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NEUTRINO CATALYSIS OF NUCLEAR SYNTHESIS REACTIONS IN COLD HYDROGEN

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Abstract

It is shown that the nuclear reaction of fusion in cold hydrogen is possible due to formation of metastable atoms of dineutroneum existing as a bound state of two neutrons and one neutrino. Such atoms can appear in a reaction of deuterons with free or quasi-free electrons. The estimation of mass, size and lifetime of dineutroneum atom is fulfilled.

1 Introduction

There are considered here low energy nuclear reactions (LENR) which lead to transmutations of elements. These reactions result at super-low energies of particles without accompanying intensive ionizing radiation [1]. The cold fusion (CF) is the nuclear synthesis reaction in gaseous, or absorbed by condensed matter hydrogen at the temperature $T_{cf} \leq 10^3 K$ that is essentially lower, than for thermonuclear reactions [2]. There is an opinion that physical lows forbid such processes. However, this opinion is wrong.

In 1937 L.W. Alvarez discovered the electron capture, what is the simplest example of LENR. In 1957 in the Berkley Nuclear Centre (USA), the research team headed by L.W. Alvarez [3] discovered the μ - catalysis. So, both LENR and the cold fusion were discovered by the same person, and he is the Nobel prize-winner (1968) L.W. Alvarez.

Unfortunately, majority of scientific community ignores the experimentally observable existence of LENR. This happens, to my mind, in consequence of:

- the absence of the conventional mechanism of the deuterons electrical

  charge screening;

- the fact, that the probability for thermal deuterons to overcome the Coulomb barrier is unimaginably small ($P \sim 10^{-2730}$).

A new mechanism of CF reactions were suggested in [1]. This mechanism does not contradict the known laws of physics and is based on the phenomenon of generating neutron-like particles with large internal energy. These particles were revealed in experiments with an electron accelerator [4]. Later on, these particles were interpreted as the bound state of the two neutrons and one neutrino [1].

Laws of physics do not impose basic theoretical bans on the existence of the metastable bound state of the two neutrons and neutrino, because a neutrino is a massive particle [5].

Due to interaction with quarks in a nucleon, a neutrino can "linger" inside it. This delay is caused, because the effective $N\nu$ - potential

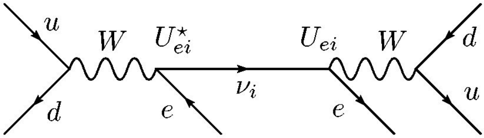

Figure 1: The typical diagram of the electroweak process [6,7].

corresponding to W - boson exchange (Fig. 1), is a short-range and very deep one. Its depth is still rather small to keep antineutrino, proton and electron in the bound state (i.e. like a neutron) for a long time, but just enough to consider a proton like the stable bound state of three particles, positron, neutron and neutrino. It is well known, that three-body effects allow an existence of 3 particles' bound states, which pair potentials are insufficiently deep to form 2 particles' bound states.

A long lifetime of the neutrino inside a nucleus can be treated on the basis of exotic Miheev - Smirnov - Volfenstein effect at low energies [8]. Let us explain this in more detail. If the energy of incoming electron is resonant (i.e. renormalized masses of all three types of neutrinos (ν_e, ν_μ, ν_τ) inside a nucleon are approximately equal after the electron capture), the exotic nucleus is generated at the first stage of electroweak process (two left vertexes in the diagram 1), which cannot decay until an oscillation have been finished. The exotic nucleus D_ν is metastable, because the energy conservation law forbids its decay with μ - or τ - lepton emission. The channel $D_\nu \to 2n + \nu_e$ is also closed. Thus, theoretical consideration of the bound state of the neutrino inside a nucleus in the framework of any potential model gives us only phenomenological description of the observable effect.

From this standpoint, we shall consider hypothetical metastable exotic atom (exotic nucleus) dineutroneum, which is the bound state of two neutrons and one neutrino, as was mentioned above. The aim of this work is to estimate the mass, size and lifetime of the dineutroneum atom which is formed due to the interaction of deuterons with electrons.

