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Research Article

On Problems of Widom–Larsen Theory Applicability to Analysis and Explanation of Rossi Experiments

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Abstract

The effectiveness and possibility of application of Widom–Larsen (W–L) theory for explanation of Rossi experiments on stimulation of (p, Ni^A) low-energy nuclear reactions (LENR) is analyzed. The carried out analysis has shown that W–L theory, which is connected with the inverse reaction of beta-decay in variable electric field of surface plasmon in metal hydride, is unsuitable for the description and explanation of Rossi experiments in metal hydrides.

Keywords: Inverse beta-decay, LENR, Ponderomotive force, Rossi experiments, Widom–Larsen theory

1. Introduction

Theoretical explanation of important Rossi–Focardi (R–F) experiments (e.g. [1,2]) is usually associated with Widom–Larsen (W–L) theory (see [3–8]).

The general scenario of such theory includes three consecutive steps.

- Process of increase of electron mass with $\Delta m_e > 0$ by "dressed up" effect and formation of slow heavy electrons by ponderomotive nonlinear action of variable electric field of surface plasmon;
- Transformations of protons, which are situated in the form of monoatomic hydrogen layer on Ni surface, into slow neutrons in inverse reaction of beta-decay

$$\tilde{e}^- + p \rightarrow n + \nu, \qquad \tilde{m}_e \equiv m_e + \Delta E/c^2,$$
$$\Delta E = \Delta m_e c^2 > |Q_{e^-p}|, \qquad Q_{e^-p} \approx -0.78\,\text{MeV} \tag{1}$$

with the help of "dressed up" heavy electrons. For realization of such reaction the variable electric field $|E(\vec{r},t)|_{\max} \geq |E(\vec{r},t)|_{\text{thresh}} \approx 3 \times 10^{10}$ V/cm is needed [1,2].

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- Immediate absorption of these slow neutrons in a matrix and stimulations of nonbarrier nuclear reactions

$$\mathrm{n} + {}_{Z}\mathrm{Ni}^{A} \rightarrow {}_{Z}\mathrm{Ni}^{*A+1} \rightarrow {}_{Z_1}Y^{A_1} + {}_{Z-Z_1}\mathrm{K}^{A-A_1} + N\gamma + \Delta Q \rightarrow \dots \quad (2)$$

The main questions are the following: are the process of stimulated inverse beta-decay reaction in metal hydrides like Ni + H possible (a) and efficient enough (b)?

The general idea of such method is very attractive. Its ideological part is close to well-known process of inverse beta-decay reaction

$$\Delta W + \mathrm{e}^{-} + {}_{Z}\mathrm{X}^{A} \rightarrow {}_{Z-1}\mathrm{Y}^{A} + \nu, \quad (3)$$

which takes place during the neutronization process that is stimulated by gravitational collapse of stars with masses $M > 1.45M_{\otimes}$ and leads to the formation of neutron stars ($M_{\otimes}$ is the mass of the Sun). This process is connected with the increase of Fermi energy

$$W_{\mathrm{F}} \equiv (3\pi^2)^{1/3}\hbar c n_{\mathrm{e}}^{1/3} \geq (M_{(A,Z-1)} - M_{(A,Z)} - m_{\mathrm{e}})c^2 \quad (4)$$

of relativistic degenerate electron gas with electron number density

$$n_{\mathrm{e}} \geq m_{\mathrm{e}}^3 c^3/3\pi^2\hbar^3 \approx 10^{30}\ \mathrm{cm}^{-3}$$

during gravitational collapse.

Both processes (W–L process and process of astrophysical neutronization (AN)) are connected with the increase of electron energy but in different ways:

- AN process is connected with the formation of relativistic electrons with great momentum

  $$p_{\mathrm{e}} = \sqrt{\gamma^2 - 1}\ m_{\mathrm{e}}c \geq m_{\mathrm{e}}c$$

  and great relativistic energy

  $$W_{\mathrm{e}} = \gamma m_{\mathrm{e}} c^2 \quad (5a)$$

- predicted W–L process is connected with the formation of fixed or slow "dressed up" heavy electrons with low momentum $p_{\mathrm{e}} \ll m_{\mathrm{e}}c$, great renormalized mass and great energy

  $$W_{\mathrm{e}} = \tilde{m}_{\mathrm{e}} c^2. \quad (5b)$$

AN process is real and plays very important role in the evolution of the Universe. Reality of W–L process in R–F experiments will be discussed below.

