameters of the considered quasi-molecule. If the quasi-molecule is in the ground-state then (n=1) and one has:

distance between the nuclei $l_H = 2.043(2a_o) = 2.165\text{Å}$,

electron binding energy $W_{D2^+} = 24.16\text{eV}$.

Let us assume now that the binding energy of the electron is in a some way changed by the value

$$\delta W = W_D(1 - 0.907) = 2.47\text{eV},$$

so that the parameter w is very close to unity. At $w \longrightarrow 1$ electron much of time spends in the vicinity of the center of quasi-molecule and nuclei attracted by the electron can come closely to each other

and fuse. Taking into account that an electron moving between the nuclei can emit electromagnetic radiation and fusion energy may be released in form of soft X-rays, one arrives at a conclusion that quite new nuclear channells, as given below:

$$D(p) + e + D(p) \longrightarrow T(D, He^4 + e) + \hbar\int d\nu$$

can exist (the term $\hbar\int d\nu$ in the above represents the whole spectrum of photons emited by the electron in the whole collapse phase).

PROBABILITY OF ELECTRON CATALYZED FUSION

To describe dynamics of the (D+e+D) system when the parameter w is close to unity it is convenient to expand potential in the vicinity of the saddle point into series and retaining the first term of the expansion to operate with a simplified equation of motion for the electron:

$$m\frac{d^2x}{dt^2} = \left[\frac{4Ze^2}{X^3}\right] x \ . \qquad (6)$$

At the assumption X=const the integration can be effectivelly carried out and one obtains

$$x \simeq X\ (v_o/v_x)\mathrm{sh}(v_x t/X) \ , \qquad (7)$$

where x is a distance of the electron that has started at t=0 from the center of the quasi-molecule, v_o is electron velocity in the center, and v_x is defined by:

$$v_x = 2(Ze^2/mX)^{1/2} \ . \qquad (8)$$

Two nuclei can without appreciable change of kinetic energy approach closely to each other on a distance much smaller than X providing during the time which is needed for the nuclei of velocity V to travel the distance X the shift of the electron from the center is much smaller than X. The depth of tunnelling Rt may be in the first approximation identified with the distance travelled by the electron during the time $t \simeq X/V$. Since x(t) is given by Eq.(6), than at $V << v_x$ one approximately has:

$$R_t \simeq X(v_o/2v_x)\exp(v_x/V) \ . \qquad (9)$$

The depth of Coulomb tunnelling is, therefore, at given X and V, entirelly determined by initial value of electron velocity - v_o. At some statistical distribution in v_o, there is always some probability of the Coulomb barrier tunnelling to any distance Rt. Probability of tunnelling to the distance smaller then Rt is simply

given by:

$$P_{cbt} = \int_{o}^{v_o=2v_x(R_t/X)\ \exp(-v_x/V)} p(v_o)\, dv_o \quad . \tag{10}$$

Since $p(v_o)$ in general, may have the form:

$$p(v_o) \simeq \frac{1}{V}\left[\frac{V}{v_o}\right]^k, \text{ where } 0<v_o<V \quad , \tag{11}$$

therefore,

$$P_{cbt} = \frac{1}{1-k}\,(2R_t v_x/XV)^{(1-k)} e^{-(1-k)(v_x/V)} \quad . \tag{12}$$

For low energy collisions, when proton of relatively small velocity approaches hydrogen atom, one can assume that v_o is randomly distributed between 0 and V, then k=0, and one obtains:

$$P_{cbt} \simeq 2(R_t/X)(v_x/V)\exp(-v_x/V). \tag{13}$$

In this point it is worthy to note that the exponential factor at $X \approx a_o$ is almost the same as that in the Gamov relation (for two deuterons we roughly have $(v_x/V) \simeq (200\text{keV}/E_D)^{1/2}$).

To apply the derived Coulomb barrier tunnelling formula to real nuclear collision process one must ascribe some physical sense to the distance R_t.

Thus, one can identify Rt with a distance at which interaction between the nuclei and an electron becomes dominated by short range spin magnetic forces which can keep them together (like nucleons are kept in the nucleus). Denoting electron and nuclear magnetic moments respectively by μ_e and μ_n one has:

$$\frac{\mu_e \mu_n}{X^4} = \frac{e^2}{X^2}\bigg|_{X=R_t} \qquad R_t = \left[\frac{\mu_e\mu_n}{e^2}\right]^{1/2} \simeq \lambda\!\!\!^{-}_c (m_e/M_p)^{1/2}, \tag{14}$$

where $\lambda\!\!\!^{-}_c$ is electron Compton wave length and M_p is mass of the proton.