2 Main formalism

The known Hamiltonian of weak interaction is

$$H' = \frac{G}{\sqrt{2}} \int J^{\lambda +}(\vec{r})\hat{G}(\vec{r},\vec{r}\,')J_\lambda(\vec{r}\,')d\vec{r}d\vec{r}\,', \qquad (1)$$

with G the Fermi constant of universal weak interaction, $J_\lambda(\vec{r}$ the weak current, and $\hat{G}(\vec{r},\vec{r}\,')$ the propagator. Let us introduce definition in accord to [9]

$$J^{\lambda +} = (J_\lambda)^+, \qquad \lambda = 1,2,3,$$
$$J^{4+} = -(J_4)^+, \qquad (2)$$

and similarly for others 4- vector operators. In the standard model, the weak interaction is caused by exchange of the W- boson with mass $\approx 90 GeV$. Therefore, if we consider the low energy weak processes, an approximation $m_W \to \infty$ can be used. Accordingly, the interaction is quite local, and components of the weak current in Hamiltonian (1) should be taken at the same point of space $\hat{G}(\vec{r},\vec{r}\,') = \delta(\vec{r}-\vec{r}\,')$. Hence

$$H' = \frac{G}{\sqrt{2}} \int J^{\lambda +}(\vec{r})J_\lambda(\vec{r})d\vec{r}. \qquad (3)$$

The Lorenz invariant weak current is well known. For example, β - decay of a neutron is described by the Hamiltonian [9]

$$H' = \frac{G}{\sqrt{2}} \int [\overline{\psi}_n(\vec{r})\gamma^\lambda(1+\gamma_5)\psi_p(\vec{r})]^+ \cdot [\overline{\psi}_e(\vec{r})\gamma_\lambda(1+\gamma_5)\psi_{\nu_e}(\vec{r})]d\vec{r}. \qquad (4)$$

To describe the weak processes in nuclear physics, one needs a non-relativistic Hamiltonian $h'(\vec{r}))$. The model of the Hamiltonian was derived in the early papers by Fermi, Gamov and Teller, and looks like [9]

$$h'(\vec{r},t) = \frac{G}{\sqrt{2}}\{i\beta[f_1\gamma_\lambda + f_2\sigma_{\lambda\rho}k^\rho + (g_1\gamma_\lambda + ig_2k_\lambda)\gamma_5]\}^+ j^\lambda(\vec{r},t) + h.c. \qquad (5)$$

In (5)

$$j_\lambda(\vec{r},t) = [i\overline{\psi}_l(\vec{r})\gamma_\lambda(1+\gamma_5)\psi_{\nu_l}(\vec{r})] \cdot exp\left(-\frac{i}{\hbar}(E_{\nu_l} - E_l)t)\right) \qquad (6)$$

is the lepton current, E - the energy positive for particles and negative for antiparticles, f_1, f_2, g_1, g_2 the formfactors, $\psi(\vec{r})$ - lepton wave function (WF).

In the works devoted to the nuclear β - processes, the WFs of free leptons in (6) are usually chosen as plane waves with the momentum $\vec{p}$[1]. Thus, the lepton's current (6) looks like:

$$j_\lambda(\vec{r},t) = L^{-3} b_\lambda exp(i\vec{k}\cdot\vec{r})\cdot exp\left(-\frac{i}{\hbar}(E_\nu - E_e)t\right) \qquad (7)$$

where $\vec{k} = \vec{\nu} - \vec{e}$ is the lepton transferred momentum, v the wave vector of the neutrino, e the wave vector of the electron, L^3 is the normalization volume,

$$b_\lambda(\underline{m}_e, \underline{m}_\nu) = (i\overline{u}(\underline{m}_e)\gamma_\lambda w_\nu(\underline{m}_\nu)) \qquad (7)$$

and

$$w_\nu(\underline{m}_\nu) = (1+\gamma_5)u_\nu(\underline{m}_\nu). \qquad (9)$$

The spinor

$$w_\nu(\underline{m}_\nu) = \frac{1}{\sqrt{2}}\begin{pmatrix}1\\-1\end{pmatrix}(1-(\vec{\sigma}\cdot\vec{\nu}))\,\chi_{1/2}(\underline{m}_\nu), \qquad (10)$$

$m_\nu = \pm 1/2$ the spin projection of neutrino (corresponds to spin "up" and spin "down").

