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On the existence of long-living exoatom "neutroneum"

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***Abstract*—We demonstrate that exoatom "neutroneum" is the low-laying extremely narrow resonance in the elastic electron-proton scattering. This resonance is caused by the weak interaction and corresponds to the transition from initial state of the system "electron + proton" into the virtual neutron-neutrino pair. Due to its small width and amplitude, this resonance cannot be registered in the direct *ep*-scattering experiment. The third particle at the collision of the electron and the atom of hydrogen results a three-body effect. The cross-section of the neutroneum creation contains the two-particle propagator of the electron and proton (i.e., excited hydrogen) under the integral. Therefore the width of the electroweak *eH*-resonance at colliding the electron and the hydrogen atom is by fourteen orders more than the width of the similar resonance in elastic *ep*-scattering. Its properties can be investigated experimentally. The size, lifetime, threshold and cross-section of the neutroneum creation are estimated. It is shown that the threshold energy of the neutroneum creation is considerably smaller than the threshold energy of the thermonuclear reactions. It means that neutron-like nuclear-active particles can be created at ultralow energies, and, hence, can induce nuclear reactions similar to those, which are caused by neutrons, in all cases, when nuclear reactions with charged particles are forbidden by a high Coulomb barrier.**

I. Introduction

The hypothesis of exotic neutrinos atoms "neutroneum" and "dineutroneum" existence has been formulated and partially proved in [1], [2], [3], [4], [5], [6], [7]. This hypothesis is supported by experimental data on cold fusion which is forbidden by high Coulomb barrier. For example, the penetration factor of the Coulomb barrier for "cold nuclear fusion" at the room temperature is about $P \sim 10^{-2740}$.

The basic criticism of numerous works on "cold fusion" (CF) is based on this estimation and bad reproducibility of basic experimental data on CF. But a lot of experimental data was received in the best scientific laboratories, which incontestably proves that "forbidden" processes take place [8]. As it was mentioned in [8], the observable nuclear reactions are not thermonuclear. This conclusion concerns first of all helium, because the charge of its nucleus is twice more larger than a proton charge, and the Coulomb barrier at the low energies [8] is impenetrable.

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Experimental data [8] on nuclear reactions at high-current electric discharge in helium were confirmed by P.L. Kapitsa [9] (two years earlier than Kurchatov's [8]). Thus, results of the best experimentalists of the XX-th century indicate - we have to look for new, still unknown, mechanisms of "neutralization" of the electric charge of the lightest nuclei at low energies.

The hypothetical neutrinos exoatoms "neutroneum" and "dineutroneum" [1]-[7] are the possible particles, which induce CF and low energies nuclear reactions (LENR). According to it, we have to classify the neutrinos exoatoms in the framework of elementary particles physics.

Hypothetical particle "neutroneum" is created by a collision between the free electron and hydrogen atom, and than it decays into proton and electron [1]-[7]. The existence of the neutrinos exoatoms is possible because the Hamiltonian of the *ep*-interaction includes not only electromagnetic, but also weak terms (fig. 1).

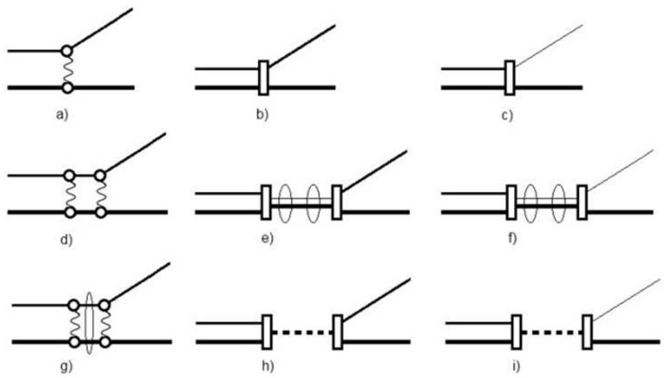

Figure 1. Electromagnetic and weak interaction amplitudes of elastic scattering and nuclear reactions at *ep*-collisions:
a) one-photon exchange, elastic scattering;
b) virtual Z^0-boson exchange, elastic scattering;
c) virtual W-boson exchange, reaction $e^- + p \to n + \nu_e$;
d) two-photon exchange, elastic scattering;
e) regular part of the contribution of two-step weak process into amplitude of $e^- + p \to e^- + p$ scattering;
f) regular part of the contribution of two-step weak process into amplitude $e^- + p \to n + \nu_e$ reaction;
g) contribution of the discrete spectrum states into elastic scattering;
h) singular part of the two-step weak process contribution (contribution of the pole corresponding to neutroneum creation) into amplitude of the elastic $e^- + p \to n_\nu \to e^- + p$ scattering;
i) singular part of the contribution of two-step weak process (contribution of the pole corresponding to neutroneum creation) into amplitude $e^- + p \to n_\nu \to n + \nu_e$ reaction.

Table I. Lines and vertexes of the Feynman diagrams

Symbol	Interpretation of the vertexes and lines	Comments
▯	Weak interaction	UFI, SM
∘	Electromagnetic interaction	QED
●	Strong interaction (vertexes f_{pNN}, f_{pND}, f_{rNN} и f_{rND})	RQT
∿∿∿	Photon	QED
– – – –	π- and ρ- meson	RQT
───	Neutrino	RQT, SM
───	Electron	QED, RQT, SM
━━━	Nucleon	RQT, SM
▬▬▬	Δ- isobar	RQT
	External line - hydrogen wave function Two-partical propagator of the proton and electron	QED, RQT
	Regular part of the two-partical propagator of the neutron and neutrino	RQT, UFI, SM
▪▪▪▪▪	External line – neutroneum wave function Singular part of the two-partical propagator of the neutron and neutrino	Hypothesis RQT, UFI, SM

Vertexes and lines of the Feynman's diagrams are described in Table I[1].