Let us assume now that the electron of the $H_2^+(D_2^+)$ quasimolecule has lost in some way, in a collision with a free electron for instance, some amount of kinetic energy - ΔE. If energy loss was large, larger than $(mv_o^2/2)$, then quasi-molecule becomes splitted into two fragments: the bare proton and the neutral tightly bound (p-e) quasi-atomic system. As a result of attractive charge-dipole interaction between the proton and the (p-e)quasi-atom, these two, being initially at rest, fragments of

the quasi-molecule start to move and their kinetic energy increases at a cost of potential energy of the system. Kinetic energy of both fragments may be easily found from energy conservation law and from the adiabatic invariant - the latter at w>1 has the form:

$$I = 2(mZe^2Xw)^{1/2}\{E(1/w^{1/2}) - (1-1/w)\ K(1/w^{1/2})\}. \qquad (15)$$

Since w decreases with decrease of X, the parameter w becomes at some distance X=X1 equal to unity. Further evolution of the system, however, which in principle is the same as just described above, depends upon the particular value of v_o which is determined by the position of the electron in the moment when X(t)=X1. Coulomb barier tunnelling probability can be, therefore, calculated from Eq.(10) providing we respectively replaced:

$$X \text{ by } X_1$$

and

$$MV^2/2 \text{ by } (Z-1/4)e^2/X_1.$$

At large transfers of energy, that is for ΔE much larger than $mv_o^2/2$, Eq(12) yields:

$$X_1=(\Pi/4)^2(2Ze^2/\Delta E).$$

At very slow motion of the two nuclei $p(v_o)$ is strongly peaked at $v_o \rightarrow 0$ and in the first approximation one can assume

$$p(v_o)=1/(v_o)^{1/2}.$$

Accordingly to Eqs(11) and (12) one, therefore, obtains:

$$P_{cbt} \simeq (R_t/X_1)^{1/2}(M/3m_e)^{1/4}\exp-(2M/3m_e)^{1/2}. \qquad (16)$$

Since the expression before the exponent in the above equation is not much different from unity, probability of molecular fusion is first of all determined by the exponential factor. Probability of fusion of two deuterons is, therefore, of the order of 10^{-18}.

It is worthy to note that the presented theoretical scheme can be applied to interpretation of muon catalysed fusion which may follow exchange of electron by muon in the D_2^+ quasi-molecule. Thus, replacing m_e in Eq.(16) by m_μ, where m_μ is the mass of the muon, and assuming:

$$\Delta E \simeq \text{energy of the muonic atom } [U_i^H(m_\mu/m_e)],$$

one obtains:

$$P^{\mu}_{cbt} = (m_{\mu}/m_e)^{3/2} (R_t/2a_o)\, e^{-(2M/3m_{\mu})^{1/2}} \simeq 0.2 \,. \qquad (17)$$

Taking into account that one muon can catalyze some number (κ) of fusions one obtains result, which is in a surprisingly good agreement with the experiment - the experimental value for the product ($P_{cbt} . \kappa$) is somewhere about 200.

FUSION IN Pd-LATTICE.

To make some conclusions upon the cold fusion in the Pd-lattice, it is neccessary to answer at first the following question: does really hydrogen in Pd lattice exists in the form of needle-like H_2^+ quasi-molecules?

The question has found a positive answer, see Fig.2., as various physical properties of Pd/H system that were calculated using the described above model of H_2^+ quasi-molecule have found to be in a good agreement with the experiment - see Fig.3, Table I and references 19 and 21.