The lifetime of dineutroneum can be estimated within the approximation of allowed transitions. Therefore, we shall neglect the small contribution of the terms $\hbar k/(Mc)$, p/Mc, kR due to the forbidden transitions, and obtain the non-relativistic limit of the Hamiltonian (5) in the plane wave approximation [9]:

$$h'(\vec{r}) = \frac{G}{\sqrt{2}L^3} e^{i\vec{k}\vec{r}} \cdot \sum_{j=1}^{A} [if_1 \cdot b_4 - g_1(\vec{b}\cdot\vec{\sigma}]_j \cdot (\tau_+)_j \cdot \delta(\vec{r}-\vec{r}_j) + \ldots \qquad (11)$$

The Pauli matrixes τ_1 and τ_2 (τ_{+1}, τ_{-1}) are well known:

$$\begin{cases} \tau_+ = (\tau_1 + i\tau_2)/2 = -\tau_{+1}/\sqrt{2} & \rightarrow \quad \tau_+|p>=|0>,\ \tau_+|n>=|p>, \\ \tau_- = (\tau_1 - i\tau_2)/2 = \tau_{-1}/\sqrt{2} & \rightarrow \quad \tau_-|n>=|0>,\ \tau_-|p>=|n>. \end{cases} \qquad (12)$$

[1] In reactions of electron capture, - decay into a bound state and in mesoatoms the charged lepton occupies the bound state and its WF belongs to the discrete spectrum

The approximated Hamiltonian (11) is used to describe the nuclear processes with the dineutroneum.

First, we take into account, that the mass of dineutroneum is less than the double mass of the neutron. Therefore, neutrino in the atom of dineutroneum is in the bound state, and the Hamiltonian looks like

$$h'(\vec{r}) = \frac{G_\beta}{\sqrt{2}L^{3/2}}\psi_\nu(\vec{r}_c)\cdot e^{-i\vec{\epsilon}\cdot\vec{r}}\cdot\{\sum_{i=1}^{2}\delta(\vec{r}-\vec{r}_c)[ib_4-\lambda\cdot(\vec{b}\cdot\vec{\sigma}^i)]\tau_+^{(i)}\}+h.c, \tag{13}$$

where $\psi_\nu(\vec{r}_c)$ is the spatial part of the neutrino's WF, $G_\beta = f_1 G$, index c indicates the radius-vector of the neutrino which origin is in the centre- mass of the dineutroneum because of translation-invariance of the Hamiltonian $h'(\vec{r})$.

According to a "golden Fermi's rule", the probability of the transition to the continuum states per unit of time is equal:

$$dw_{fi} = \frac{2\pi}{\hbar}\delta(E_f - E_i)\left|< f|V|i >\right|^2 dn_f. \tag{14}$$

Hence, the decay probability of the bound state of two neutrons and one neutrino within the channel $D_\nu \to d + e^-$ per the time unit is equal to:

$$w_{D_\nu\to d+e^-} = \frac{2\pi}{\hbar}\int\frac{L^3 d\vec{p}_e}{(2\pi\hbar)^3}\cdot\frac{L^3 d\vec{p}_d}{(2\pi\hbar)^3}\cdot\delta(E_i - E_f)\times$$

$$\times\int\left\langle\left|\left\langle d|h'(\vec{r'}|D_\nu^{(N)}\right\rangle d\vec{r'}\right|^2\right\rangle. \tag{15}$$

The WFs $|D_\nu^{(N)} >$ and $< d|$ depend on the coordinates, spins and isospins of nucleons, and matrix elements of the transition $D_\nu \to d + e^-$ in the space of leptons are already included into the Hamiltonian $h'(\vec{r'})$ by definition. The external triangular brackets in (15) mean the averaging by projections of spins of all initial particles, and analogous summation in the final state.