We will represent the two-partical propagator of the "neutrino + neutron" pair (fig. 1) as a sum of regular and singular terms (fig. 2).

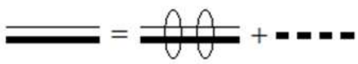

Figure 2. Two-partical propagator "neutrino + neutron". The first term ($\hat{r}$) - regular, and the second ($\hat{s}$) - singular.

If the energy of ingoing electron is over the threshold for $e^- + p \to n + \nu_e$ reaction, then neutron and neutrino are the real particles (fig. 1c).

The channel $e^- + p \to n + \nu_e$ is closed at the low energies, but diagram 1e is nonzero. Thus, the amplitude of the $ep \to n\nu_e$-transition $A_{ep\to n\nu_e} \neq 0$, and a time delay of the inverse transition $n\nu_e \to ep$ can be extremely long due to the high depth of effective n_ν- interaction potential (see, for example, [10]). This scenario is possible, if the amplitude $A_{ep\to n\nu_e} \neq 0$ has a pole in the complex energy plane. In this case, we deal with the authentic resonance.

The long-living hadron resonances, caused by the strong interaction, are traditionally considered as elementary particles. In our case, a leptonic number of the resonance, caused by the weak interaction, is nonzero. Therefore we have to consider it as neutrino's exoatom.

The basic argument against the existence of such exoatoms - Compton wavelength of neutrino is much larger than nucleon radius. But an existence of the bound states of the relativistic particles which Compton wavelength $\lambda_C > R_0$ (R_0 - interaction radius) is strictly forbidden by Heisenberg uncertainty principle [11], [12], [13].

The main counterargument is that a neutron decays into proton, electron and electronic anti-neutrino. There is no lepton that satisfies the above mentioned criterion: "uncertainty principle ⇔ leptons Compton wavelength" in this case. Heisenberg proposed a rational solution of this problem [13]. He postulate that a relation between "a part and a whole" in microcosm and macrocosm are rather different. From this point of view, neutroneum (hypothetical particle, the leptonic number $L_e = 1$) is completely similar to a neutron, because in both cases only β-decay channel is open. Moreover, we can consider neutron as an exotic electroweak resonance. One can create it, for example, by the weak process $e^- + p \to n + \nu_e$ (if the electron energy is higher than the reaction threshold energy). We will prove this statement.

Neutron decay $n \to p + e^- + \tilde{\nu}_e$ indicates its electroweak nature and permits us to establish analogue of hadron resonances [14] and electroweak resonances. To explain this analogy we consider the well-known hadron resonance - Δ-isobar.

The excitation of this resonance takes place, for example, in pp-collision at the intermediate energies (charge-exchange reaction $p + p \to n + \Delta^{++}$, fig. 3). There are two stable particles (protons) in the initial state and two unstable particles (neutron and Δ-isobar) in the final state. The neutron decays into proton, electron and electronic antineutrino. The Δ-isobar decays into proton and π^+-meson. The reason of neutron decay is the weak interaction. Due to it, the neutron lifetime is immeasurably longer than Δ^{++}-isobar lifetime. Therefore,

[1]Abbreviations: QED – quantum electrodynamics; UFI – universal Fermi interaction; RQT – relativistic quantum theory; SM – standard model.

in the framework of nuclear physics we can consider neutron as a stable particle.

We can consider Δ-isobar decay $\Delta^{++} \to p + \pi^{+}$ as a separate process, because the properties of this resonance do not depend on the way of its excitation. The Δ^{++}(1232)-isobar, created in a charge-exchange reaction $p(p,n)\Delta^{++}$, and decaying into proton and π^{+}-meson (fig. 4), and Δ^{++}(1232)-isobar, created in $p\pi$-elastic scattering ($\pi^{+} + p \to \Delta^{++} \to \pi^{+} + p$, fig. 5) are the same resonances.

Invariant properties of hadron resonances concerning the excitation mechanism led physicists to consensus of their status. Since Fermi's discovery of the Δ^{++}(1232)-isobar, all hadron resonances are considered as elementary particles.

Evident result of comparative analysis of diagrams in fig. 3, 4 and 5 is the following: the line on the corresponding diagram is external, or internal, depending on the conventional products of reactions with the hadron resonance participation.

If we calculate the Δ^{++}(1232)-isobar lifetime then the bold line on the diagram fig. 6 is external. If we calculate the shape of Δ-peak in the cross-section of the elastic $\pi^{+}p$-scattering or pion creation cross-section for pp-collisions at the Δ^{++}(1232)-isobars excitation region, then the same line should be considered as internal. That is the basic idea for the neutroneum identification.

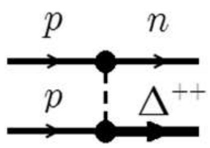

Figure 3. Resonant charge-exchange reaction at *pp*-collisions.

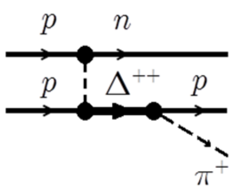

Figure 4. Resonant pion creation at *pp*-collisions.

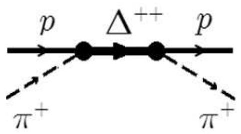

Figure 5. Elastic $\pi^{+}p$-scattering with the Δ^{++}(1232)-isobar excitation.

What is the difference between the perfectly studied neutron and hypothetical neutroneum? For better understanding we have to carry out the comparative analysis of the several diagrams.