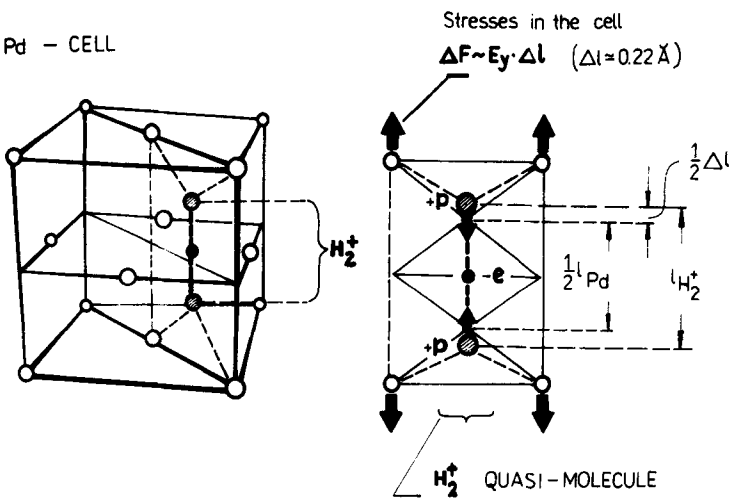


Fig.2. Hydrogen in Pd-lattice can in principle occupy tetrahedral as well as octahedral vacancies. One of the possible ways is shown above. Since the length of the H_2^+ quasi-molecule (2.160 Å) is a little bit longer that the distance between the vacancies (1.940Å) hydrogen tends to expand of the Pd-cell. Elongation of the cell can be easily calculated as the value of the Young modulus of palladium is known from the experiment and Young modulus of the quasi-molecule is known from the theory.

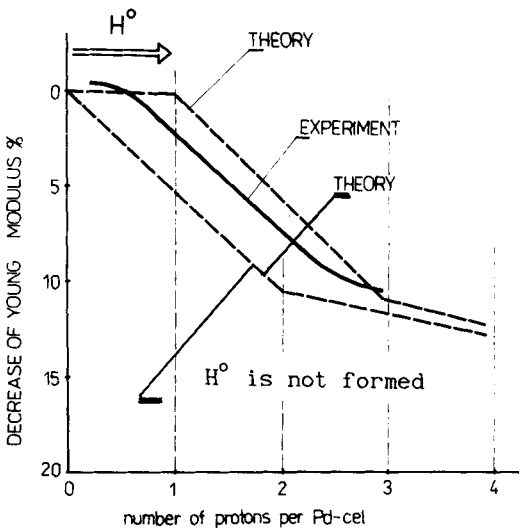


Fig.3. There is shown the change of Young modulus as a function of the content of hydrogen in the Pd-electrode. In view of a remarkable agreement between the theory and experiment, see Table 1, one can suppose that hydrogen in Pd-lattice do really exists in the form of linear H_2^+ quasi-molecules.

Table 1

Physical charcteristic of Pd/H system
(the experimental data were taken from two monographs: refs.23, 24)

	Exp. data	Present Theory
Pd-lattice constant	2x1.945 Å	-
Length of H_2^+	-	2.160 Å
Young's modulus:		
per Pd-cell	1.77x10 kg	-
per H_2^+-quasi mol.	-	8.13×10^{-9} kg
Young's Modulus (H/Pd ≈ 0.7)	1.04×10^6 kg/cm^2	1.01×10^6 kg/cm^2
Linear Expansion (H/Pd ≈ 0.7)	4.04 Å	4.05 Å
Vibrational Amplitude		
4.2°K	0.17 Å	0.15 Å
20 °C	0.23 Å	0.22 Å
Critical temperature (T_c)	300°C	320°C
"Resonance" in specific heat (T_{res})	50°K	60° K

In view of a succesful description of physical properties of Pd/H system further considerations on electron catalyzed fusion seem to have a quite firmly established basis. Trying to apply the derived relation into new, unknown regions, let us start with investigation of conditions at which the ordinary, stable H_2^+ (D_2^+) quasi-molecule may be transformed into the collapsing one. Accordingly to the considerations given above to initiate molecular fusion the parameter w, which in the undisturbed quasi-molecule is equal to 0.907, has to be changed by the value: $\Delta w = 1 - w_o \approx +0.093$. This change in w corresponds to change of the binding energy of the electron by 2.47 eV ($\Delta W_H \approx W_H \cdot \Delta w$).

Now, the question arrises: what is the nature of the process which may change binding energy od D_2^+ quasi-molecule in the Pd-lattice by 2.47eV ? Accordingly to Fleischmann and Pons, substantial release of heat takes place at high concentrations of deuterium and may be very rapid (in some other cases small heat bursts were reported). One can suppose, therefore, that rearangement of electrons at $\alpha \rightarrow \beta$ phase transitions, that are observed at high concentrations of hydrogen in the given crystalic domain, may initiate the fusion process.