Let us now consider the β - decay of the dineutroneum. The initial and final states in this case are[2]:

$$\begin{cases} \left|D_\nu^{(N)}\right\rangle = \frac{1}{\sqrt{L^3}} e^{i\vec{k}_{D_\nu}\vec{R}_{D_\nu}}\psi_{2n}(\vec{r}_2-\vec{r}_1)\chi_{00}(\vec{S})\chi_{1-1}(\vec{T}), \\ \\ |d\rangle = \frac{1}{\sqrt{L^3}} e^{i\vec{k}_d\vec{R}_d}\psi_d(\vec{r}_2-\vec{r}_1)\chi_{1m_d}(\vec{S})\chi_{00}(\vec{T}). \end{cases} \quad (16)$$

Consequently, the matrix element in (15) looks like

$$\int \left\langle d\left|h'(\vec{r}')\right| D_\nu^{(N)}\right\rangle d\vec{r}' == \frac{1}{L^3}\int d\vec{r}' d\vec{r}_1 d\vec{r}_2 e^{i(\vec{k}_{D_\nu}\vec{R}_{D_\nu}-\vec{k}_d\vec{R}_d)}\psi_d^*(\vec{r}'')\times$$

$$\times\psi_{2n}(\vec{r}'')\left\langle \chi_{1m_d}^+(\vec{S})\chi_{00}^+(\vec{T})|h'(\vec{r}')|\chi_{00}(\vec{S})\chi_{1-1}(\vec{T})\right\rangle, \quad (17)$$

where $\vec{r}'' = \vec{r}_2 - \vec{r}_1$.

The "nuclear" spin of the dineutroneum $J_i = 0$ and the deuteron's spin $J_f = 1$. Thus, we deal with the Gamov - Teller transition. According to it

$$h'_{GT}(\vec{r}) = \frac{-\lambda\cdot G_\beta}{\sqrt{2}L^{3/2}}\psi_\nu(\vec{r}_c)e^{-\vec{\epsilon}\cdot\vec{r}}\left\{\sum_{i=1}^{2}\delta(\vec{r}-\vec{r}_i)\cdot(\vec{b}\cdot\vec{\sigma}^i)\cdot\tau_+^i\right\} + h.c. \quad (18)$$

We consider the dineutroneum β - decay in its rest system. In this case $k_{D_\nu} = 0$, and (18) is simplified (details see in the Appendix):

$$\int < d|h'(\vec{r}|D_\nu^{(N)} > d\vec{r} = \frac{\lambda G_\beta\sqrt{3}}{2L^{9/2}}C_{1-m_d,1/2m_\nu}^{1/2m_e}\times$$

$$\times\int d\vec{R}d\vec{r}e^{-i\vec{k}_e\vec{R}}\psi_d^*(\vec{r})\psi_{2n}(\vec{r})\sum_{i=1}^{2}\psi_\nu(\vec{r}_i-\vec{R})e^{-i\vec{\epsilon}\vec{r}_i}. \quad (19)$$

We determine the formfactor

$$f_{overlap}^{d\Leftrightarrow D_\nu}(|\vec{e}|) = \int cos(\vec{e}\cdot\vec{r}/2)\psi_d^*(\vec{r})\psi_\nu(\vec{r}/2)\psi_{2n}(\vec{r})d\vec{r} \equiv (V_{eff}^{D_\nu})^{-1/2}. \quad (20)$$

The $V_{eff}^{D_\nu}$ means an effective volume of exotic atom of dineutroneum. This circumstance allows to present eq. (19) in the extremely compact form:

$$\int \left\langle d|h'(\vec{r})|D_\nu^{(N)}\right\rangle d\vec{r} =$$

[2]See details in [1].

$$= \frac{\lambda G_\beta \sqrt{2}}{L^{9/2}} (2\pi)^3 \delta(\vec{k}_d + \vec{e}) f_{overlap}^{d \Leftrightarrow D_\nu}(|\vec{e}|)(-1)^{1/2+m_\nu} C^{1m_d}_{1/2-m_e, 1/2m_\nu}. \quad (21)$$

In turn, eq. (15) can be presented in the form which is suitable for numerical calculations

$$w_{D_\nu \to d+e^-} = \frac{2\pi}{\hbar} \int \frac{d\vec{p}_e}{(2\pi\hbar)^3} \cdot \delta(E_i - E_f) \cdot 3 \cdot |\lambda G_\beta f_{overlap}^{d \Leftrightarrow D_\nu}(|\vec{e}|)|^2, \quad (22)$$

and evaluate the integral

$$I^{ph}_{D_\nu \to d+e^-}(p_e) = \int d\vec{p}_e \cdot \delta(E_i - E_f) = 4\pi \int dp_e p_e^2 \delta(E_{D_\nu} - E_d - E_e). \quad (23)$$