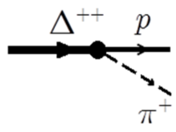

Figure 6. Decay of the Δ^{++}(1232)-isobar.

According to cross-invariance of the Feynman diagrams, fig. 7 corresponds to a few different processes.

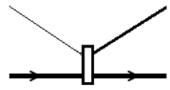

Figure 7. Weak interaction of lepton and nucleon.

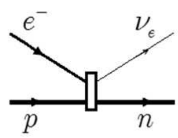

Figure 8. Neutroneum creation at *ep*-collision.

It is evident, that the same lepton line on the diagram in fig. 7 can be interpreted in different ways. For example, if the initial state corresponds only to neutron, then considered diagram should be interpreted as process of it's decay. In this case the thin line in the left part of the diagram (fig. 7) describes the process of electronic antineutrino emission: $\xleftarrow{\tilde{\nu_e}}$ and the medium (bold) thickness line in the right part of the diagram corresponds to electron (proton) emission.

If the initial state (left part of the diagram, fig. 7) corresponds to a neutron and electronic neutrino (line $\xrightarrow{\nu_e}$), then we deal with $\nu_e + n \to e^{-} + p$ reaction. According to CPT-theorem and cross-invariance of Feynman diagrams, both amplitudes $A_{n \to p + e^{-} + \tilde{\nu_e}}$ and $A_{n + \nu_e \to p + e^{-}}$ have the similar analytical properties [12], [15]. Moreover, if absolute values of momentum for each particle (line) coincide, then $\left| A_{n \to p + e^{-} + \tilde{\nu_e}} \right| = \left| A_{n + \nu_e \to p + e^{-}} \right|$.

Let's consider the weak process $e^{-} + p \to \nu_e + n$. Evidently, the diagram in fig. 8 of this process is the T-inverse diagram in fig. 7, but a neutron creation reaction has a threshold.

If ingoing electron energy is over threshold, then the cross-section of the neutron creation is nonzero ($\sigma_{p + e^{-} \to n + \nu_e} \neq 0$). In this case, we can detect such products of *ep*-collision, as neutron and neutrino.

The neutron is extremely long-lived particle, but this time is not infinite (mean life $888.6 \pm 3.5s$ [13]). Therefore, the diagram in fig. 8 can be continued by the full analogy

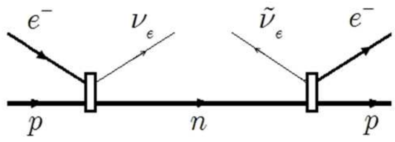

Figure 9. Prolonged diagram of neutron creation reaction at *ep*-collisions.

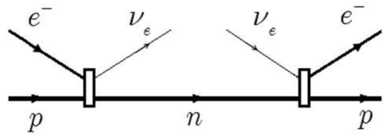

Figure 10. Reaction $\nu_e + n \to e^- + p$, colliding particles are on the mass shell.

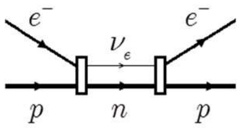

Figure 11. Elastic *ep*-scattering, off-shell effects.

to the diagram fig. 3. The result of this prolongation is evident (fig. 9).

Direct comparison of fig. 9 and fig. 4 shows, that the reaction of creating neutron $e^- + p \to n + \nu_e$ is an obvious electroweak analogue of hadron resonances excitation process. From the mathematical point of view, this analogy has a topological nature. Both internal lines (fig.4, fig. 9) must be interpreted as one-partical propagator (Δ- isobar and neutron, correspondently).

If the energy of incoming electron is over the threshold, then the diagram in fig. 9 represents $\hat{s}$-process, i.e. a real neutron creation. This neutron, as electroweak resonance, is extremely narrow due to its lifetime. Thus antineutrino emission takes place after a huge delay (neutron's lifetime). At the underthreshold energies region, the neutron is virtual, and this situation corresponds to instant $\nu_e\tilde{\nu}_e$-pair creation at the quasielastic *ep*-scattering.

We have to stress that in both cases neutron plays a role of exotic electroweak resonance.

Let's consider the most prominent aspect of the discussed problem.

According to CP-invariance of the weak interaction, we can replace outgoing antineutrino (fig. 9) by incoming neutrino (fig. 10). Due to the concept of virtual particles, we can "stick together" the broken neutrino line (diagrams in fig. 10, fig. 11). Therefore, the second-order weak interaction term in the elastic *ep*-scattering amplitude (diagram fig. 11) can be represented as a sum of the $\hat{s}$- and $\hat{r}$-terms (fig. 2). The $\hat{s}$-term corresponds to the pole in the two-partical neutron-neutrino's propagator and we named it "neutroneum".

As followed from aforesaid, neutron and neutroneum are the exotic electroweak resonances. Mathematical difference between neutron and neutroneum is very simple: the pole in the one-particle nucleon propagator corresponds to neutron, while the similar pole in the two-partical neutron-neutrino's propagator corresponds to neutroneum. The physical difference between these particles is rather more serious: neutron is fermion, while neutroneum is boson. Therefore the neutron-induced and neutroneum-induced nuclear reactions are similar only in one sense: there is no Coulomb's barrier penetration problem at super-low energies.

Conclusion: both neutron and neutroneum are resonances, and they have no stable bound states in their decay products. Thus, we have no restrictions the Compton wavelength of neutrino, "sliped" in a two-partical neutron-neutrino's propagator.

In the framework of our approach we will investigate the properties of a hypothetical resonance "neutroneum", designated as n_ν. That is the aim of this work.