In view of the fact that during the phase transition stechiometry of the Pd-lattice remains unchanged and only the lattice constant is slightly increased one can suppose that valence electrons move all the time in the same way and small changes in the lattice parameters appear as a result of reorientation of atomic cores. It is evident that any change in localisation of electric charges in the Pd-cell must have some influence upon the behaviour of the incorporated D_2^+ quasi-molecule. Particularly important, however, are changes in electric field produced by two Pd-atoms located in the close vicinity of the center of the quasi-molecule - see Fig. 4.

To investigate behaviour of the quasi-molecule in the varrying field of the lattice one must determine, first of all, the form of the perturbation potential produced by eight Pd-atomic core electrons. Thus, accordingly to the free-fall atomic model concept eight atomic shell electrons form a regular free-fall cubic configuration and the radius of the shell, identified with the mean distance between collectively moving electrons and the nucleus , may be calculated from:

$$(Z-n_e-\sigma)e^2/r_{max} = \sum_{n_e}^{n_e+8} U_{i,k} \longrightarrow (\bar{r} = 0.75\, r_{max}), \qquad (18)$$

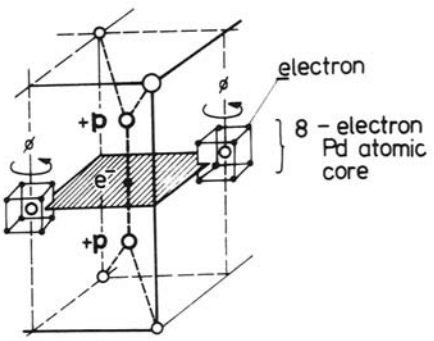
where $U_{i,k}$ are successive ionization potentials of the Pd-atom, n_e stands for number of valence electrons (in our case n_e=2), and σ, is a screening factor, which represents electrostatic interaction of electrons (for eight electrons situated at the corners of the cube one has: $\sigma = (3/2 + 2\sqrt{0.6} + 18)/8$).

The perturbation potential along the axis of the quasimolecule situated in tetrahedral vacancies of Pd cell may be written in

the following way:

$$\varphi = 2 \sum_{i=1}^{8} \frac{e}{\vec{l} + \vec{x} - \hat{k}_i \bar{r}}, \qquad (19)$$

where $\vec{l}$ represents the vector directed from the center of the given Pd-atom to the center of the considered quasi-molecule, $\hat{k}$ is the unit vector directed from the center of the atom to the given electron of the shell and $\bar{r}$ is a mean distance between collectively moving electrons and the nucleus. At the Pd-atomic core oriented with the side wall of the cube looking at the center of the quasi-molecule the energy of electrostatic interaction between D_2^+ and the core is at minimum.



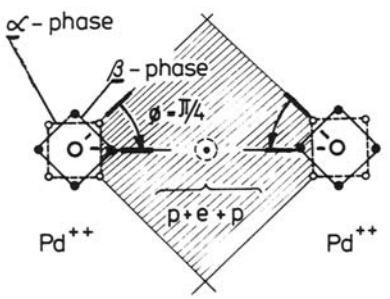


Fig. 4. There is shown situation of $H_2^+(D_2^+)$ quasi-molecule in Pd-cell (compare Fig. 2.) and the possible electron configuration in the vicinity of the center of the quasi-molecule. It is very likely that Pd atomic core during $\alpha \rightarrow \beta$ phase transition changes orientation by $\pi/4$ and molecular electron is captured in the potential well formed between two protons (see Fig. 5).

Let us assume now that the atomic core at $\alpha \rightarrow \beta$ phase transition changes orientation by $\Pi/4$ - see Fig. 4. This change has a big consequences on the behaviour of the D_2^+ quasimolecule. Now, the effective potential has in the center of the quasimolecule a

shallow minimum and the binding electron can be captured during the phase transition in a being formed potential well - see Fig.5. If this happen then stability of the quasi-molecule becomes destroyed and nuclei attracted by a centrally situated electron may reach high kinetic energy and fuse.