All the particles in our case are non-relativistic. Consequently,

$$E_{D_\nu} = m_{D\nu} c^2 + \frac{p^2_{D_\nu}}{2m_{D_\nu}},$$
$$E_d = m_d c^2 + \frac{p_d^2}{2m_d}, \quad (24)$$
$$E_e = m_e c^2 + \frac{p_e^2}{2m_e}.$$

As a result,

$$I^{ph}_{d_\nu \to d+e^-} \approx 4\pi p_e m_e, \quad (25)$$

where the momentum

$$p_e = \sqrt{2m_e \left(m_{D_\nu} c^2 - m_d c^2 - m_e c^2\right)}, \quad (26)$$

corresponds to $\vec{p}_{D_\nu} = 0$ in the rest system of dineutroneum.

The internal energy of the dineutroneum U_{D_ν} is equal to

$$U_{D_\nu} = m_{D_\nu} c^2 - m_d c^2 - m_e c^2 > 0. \quad (27)$$

Thus, eq. (26) can be presented in a rather compact form

$$p_e = \sqrt{2m_e U_{D_\nu}} \quad (28)$$

and we get the following expression:

$$w_{D\nu \to d+e^-} = \frac{3}{\pi\hbar^4} \cdot m_e \cdot \sqrt{2m_e U_{D_\nu}} \cdot |\lambda G_\beta f_{overlap}^{d \Leftrightarrow D_\nu}(|\vec{e}|)|^2. \quad (29)$$

The momentum dependence of the formfactor (20) at the low energies can be neglected

$$f^{d\Leftrightarrow D_\nu}_{overlap} = \int \psi^*_d(\vec{r})\psi_\nu(\vec{r}/2)\psi_{2n}(\vec{r})d\vec{r} \equiv (V^{D_\nu}_{eff})^{-1/2} \tag{30}$$

and

$$w_{D_\nu\to d+e^-} = \frac{3\lambda^2 \cdot G_\beta}{\pi\hbar^4 V^{D_\nu}_{eff}} cdotm_e \cdot \sqrt{2m_e U_{D_\nu}}. \tag{31}$$

Formula (30) determines the overlap integral $f^{d\Leftrightarrow D_\nu}_{overlap}$. For estimations, we accept that the bound particles participating in the reaction $D_\nu \to d + e^-$ have the orbital momentum equal to zero, and their wave functions look like

$$\psi_d(r) = \frac{1}{\sqrt{4\pi}}\frac{\chi_d(r)}{r}; \quad \psi_{2n}r\frac{1}{\sqrt{4\pi}}\frac{\chi_{2n}(r)}{r}; \quad \psi_\nu(r) = \frac{1}{\sqrt{4\pi}}\frac{\chi_\nu(r)}{r}. \tag{32}$$

Only Hulten's WF $\chi_d(r)$ in (32) is known

$$\chi_d(r) = Aexp(-\alpha_d r)[1 - exp(-\mu r)] \tag{33}$$

with the normalization constant

$$A_d = [2\alpha_d(\alpha_d + \mu)(2\alpha + \mu)]^{1/2}\,\mu^{-1}. \tag{34}$$

Here $\alpha_d = \sqrt{m_N|E|}/\hbar \approx 0.232\,fm^{-1}, \quad \mu \approx 1.1\,fm^{-1}$ [10].

We assume that

$$\chi_{2n}(r) = A_{2n}exp(-\alpha_{2n}r)\left[1 - exp(-\mu r)\right], \tag{35}$$

with

$$A_{2n} = [2\alpha_{2n}(\alpha_{2n} + \mu)(2\alpha_{2n} + \mu]^{1/2}\mu^{-1} \tag{36}$$

and equal parameters μ for deuteron and dineutroneum. For the sake of simplicity we suppose

$$\chi_\nu(r) = A_\nu exp(-2\kappa r), \tag{37}$$

where $A_\nu = [4\kappa]^{1/2}$.