II. Main formalism

Effective Hamiltonian $h''(\vec{r})$ in the nucleon's space looks like [2] - [7]:

$$h''(\vec{r}) = \frac{G_\beta}{\sqrt{2} \cdot L^{3/2}} \cdot e^{-i(\vec{e}\cdot\vec{r})} \cdot \sum_{\mu=+,-} \left[i\hat{b}_4 - \lambda \cdot (\hat{\vec{b}} \cdot \vec{\sigma}_N) \right]_\mu \cdot \\ \cdot \tau_+ \cdot \delta(\vec{r} - \vec{r}_{n_\nu}) + h.c., \quad (1)$$

where $G_\beta = \tilde{f}_1 \cdot G$, G - a constant of the weak interaction, L^3 - normalization volume, and

$$(\hat{b_\sigma})_\pm = (b_\sigma)_\pm \cdot \psi_\pm(\vec{r_c}). \quad (2)$$

The wave functions (WF) $\psi_\pm(\vec{r_c})$ can be expressed as effective WF of quasineutrino (lepton projection of neutroneum WF) in central potential [16]

$$\begin{cases} \psi_+(r) = g_{-1}(r)/\sqrt{4\pi} \\ \psi_-(r) = i f_1(r) \chi^1_{11/2m_\nu}(\vartheta, \phi) \end{cases} \quad (3)$$

The designations of [2]-[7], [16], [17], [18] are used in this paper.

III. Neutroneum decay

Neutroneum's decay is describeds by the Feynman diagram [15] (fig. 12).

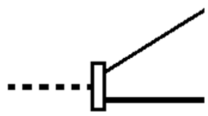

Figure 12. Neutroneum's decay.

According to the "Fermi's golden rule", decaying probability looks like [18]:

$$dw_{fi} = \frac{2\pi}{\hbar} \cdot \delta(E_f - E_i) \cdot \left|\langle f|V|i\rangle\right|^2 dn_f. \quad (4)$$

Therefore, the probability of neutroneum decay is equal:

$$w_{n_\nu \to p+e^-} = \frac{2\pi}{\hbar} \int \frac{L^3 d\vec{p}_e}{(2\pi\hbar)^3} \cdot \frac{L^3 d\vec{p}_p}{(2\pi\hbar)^3} \cdot \delta(E_i - E_f) \cdot \cdot \left\langle \left| \int \overbrace{\langle p|h''(\vec{r}')|n\rangle}\, d\vec{r}' \right|^2 \right\rangle. \quad (5)$$

External triangular brackets in (5) means averaging for spin projections ($\underline{m}_{n_\nu}$, $\underline{m}_p$, ...) of all particles in the initial state and summation in the final state. Proton (neutron) wave function is $|p\rangle$ ($|n\rangle$). Symbol $\frown$ over the matrix element (5) means that transition takes place from superposition of $|n\rangle$-states with the different projections $\underline{m}_n$ due to neutroneum has the certain integer spin.

The final expression for the neutroneum decay probability is the follows:

$$w_{n_\nu \to p+e^-} = \frac{G_\beta^2 \cdot \left|\phi(j_{n_\nu})\right|^2}{2\pi\hbar^4 V_{eff}^{n_\nu}} m_e \sqrt{2 m_e U_{n_\nu}} \cdot F_c(\eta). \quad (6)$$

The spin factor $\phi(j_{n_\nu})$ is equal: $\phi(0) = 1 + 3\lambda = 4.69, \phi(1) = 1 - \lambda = -0.23$. "Neutroneum's effective volume" $V_{eff}^{n_\nu}$ is equal [2]-[7]:

$$V_{eff}^{n_\nu} = 4\pi / g_{-1}^2(0). \quad (7)$$

The neutroneum internal energy $U_{n_\nu} > 0$ is

$$U_{n_\nu} = m_{n_\nu} c^2 - m_p c^2 - m_e c^2. \quad (8)$$

Fermi's factor $F_c(\eta)$ takes into account the Coulomb field influence for the outgoing β-electron. Point-like approximation gives us [16]:

$$F_c(\eta) = \pi\eta \cdot exp(\pi\eta) \cdot sh^{-1}(\pi\eta), \quad (9)$$

The numerical results are presented in the Table II. Neutroneum decay probability w^0 was calculated without Fermi-factor. The value w^c includes Fermi-factor. Neutroneum lifetime is $\tau_{n_\nu}^c = 1/w_{n_\nu \to p+e^-}^c$. We use the values: $\lambda = 1.23$, "neutroneum's effective volume" $V_{eff}^{n_\nu} \approx 2.7 fm^3$ corresponds to the proton's electromagnetic radius $r_0 = 0.86 fm$ [16]. Denominator $V_{eff}^{n_\nu}$ is the free parameter of the theory. Its value should be corrected on the base of the new experimental data.

Table II shows, that neutroneums decay rate at the low energies is increased due Coulomb factor by two or three times. At the energy $T_e \sim 1\ keV$ Coulomb's effects are small, and lifetime of the singlet neutroneum $\tau_{n_\nu^{(s)}}$ is of order

$$\tau_{n_\nu^{(s)}} \sim 4 \cdot 10^{-5}\ s, \quad (10)$$

This time is one order longer than muon lifetime $\tau_\mu = (2.197019 \pm 0.000021) \cdot 10^{-6}\ s$ [14].

Experiments on electric explosion of the especially pure material foils in water were carried out [19]. A lot of new chemical elements were found and non-identified "strange" radiation was registered. The capacitors battery voltage, used for electroexplosions, was less, than 5 kV [19]. This experiment supports the estimation (10), and permits us to evaluate the neutroneum creation threshold energy $\varepsilon_{tr} \sim 0.1 - 1 keV$. Therefore, the neutroneum creation threshold energy is considerably lower, than a threshold of thermonuclear reactions $\sim 10 keV$ [8], [9], [20].