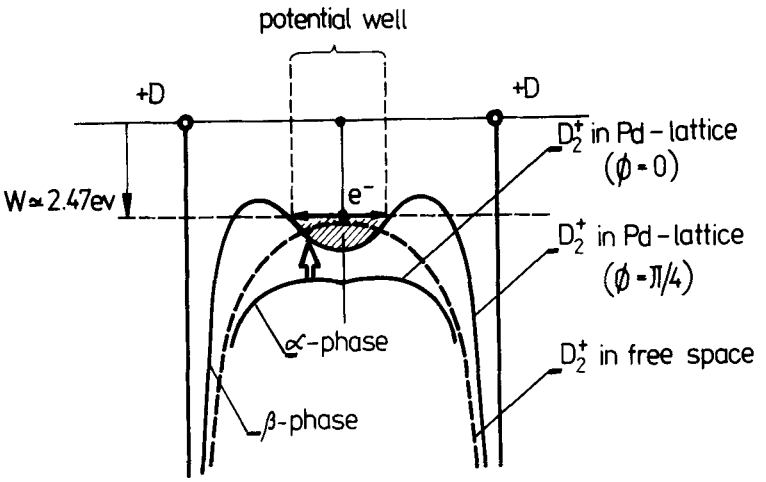


Fig.5. There is shown electric potential along the axis of $H_2^+(D_2^+)$ quasimolecule in a free state, and for a quasimolecule situated in Pd-lattice at two different orientations of Pd atomic cores (compare with Fig.4.).

To estimate, by the orders of magnitude at least, probability of Coulomb barier tunnelling and nuclear fusion rates one can use relations derived in the first part of the paper. One must remember, however, that important factors which in the lattice may influence the collapse phase cannot be at the moment sufficiently well specified. And thus, radiative and dielectric losses which may influence substantially the collapse phase are entirelly neglected. Velocity distribution of electrons captured in the potential well formed during the phase transition, which as follows from Eq.(16) determines the absolute value of Coulomb barrier tunnelling probability, remains in fact unknown, as we do know nothing about the dynamics of the phase transition. At the present stage of the development of the theory we are able, therefore, to give a very rough estimation only. The needed information can be obtained from Eq.(16) if one put X_1 equal to the half width of the potential well formed during the phase transition. Thus:

$$P_{cbt} = \begin{cases} 10^{-13} & \text{for probability of collapse of two protons} \\ 10^{-18} & \text{for probability of collapse of two deuterons} \end{cases}$$

The calculated probabilities are by few orders of magnitude lower than those estimated from the Fleischmann and Pons experiment ($P_{cbt} \sim 10^{-8}$). One can try to explain this difference by a very approximate character of the carried out analysis. One must have in view, however, that there are other possibilities. And for instance one must have in view possibility of radiative collapse - as the quasi-molecular fusion is a three body process, in which two nuclei and an electron are involved, and the system may lose energy in the form of electromagnetic radiation. To have an idea how far radiative losses can influence dynamics of process let us take into account that energy radiated at one trip of the electron between the nucleui may be of the order of:

$$\Delta E^{*} = -2\frac{Ze}{c}\frac{\mu}{X^2} v_o, \tag{20}$$

where μ is the magnetic moment of the electron and c is velocity of light (see Eq. (47) of the paper by Gryziński[22]). On the other hand, the moving electron may gain some amount of energy at each back-scattering from the moving nucleus. At $M\dot{X} > mv_o$ this gain is roughly equal to:

$$\Delta E_k \approx +2m\dot{X}v_o. \tag{21}$$

Comparing Eqs. (20) and (21) one finds the distance at which the radiative "cooling" may be equal to collisional heating. Thus,

$$X^{*}_{rc} \approx 2a_o\left(\frac{M\alpha}{m\,2}\right)^{1/3}\left(\frac{\alpha}{2}\right), \tag{22}$$

where α is fine structure constant. It follows from the above that for X smaller then the critical distance X^{*}_{rc}, radiative cooling can dominate over collisional heating and gaso-kinetic pressure of the electron may be too small to stop the nuclei and to prevent radiative collapse of the quasi-molecule.

Considering radiative collapse of D_2^{+}, quasi-molecular system one must have in view that the electron moving along a strongly elongated trajectory approaches very closely to the nucleus, and exchange of energy with individual nucleons (proton and neutron), via spin magnetic forces, may be important. The energy which the electron at a single trip around the nucleus can get from the individual nucleon, may be as high as:

$$\Delta E_{p(n)} \approx \left[\frac{\mu_{p(n)}\mu}{r_\mu^3} \right]_{r_\mu = \frac{1}{2}\lambda_c \alpha^{1/3}} = \frac{4}{\alpha^2} \cdot \frac{m}{m_p} \cdot \frac{\mu_{p(n)}}{\mu} \cdot \frac{e^2}{2a_0}, \qquad (23)$$

where $\mu_{p(n)}$ is the magnetic moment of a proton (neutron), μ is the magnetic moment of the electron and r_μ is the distance of closest approach of the electron to the nucleus (λ_c is Compton wave length of electron). During the whole collapse phase, a significant amount of internal energy of fusing nuclei may be, therefore, transferred from individual nucleous to the electron and released in the form of soft X-ray radiation. As a result, other channels of nuclear synthesis, like synthesis He^4 directly from two deuterons, may exist.