According to (30)

$$f_{overlap}^{d\Leftrightarrow D_\nu^{(N)}} = \frac{2}{\sqrt{4\pi}} \int\limits_0^\infty \frac{\chi_d(r)\chi_\nu(r/2)\chi_{2n}(r)}{r} dr. \qquad (38)$$

This integral in a view of (33), (35) and (37) can be calculated analytically

$$f_{overlap}^{d\Leftrightarrow D_\nu^{(N)}} = \frac{A_{2n}A_dA_\nu}{\sqrt{\pi}} ln \left(\frac{\alpha_{2n}^{(\nu)})^2}{(\alpha_{2n}^{(\nu)})^2 - \mu^2} \right), \qquad (39)$$

where $\alpha_{2n}^{(\nu)} = \kappa + \alpha_d + \alpha_{2n} + \mu$. In this work, we suppose $\chi_d(r) \approx \chi_{2n}(r)$ (i.e. $\alpha_{2n} \sim \alpha_d$).

Let us estimate $V_{eff}^{D_\nu}$ in the rough approximation $\alpha_{2n} = \alpha_d$. The decaying dineutroneum is created in the reaction of electron capture by deuteron. Thus, we suppose neutrino to be "smeared" in a deuteron. This assumption implies an estimation $\kappa = \alpha_{2n} = 0.232\, fm^{-1}$. Consequently, we estimate $V_{eff}^{D_\nu} \approx 20\, fm^3$.

The standard Coulomb corrections also can be considered

$$w_{D_\nu \Leftrightarrow d+e^-} = \frac{3|\lambda|^2 \cdot |G_\beta|^2}{\pi\hbar^4 V_{eff}^{D_\nu}} \cdot m_e \cdot p_e \cdot F(\eta). \qquad (40)$$

The Fermi function $F(\eta)$ in the "point-like deuteron" approximation is equal to [11]

$$F(\eta) \approx \pi\eta \cdot exp(\pi\eta) sh^{-1}(\pi\eta). \qquad (41)$$

All previous calculations were carried out under the assumption, that neutrino inside the dineutroneum is the electron's neutrino $|\nu_e>$. Taking account the MSV- effect, we insert the electron's neutrino weight $\left\langle | <\nu|\nu_e> |^2 \right\rangle \sim \frac{1}{2} \sim \frac{1}{3}$ into (40) [8]:

$$w_{D_\nu \Leftrightarrow d+e^-} = \left\langle | <\nu|\nu_e> |^2 \right\rangle \cdot \frac{3|\lambda|^2 \cdot |G_\beta|^2}{\pi\hbar^4 V_{eff}^{D_\nu}} \cdot m_e \cdot p_e \cdot F(\eta), \qquad (42)$$

where $\left\langle | <\nu|\nu_e> |^2 \right\rangle$ is the probability for the neutrino to be in the state $|\nu_e>$ in the dineutroneum.

$T_e[eV]$	$w^0_{D_\nu \to d+e^-}$	$w^c_{D_\nu \to d+e^-}$	$t^c_{D_\nu}$
0.1	16.5	1.1×10^3	9.3×10^{-4}
1.0	4.8×10^1	1.1×10^3	9.3×10^{-4}
10	1.5×10^2	1.1×10^3	9.3×10^{-4}
10^2	4.8×10^3	1.2×10^3	8.3×10^{-4}
10^3	1.5×10^3	2.1×10^3	4.7×10^{-4}

Table 1: The energy dependence of w^0, w^c and the lifetime $\tau^c_{D_\nu}$.

In the table 1 the values of w^0, w^c and a lifetime $\tau^c_{D_\nu} = 1/w^c_{D_\nu \Leftrightarrow d+d^-}$ are displayed. An approximation $V^{D_\nu}_{eff} = 20\, fm^3$, $< \nu|\nu_e >= 1$ is used.

We can see from the table 1, that at the low energies, the probability of the β - decay of the dineutroneum can increase almost by two orders of magnitude owing to the Coulomb interaction. At $T_e > 1KeV$ this effect becomes insignificant. Therefore, if the dineutroneum atom is created, it lives long enough. The threshold of its creation is estimated at the level $10 - 15eV$, what is much lower than that for thermonuclear reactions $T_{tresh} << T_{tn} \sim 10KeV$.