This conclusion is fundamental. It means, that neutron-like particles can be created at low energies, and, hence, induce the nuclear reactions, similar to reactions, induced by neutrons, when nuclear reactions with the charged particles are forbidden by the high Coulomb barrier.

IV. Neutroneum creation

In an accordance with conservation laws and selection rules, hypothetical "neutroneum" can be created by *ep*-collisions, or in eH-collisions. Electron capture (i.e., reaction $e^- + p \to n_\nu$) is strictly forbidden by the conservation laws.

At the underthreshold energies the "neutroneum" is a virtual particle, and contribution of the weak interaction to the amplitude of the elastic *ep*-scattering ($e^- + p \to n_\nu \to e^- + p$) is negligible. This situation partially takes place just for the overthreshold energies. The cross-section $\sigma_{p+e^- \to n_{\nu_e} + X}$ of the inclusive reaction $p + e^- \to n_{\nu_e} + X$ is vanishing due to two important circumstances: 1) diagram 1h corresponds to extremely narrow resonance ($\Gamma_{n_\nu} \leq 2.5 \cdot 10^{-11}\ eV$), which we cannot measure in the direct experiment on the *ep*-scattering; 2) if $X = \gamma$, then cross-section $\sigma_{p+e^- \to n_{\nu_e} + X}$ is suppressed by additional small parameter - thin-structure constant α. The exception of this common rule – solid state processes, when $X = phonon$, but the analysis of such processes is out of the scope of this paper.

Let's consider continuous spectrum electron capture by the hydrogen atom

$$H(e, e') n_\nu. \quad (11)$$

According to the main idea, illustrated by fig. 2, we can consider full contribution of the weak interaction into cross-sections of eH-scattering and reactions, as a sum of the $\hat{r}$-term and $\hat{s}$-term (fig. 13, 14).

Singularities position of the neutroneum propagator on the complex energies plane is unknown. The nature of this problem is a nonperturbative effect in the framework of the Standard Model (SM) at the superlow energies. But according to a very trustfull estimation $\varepsilon_{tr} \sim 0.1 - 1 keV$, the two-particle neutron-neutrino's propagator has a pole, corresponds to the neutroneum mass $m_{n_\nu} = m_p + m_e + U_{n_\nu} c^{-2} < m_n$.

To calculate the cross-section of the electron capture (11) at the neutroneum excitation region, we have to take into account three-body effects. The third particle at the collision between the electron and the hydrogen atom plays

Table II
DECAYS RATES AND LIFETIMES FOR THE SINGLET ($n_\nu^{(s)}$) AND TRIPLET ($n_\nu^{(t)}$) EXOATOMS NEUTRONEUM

$T_e[eV]$	$w^0_{n_\nu^{(s)}\to p+e^-}$	$w^c_{n_\nu^{(s)}\to p+e^-}$	$\tau^c_{n_\nu^{(s)}}$	$w^0_{n_\nu^{(t)}\to p+e^-}$	$w^c_{n_\nu^{(t)}\to p+e^-}$	$\tau^c_{n_\nu^{(t)}}$
10^2	$8.8\cdot 10^3$	$2.2\cdot 10^4$	$4.5\cdot 10^{-5}$	$2.2\cdot 10^1$	$5.4\cdot 10^1$	$1.8\cdot 10^{-2}$
10^3	$2.7\cdot 10^4$	$3.8\cdot 10^4$	$2.8\cdot 10^{-5}$	$6.8\cdot 10^1$	$9.5\cdot 10^1$	$1.1\cdot 10^{-2}$
10^4	$8.8\cdot 10^4$	$9.6\cdot 10^4$	$1.0\cdot 10^{-5}$	$2.2\cdot 10^2$	$2.4\cdot 10^2$	$4.2\cdot 10^{-3}$

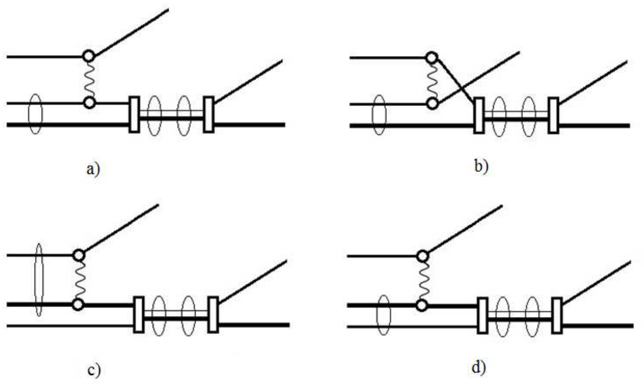

Figure 13. The regular contribution of weak interaction to ionisation amplitude of the hydrogen atom.

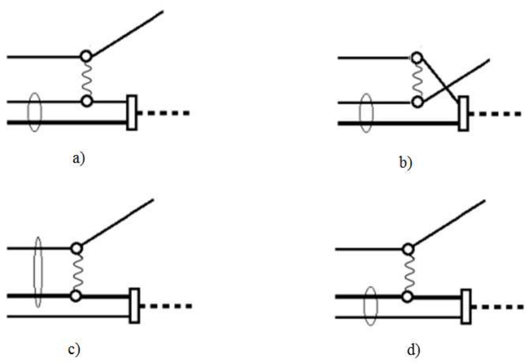

Figure 14. The contribution of weak interaction to amplitude of reaction of the neutroneum creation.

a role of the catastrophical amplifier of the neutroneum creation cross-section. In the framework of the three-body problem we have to integrate the two-particle propagator of the electron and proton (i.e., excited hydrogen) over the virtual states. This convolution gives us enormous amplification ($\sim 10^{14}$) not only for the total cross-section, but also for the width of the resonance, and its properties can be investigated experimentally.