Considering other possibilities of molecular fusion one must have in view that proton and deuteron can fuse and He^3 as well as tritium can be produced:

$$D+e+p \begin{cases} \nearrow T + h\int d\nu \\ \searrow H_e^3 + e + h\int d\nu \end{cases}$$

One can be suprised but quasi-molecular synthesis of deuterium from protons cannot be a priori excluded.

EXPERIMENTAL MYSTERIES AND THE THEORY

As follows from informations gathered from various laboratories in USA and all over the world, see for instance DOE report, the following may be considered as well established facts:

- until now nobody but Fleischmann and Pons has observed a distinct release of heat,
- small unreproducible and uncontrolable heat bursts are time to time observed,
- there is lack (or minute quantities only) of neutrons and gamma rays,
- quantum calculations are in qualitative disagreement with experimental results (there were recently undertaken some efforts to modify the existing theory but results seems still to be unsatisfactory[25-27]

Traying to understand enigmatic results and lack of sucess in reproducing the Fleischmann and Pons experiment one must have in view that conditions of the original experiment still remain unknown. Various investigators supposing the effect may depend upon the structure of the material of the electrode , have used Pd-electrodes of various dimensions and shapes, and made by means of different technologies. Nobody, however, has used Pd-electrode manufactured from a single crystal and there are some reasons to suppose that the electrode should be cut from a single crystal[28].

Thus, on the basis of considerations carried out above one can suppose that the collaps of a needle-like hydrogen quasimolecule to

the nuclear size may be not possible at a lack of axial symmetry in the material enviroment. Estimations show that even relatively small perpendicular component of the electric field around the central point of the quasimolecule may have a destructive influence upon the collapse phase and a good axial symmetry of the field may be achieved in the regular crystalic lattice only. To mantain a good field symmetry there must be some order in localisation and orientation of the needle like D_2 quasimolecules - those should be oriented in the whole crystal in the same way (and this implies that electric field during electrolysis should be oriented along one of the main axis of the Pd-lattice).

If Pd-electrode is prepared from a polycrystalic material than the basic parameter of the experiment is in fact out of control. One can suppose that small heat bursts that were sometimes observed during the electrolysis were due to uncontrolled phase transistions in individual crystalic domaines. Since the typical seize of the domain is of the order of 10^{-3} cm, therefore, the heat bursts in experiments with polycrystalic electrodes ought be by nine order of magnitudes smaller, than in the Fleischman and Pons experiment being bellow sensitivity of any calorimetric measurement. Occasionely only the domain may be as large as one milimiter and only those heat bursts may be detected. Since each domain works once experimental results with polycristalic electrodes can not be reproducible *).

Commenting negative results reported by many investigators trying to replicate Fleischmann and Pons experiment one must have in view, that neutrons and hard γ-rays in the quasi-molecular mechanism may be not emited, and traditional nuclear diagnostics is not suitable to observe the cold fusion synthesis (soft X-rays diagnostics should be used).

Summarising, it seems justified to claim that the radiative collapse form the essence of cold fusion. Whithin this concept one can quite satisfactorilly explain:

- geophysical data on heat generation in the Earth mantle and relative abundance of light elements;
- high local concentrations of He^3 in some minerals;
- heat generation in the electrolytical Pd-device;
- negligible amounts of neutrons and γ-rays in the cold fusion experiments;
- occasional emission of neutrons and γ-rays in form of bursts and spikes.

*) It is worthy to note that in the Fleischmann and Pons enigmatic paper there are some hints, that their electrode was made from a single crystal . From acknowledgments of the first version of their paper one can learn that the used palladium was not ordinary commercial palladium. Moreover, their Pd-electrode, accordingly to the cubic symmetry of the lattice had the form of a cube. A remark made by Pons during one of his oral talks, see DOE report, that electrode should be properly cut does make sense in the only case, if the material used for the electrod was a single crystal.

Since the fusion activation energy ot the quasi-molecule is not small (in the molecular energy scale), the initial collaps phase is very sensitive to physical conditions existing in the lattice, and the fusion goes whithout emission of neutrons and γ-rays one can understand the lack of rapid succes in replication of Fleischmann and Pons experiment.

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