Let us consider the dependence of the dineutroneum lifetime on its size. This dependence should be taking account, since the triplet length of the neutron-neutron scattering much exceeds the deuteron's effective radius r_d. Table 2 demonstrates the results of theoretical calculations of the β - decay rate
$w^c_{D_\nu \to d+e^-}$ and lifetime $\tau^c_{D_\nu}$ as a function of the parameter α_d/α_{2n} at $T_e = 10Tev$ (we suppose that $\kappa = \alpha_{2n}$).

It follows from Table 2, that if the size of dineutroneum alike the size of deuterium mesoatom, its lifetime would be almost 3 seconds. Consequently, one can conclude that the exotic dineutroneum atom is metastable and its lifetime $\tau_{D_\nu} \sim 10^{-3}\, sec$, i.e. three orders more than lifetime of the muon [5] $\tau_\mu = (2.197019 \pm 0.000021) \times 10^{-6}\, s$.

Our preliminary analysis shows, that such properties of dineutroneum as: metastability, electrical neutrality and small sizes, allow nuclear reactions of dineutroneum with nuclei in condensed matter.

If we take into account large cross section of the e - capture ($\sigma \sim$ 10 mbarn for the $e^- + D \to D_\nu + X$ reaction [4], it is possible easily explain a numerous experimental data on cold fusion in the condensed

α_d/α_{2n}	$w^c_{D_\nu \to d+e^-}$	$\tau^c_{D_\nu}$
1	1.1×10^3	9.3×10^{-4}
10	3.1×10^3	3.2×10^{-2}
10^2	$3.6\times^{-1}$	2.7

Table 2: The dependence of rate of the β - decay of the dineutroneum on the ratio α_d/α_{2n}.

matter (see [1, 12, 13, 19, 20]). For example, there are observed [19,20] such reactions as

$$D_\nu +^A_{46} Pd \to^{A+1}_{46} Pd + p + e^-$$

$$D_\nu + p \to \begin{cases} t + \nu_e + 5.45 Mev \\ ^3_2He + e^- + 5.47 Mev \end{cases} \tag{43}$$

$$D_\nu + d \to^4_2 He + e^- + 23.85 MeV.$$

3 Conclusions:

1. The atom of dineutroneum is metastable ($\tau_\nu \sim 10^{-3}\, s$).
2. The size of dineutroneum are commensurable with the size of deuteron.
3. The mass of dineutroneum $M_{D_\nu} = 2.01410223\, e = 1876.0979650\, MeV$.
4. Metastability, electrical neutrality and small size allow nuclear reactions of the dineutroneum exotic atoms with nuclei both in gases, and in a condensed matter (for example: $D_\nu + p \to t + \nu_e,\ D_\nu + p \to^3_2 He + e^-,\ D_\nu + d \to^4_2 He + e^-$). This presents the clear explanation of many experiments on cold fusion [14-22].

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Appendix. Spin and isospins matrix elements

The isospins matrix element is equal

$$\left\langle \chi_{00}(\vec{T})|\tau_{-}^{(i)}|\chi_{1-1}(\vec{T})\right\rangle =$$

$$= \frac{1}{\sqrt{2}}\left\langle [p(1)n(2) - p(2)n(1)]|\tau_{+}^{(i)}|n(1)n(2)\right\rangle = \frac{(-1)^{i-1}}{\sqrt{2}}. \qquad (A.1)$$

The spin matrix element is more complicated

$$\left\langle \chi_{1m_d}(\vec{S})|\sigma_k^{(i)}|\chi_{00}(\vec{S})\right\rangle = \sum_{m_1 m_2} C^{1m_d}_{1/2m_1,1/2m_2} \sum_{m_3 m_4} C^{00}_{1/2m_3,1/2m_4} \times$$

$$\times \left\langle \chi^{(1)}_{1/2m_1}\chi^{(2)}_{1/2m_2}|\sigma_k^{(i)}|\chi^{(1)}_{1/2m_3}\chi^{(2)}_{1/2m_4}\right\rangle \qquad (A.2)$$