According to (8) and evident inequality $m_p \gg m_e$ we evaluate neutroneum creation threshold:

$$\varepsilon_{tr} \approx U_{n_\nu} + \varepsilon_H. \tag{12}$$

where $\varepsilon_H = 13.6eV$ - electron's binding energy for the hydrogen atom.

Neutroneum creation cross-section looks like:

$$\sigma_{H(e,e')n_\nu} = \frac{2\pi L^3}{\hbar v_e}\int dn_f \delta(E_i - E_f)\cdot$$
$$\cdot\left\langle \left|\hat{s}\int dn_v \frac{\int d\vec{r}\,'\cdot \overbrace{\langle n|h''(\vec{r}\,')|p\rangle}\cdot\langle e'+e+p|V_c|e+H\rangle}{E_i - E_v + i0}\right|^2\right\rangle \tag{13}$$

where v_e - ingoing electron's velocity in the proton's rest frame, dn_f (dn_v) - final (virtual) states density. Projection operator $\hat{s}$ takes into account only pole contribution into neutroneum creation cross-section $\sigma_{H(e,e')n_\nu}$.

Potential V_c (photon propagator line between two electromagnetic vertexes, fig. 13, fig. 14) is equal to Coulomb potential

$$V_c(\vec{r}_p, \vec{r}_{e_1}, \vec{r}_{e_2}) = \frac{e^2}{|\vec{r}_e - \vec{r}_{e'}|} - \frac{e^2}{|\vec{r}_p - \vec{r}_e|}. \tag{14}$$

Let's consider neutroneum creation at the eH-collision (electron's energy $\sim 10^2 - 10^3\ eV$). The differential and total cross-sections of the $H(e,e')n_\nu$ reaction are equal [1]-[7]:

$$\frac{d\sigma_{H(e,e')n_\nu}}{d\Omega_{n_\nu}} = \sigma^{(0)}_{H(e,e')n_\nu}\cdot\sqrt{\xi^2_{n_\nu} - \xi^2_{\hat{n}_\nu}}\cdot$$
$$\cdot\sum_{+,-}\left\{F_c^2(\eta^{(\pm)})(x^{(\pm)}_{n_\nu})^2\left|\Phi(x^{(\pm)}_{n_\nu})\right|^2\right\}, \tag{15}$$

where

$$\sigma^{(0)}_{H(e,e')n_\nu} = 2\tilde{\phi}^2(j_{n_\nu})\frac{G_\beta^2\cdot\varepsilon_e^2}{\pi(\hbar c)^4}\frac{a_B^3}{V_{eff}^{n_\nu}}. \tag{16}$$

Here: $\tilde{\phi}(j_{n_\nu}) = \sqrt{2j_{n_\nu}+1}\cdot\phi(j_{n_\nu})$ - spin factor, a_B - Bohr radius, $\varepsilon_e = m_e c^2$ - electron mass, ξ_{n_ν} - cosine of the neutroneum momentum angle, $\xi_{\hat{n}_\nu}$ - a boundary cosine of the angle of outcoming neutroneum, $\eta^{(\pm)} = (x^{(\pm)}_{n_\nu})^{-1}$ - Coulomb parameter.

If $V_{eff}^{n_\nu} \approx 2.7fm^3$ then

$$\sigma^{(0)}_{H(e,e')n_\nu} = 2\mu barn. \tag{17}$$

The dimensionless momentum $x^{(\pm)}_{n_\nu}$ depends on the incoming electron energy and the angle of the neutroneum momentum:

$$x^{(\pm)}_{n_\nu} = x_e\cdot\left[\xi_{n_\nu} \pm \sqrt{\xi_{n_\nu} - \xi_{\hat{n}_\nu}}\right], \tag{18}$$

where $\vec{x}_e = \vec{k}_e a_B$, $\vec{k}_e$ - wave vector of the incoming electron, and $\Phi(x^{(\pm)}_{n_\nu})$ - formfactor.

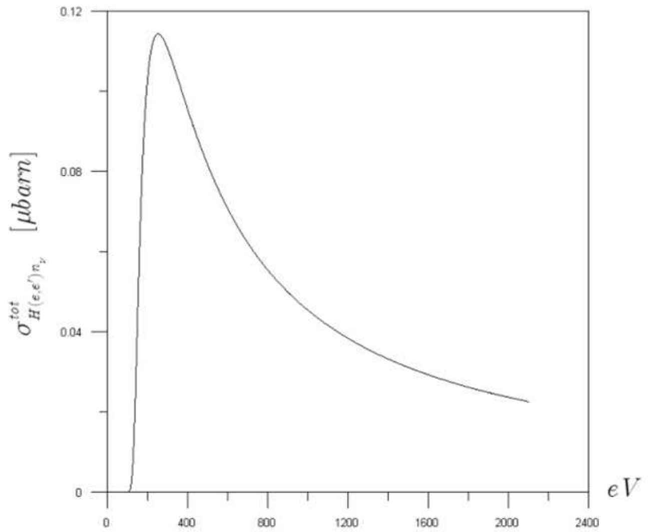

Figure 15. Energy dependence of the total cross-section of the neutroneum creation. Threshold energy $\varepsilon_{tr} = 100\ eV$.

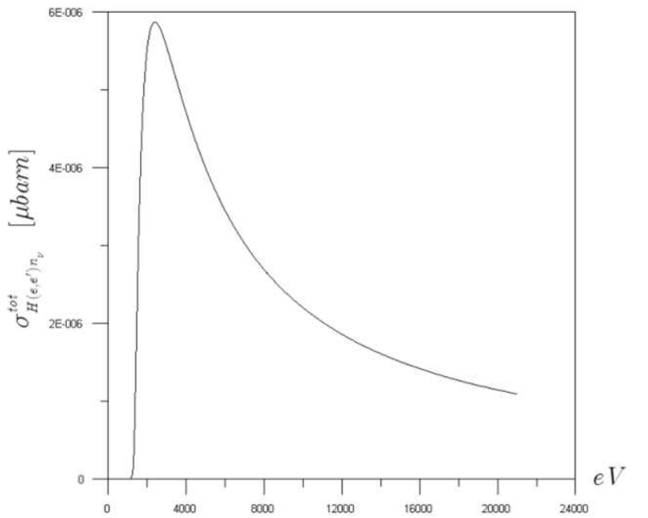

Figure 16. Energy dependence of the total cross-section of the neutroneum creation. Threshold energy $\varepsilon_{tr} = 1000\ eV$.

The energy dependence of the total cross-section of the neutroneum creation is resonant (fig. 15, fig. 16).

Fig. 15, 16 demonstrate us that the resonance shape essentially differs from Breit-Wigner, and almost ε_{tr}-independent. The resonance width at semiheight are between $1 \leq \Gamma_{H(e,e')n_\nu} \leq 6\ keV$, therefore $\Gamma_{H(e,e')n_\nu}/\Gamma_{n_\nu} \sim 10^{14} \gg 1$.

At $\varepsilon_{tr} \sim 0.1\ keV$ the cross-section at the vicinity of the resonance peak is of order

$$\left[\sigma^{tot}_{H(e,e')n_\nu}\right]_{max} \sim 0.1 \mu barn. \qquad (19)$$

Due to increasing the threshold energy up to the $\varepsilon_{tr} \sim 1\ keV$, the maximum value of the cross-section of the neutroneum creation catastrophically decreases under the law, slightly different from the sedate $\left[\sigma^{tot}_{H(e,e')n_\nu}\right]_{max} \sim \varepsilon_{tr}^{-6}$, down to the value $\left[\sigma^{tot}_{H(e,e')n_\nu}\right]_{max} \sim 6 \cdot 10^{-6}\ \mu barn$.

V. Theoretical predictions

There are no any bans for such "forbidden" processes as:

1) emulation of DD-fusion in low-energy experiments [21]

$$\begin{cases} D_\nu + d \to t_\nu(1\ MeV) + p(3\ MeV); \\ \qquad t_\nu \to t + e^- \\ D_\nu + d \to {}^3_2He_\nu(0.82\ MeV) + n(2.45\ MeV); \\ \qquad {}^3_2He_\nu \to {}^3_2He + e^- \end{cases} \qquad (20)$$

2) deuterium creates not only in the known Bethe reaction $p + p \to d + e^+ + \nu_e$, but also in the chain of reactions, which beginning from creation of exoatom "deutroneum" (d_ν) – bound state of proton and neutroneum. "Deutroneum" is a product of radiative capture reaction: $n_\nu + p \to d_\nu + \gamma$, $\varepsilon \sim 300 - 400 keV$ (see [8]). The energy of γ-quanta is commensurable with $\varepsilon_e = m_e c^2$, therefore "deutroneum" mass more than the deuteron mass, but less than a sum of masses of two protons and electron. Therefore only the decay channel $d_\nu \to d + \nu_e$ is opened, but the decay channel $d_\nu \to 2p + e^-$ is closed. Unlike of Bethe cycle, this reaction is not accompanied by positron creation, and neutroneum creation cross-section at least of 8 orders more than cross-section of Bethe reaction.
3) tritium creation without neutrons emission

$$D_\nu + p \to t + \nu_e; \qquad (21)$$

Therefore the abnormal ratio tritium/neutrons ($t/n \gg 1$) at tritium creation at the electrolisys should be observed [22].
4) helium creation without γ-quanta emission [23]:

$$D_\nu + d \to \alpha + e^- \qquad (22)$$

5) short-lived isotopes creation at ultralow energies [24]:

$$D_\nu + {}^{108}_{46}Pd \to n_\nu + {}^{109}_{46}Pd; \qquad n_\nu \to p + e^- \quad (23)$$

6) high-energy α-particles emission by deuterated metals under the electron beam or X-ray beam bombarding [25]. For example

$$D_\nu + {}^6_3Li \to n_\nu + {}^4_2He_\nu + {}^4_2He + 23.802\ MeV; \quad E_\alpha \approx 11.9 MeV (24)$$

7) nonexponential law of the radioactive decay for nuclei of the heavy hydrogen-like ions which are decaying due to the orbital electron capture [26].

The theory of exotic electroweak processes, based on the well-known physical lows, explains all available experimental data on CF and LENR. Thus, to verify this theory, we have to reproduce at least one of the experiments [21]-[26]. Independent groups of highly qualified researchers have to carry out this "experimentum crucis" in the best nuclear centers. The aim of this experiment will be precision measurements of the free parameters: the threshold ε_{tr} and "neutroneum effective volume" $V_{eff}^{n_\nu}$.

VI. Summary

We can summarize the aforesaid as follows.