According to the Clebsh - Gordan coefficients' properties

$$\left\langle \chi_{1m_d}(\vec{S})|\sigma_k^{(i)}|\chi_{00}(\vec{S})\right\rangle = -\left\langle \chi_{1m_d}(\vec{S})|\sigma_k^{(i)}|\chi_{00}(\vec{S})\right\rangle. \qquad (A.3)$$

If $i = 1$ one obtains

$$S_f = \sum_{m_1 m_2} C^{1m_d}_{1/2m_1,1/2m_2} \sum_{m_3,m_4} C^{00}_{1/2m_3,1/2m_4}\delta_{m_2 m_4}\left\langle \chi^{(1)}_{1/2m_1}|\sigma_k^{(1)}|\chi^{(1)}_{1/2m_3}\right\rangle. \qquad (A.4)$$

It is evident, that

$$\sigma|mu\chi_{1/2\sigma} = -\sqrt{3}\sum_{\sigma'} C^{1/2\sigma'}_{1\mu 1/2\sigma}\chi_{1/2\sigma'}. \qquad (A.5)$$

Thus

$$S_f = \sqrt{3}\sum_{m_1,m_2,m_3} C^{1m_d}_{1/2m_2 1/2m_1} C^{00}_{1/2m_2 1/2m_1} C^{km_1}_{1k1/2m_1} \qquad (A.6)$$

and:

$$S_{C-G} = \sum_{m'',\sigma,\sigma'} C^{j'm'}_{j''m''1/2\sigma'} C^{jm}_{j''m''1/2\sigma} C^{1/2\sigma'}_{1\mu 1/2\sigma} \equiv \sqrt{2\cdot\hat{j}'\cdot\hat{j}}\cdot F_{ang} =$$

$$= \sqrt{2 \cdot \hat{j}' \cdot \hat{j}} \sum_{m'',\sigma,\sigma'} (-1)^{l-1/2+m''+j''-1/2+m+1/2+\sigma'} \times$$

$$\times \begin{pmatrix} j'' & 1/2 & j' \\ m'' & \sigma' & -m' \end{pmatrix} \begin{pmatrix} j'' & 1/2 & j \\ m'' & \sigma & -m \end{pmatrix} \begin{pmatrix} 1 & 1/2 & 1/2 \\ \mu & \sigma & -\sigma' \end{pmatrix}, \quad (A.7)$$

where $\hat{j} = 2j + 1$. The sum of three $3jm$ - Wigner symbols F_{ang} is equal to

$$F_{ang} = (-1)^{j-1/2+l+j'+m'} \begin{pmatrix} j' & 1 & j \\ m' & -\mu & m \end{pmatrix} \begin{pmatrix} j' & 1 & j \\ 1/2 & l & 1/2 \end{pmatrix}. \quad (A.8)$$

Inserting (8) in (7), we get the value of S:

$$S = \sqrt{2(2j+1)}(-1)^{j+l-1/2} C^{j'm'}_{1\mu m} \begin{pmatrix} j' & 1 & j \\ 1/2 & l & 1/2 \end{pmatrix}. \quad (A.9)$$

Thus, we derive the result

$$\left\langle \chi_{1m_d}(\vec{S}) | \sigma^{(i)}_k | \chi_{00}(\vec{S}) \right\rangle = (-1)^{i-1} \delta_{-k,m_d}. \quad (A.10)$$

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Comment on NEUTRINO CATALYSIS OF NUCLEAR SYNTHESIS REACTIONS IB COLD HYDROGEN

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In the paper of Dr. Ratis it has been discussed how the nuclear reaction of fusion in cold hydrogen is possible due to formation of metastable atoms of dineutroneum existing as a bound state of two neutrons and one neutrino. According to this approach, such atoms can appear in a reaction of deuterons with free or quasi-free electrons.

I do not have any opinion concerning the possibility of cold fusion. As it is very well know, it is a very exciting field, without any experimental conformation so far. However, the main result, namely the formation of metastable atoms of dineutroneum existing as a bound state of two neutrons and one neutrino, is extremely interesting. This model and calculations might be important for understanding of a number of not solved, or partially solved, problems of atom theory and quantum chemistry. I strongly recommend this paper of Dr. Ratis for publication.