1) It is proved that as neutron, as neutroneum are the exotic electroweak resonances.
2) Neutroneum exists due to CPT-theorem and Feynman's diagrams crossing-symmetry and we can consider this resonance as quasi-bound (not bound) state of neutron and neutrino in accordance to Zahariev's theorem [7], [27].
3) The hypothetical elementary particle "neutroneum" is neutral.
4) Neutroneum is boson. Its spin is $s_{n_\nu} = 0$ (may be, $s_{n_\nu} = 1$).
5) Neutroneum isospin $T_{n_\nu} = 1/2, \quad (T_{n_\nu})_z = -1/2$.
6) Barion and lepton quantum numbers of the neutroneum are the unity ($B = L_e = 1$).
7) The neutroneum lifetime is of order $\tau_{n_\nu} \sim 4 \cdot 10^{-5}\ s$.
8) The neutroneum mass is $m_{n_\nu} c^2 = m_p c^2 + m_e c^2 + U_{n_\nu} \lesssim 938.788\ MeV$.
9) The neutroneum width is $\Gamma_{n_\nu} \lesssim 2.5 \cdot 10^{-11}\ eV$ (we suppose $V_{eff}^{n_\nu} \approx 2.7\ fm^3$).
10) The upper limit of the cross-section of the neutroneum creation is $\sigma^{max}_{H(e,e')n_\nu} \sim 0.1\ \mu barn$.
11) The threshold of the neutroneum creation reaction is about $\varepsilon_{tr} \sim 0.1 - 1\ keV$.Thus the energy of the neutroneum creation threshold is considerably smaller than the threshold energy of the thermonuclear reactions. It means that neutron-like nuclear-active particles can be created at the ultralow energies, and, hence, can underlie the nuclear reactions similar to reactions, caused by neutrons, in all cases, when nuclear reactions with the charged particles are forbidden by a high Coulomb barrier.
12) Weak interaction can be a reason of the long-time (in compare to a nuclear time) neutralisation of a charge of a proton, and, thus, can play a role of the "neutrinous catalyst" of the nuclear reactions at ultralow energies.
13) The qualitative explanation of the results of the Kurchatov's experiments is offered.
14) A lot of "experimentum crucis" are proposed.

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References

[1] Ratis Yu.L. Metastable nuclear-active substance dineutroneum. Patent N 2008147689. (Rospatent priority information N062435, 04.12.2008).
[2] Ratis Yu.L. *Controlled "thermonuclear" or cold fusion? The drama of the ideas.* Issue SSC RAS, Samara, 2009.
[3] Ratis Yu.L. *Applied physics (rus)*, 21(1), 2010.
[4] Ratis Yu.L. http://es.arxiv.org/abs/0909.5561.
[5] Ratis Yu.L. *The Old and New Concepts of Physics*, 6(4):525, 2009.
[6] Ratis Yu.L. *Proceedings of the LXII International Conference NUCLEUS 2012, Voronezh-2012. Ed. by A.K. Vlasnikov. (Saint-Petersburg University, Saint-Petersburg, 2012)*, page 62, 2012.
[7] Ratis Yu.L. *Abstracts of the XXI International Seminar on Interaction of Neutrons with Nuclei, Dubna: JINR*, page 69, 2013.
[8] Kurchatov I.V. *Atomic energy*, (3):65, 1956.
[9] Kapitsa P.L. *Experiment. Theory. Practice.* Nauka, Moscow, 1981.
[10] Hussein M.A., Saad A.I. *J. Mod. Phys.*, (1):244, 2010.
[11] Landau L.D., Peierls R. *Zs. Phys.*, (62):188, 1930.
[12] Berestetsky V.B., Lifshits E.M., Pitaevsky L.P. *Quantum electrodynamics. Theoretical physics, v.4.* Nauka, Moscow, 1989.
[13] Heisenberg W. *Der Teil und das Ganze Gespräche im Umkreis der Atomphysik.* München, 1969.
[14] Amsler C. et al. Particle data group. *Phys. Lett. B*, (1):667, 2008.
[15] Bjorken J.D., Drell S.D. *Relativistic Quantum Mechanics.* McGraw-Hill Book Company, 1964.
[16] Eisenberg J.M., Greiner W. *Nuclear theory. v2. Excitation mechanisms of the nucleus. Electromagnetic and weak interactions.* North-Holland publishing company, Amsterdam-London, 1970.
[17] Varshalovich D.A., Moskalev A.N., Khersonsky V.K. *Quantum Theory of Angular Momentum.* World Scientific Pub, 1988.
[18] Landau L.D., Lifshits E.M. *Quantum mechanics. Nonrelativistic theory. Theoretical physics. v.3.* Nauka, Moscow, 1989.
[19] Agapov A.S., Kalensky V.A., Kajtukov C.B. et al. *Applied physics (rus)*, (1):37, 2007.
[20] Zeldovich Ya.B., Gershtein S.S. Particle data group. *Uspekhi Fizicheskikh Nauk (Sov.Phys.- Uspekhi)*, 71(4):581, 1960.
[21] S.E. Jones, E.P. Palmer, J.B. Czirr et al. *Nature*, 338:737, 1989.
[22] Tsarev V.A. *Uspekhi Fizicheskikh Nauk (Sov.Phys.- Uspekhi)*, 162(10):63, 1992.
[23] Arata Y., Zhang Y.-C. *Proceedings of the Japan Academy. Ser. B: Physical and Biological Sciences*, 78(3):57, 2002.
[24] Savvatimova I.B., Karabut A.B. *Surface. X-ray, synchrotron and neutron researches*, (1):76, 1996.
[25] Lipson A.G., Chernov I.P., Rusetsky A.S. et al. *Doklady RAS*, 425(5):1, 2009.
[26] Litvinov Yu.A., Bosh F. et al. arXiv:0801.2079v1 [nucl-ex], (2008).
[27] Zhigunov V.P., Zahariev B.N. *Methods of the strong coupled channels in the quantum theory of scattering.* Atomizdat, Moscow, 1974.