2. Reality of W–L Process in Rossi Experiments

2.1. Influence of electron motion on electric field of surface plasmon of metal hydride

In works [3,4] it was supposed that surface electrons of metal hydride are under the influence of strong variable electric field

$$\vec{E}(\vec{r}, t) = \vec{E}_0(\vec{r}) \cos \Omega t \quad (6)$$

with intensity

$$\left\langle \left| \vec{E}_0^{(\max)} \right| \right\rangle \approx e n_{\mathrm{p}}^{2/3} \approx 10^{10}\,\mathrm{V/cm}$$

and frequency $\Omega = \omega_{\mathrm{p}} \approx 10^{13}\,\mathrm{s}^{-1}$, generated by plasma fluctuations of ions with concentration n_{p}.

From the other hand it is implicitly supposed that these electrons do not react the field $\vec{E}(\vec{r}, t)$, do not change own (electron) state of motion under the influence of the field $\vec{E}(\vec{r}, t)$ and do not influence this field. It means that authors of [3,4] have used the assumption of a invariance of electron state at periodical oscillations of surface nuclei (protons) near the equilibrium position.

According to the general concepts of quantum mechanics and quantum statistics such assumption corresponds to the condition of ideality of degenerated electron gas, when average kinetic electron energy $\bar{T}_{\mathrm{e}}$ exceeds greatly the average potential energy $|\bar{V}_{\mathrm{e}}|$.

On the other hand in the same work [4] (see Eq. (24)) the following expression for electron density was used:

$$n_{\mathrm{e}} = 1/\pi a^3 \approx 3 \times 10^{23}\,\mathrm{cm}^{-3},$$

which corresponds to the opposite condition $\bar{T}_{\mathrm{e}} < |\bar{V}_{\mathrm{e}}|$. More exact analysis based on *Virial theorem* shows that in atom of hydrogen the similar opposite condition $\bar{T}_{\mathrm{e}} = 0.5|\bar{V}_{\mathrm{e}}|$ takes place.

At the breaking of the condition of electron gas ideality the situation cardinally changes in comparison with assumptions used in [3,4]. In this case electrons (as easier particles) move much faster then protons and immediately react to the breaking of both local charge equilibrium and formation of additional local electric field $\vec{E}(\vec{r}, t)$ during plasma oscillation. Motion of electrons leads to the adiabatic compensation of electric field $\vec{E}(\vec{r}, t)$ connected with the motion of protons. From the plasma theory follows that any local nonequilibrium in plasma exists for no more than the period $T_{\mathrm{e}} = 2\pi/\omega_{\mathrm{e}}$ of electron plasma frequency

$$\omega_{\mathrm{e}} = \sqrt{4\pi n_{\mathrm{e}} e^2/m_{\mathrm{e}}}. \tag{7a}$$

In metals $T_{\mathrm{e}} \approx (1-3) \times 10^{-16}\,\mathrm{s}$ that is by 100–1000 times less then the period of heavy ion (proton) plasma frequency

$$\omega_{\mathrm{p}} = \sqrt{4\pi n_{\mathrm{p}} e^2/M_{\mathrm{p}}}. \tag{7b}$$

The same effect takes place for surface plasmon oscillations. At such relation of T_{e} and T_{p} all electrons in plasma and in metals always follow protons and movement of protons is be close to adiabatic.

Hence, actual electric field in the volume o f ionic surface plasmon is by many orders (in $\omega_{\mathrm{e}}/\omega_{\mathrm{p}} \gg 1$ times) less then the value $\left\langle \left| \vec{E}_0^{(\max)} \right| \right\rangle \approx e n_{\mathrm{p}}^{2/3} \approx 10^{10}\,\mathrm{V/cm}$ predicted in [3,4].

Another approach also shows that this electric field is much lower then the predicted value $\langle|\vec{E}_0^{(\max)}|\rangle \approx 10^{10}\,\mathrm{V/cm}$, which is based on the analysis of the method of $E_0^{(\max)}$ calculation used in [4].

In this work the main model was connected with proton embedded in a sphere with a mean electronic charge density $\rho_{\mathrm{e}} = -en$. It is standard Wigner–Zeitz cell. If the proton suffers a small displacement u then an electric field $\vec{E}(\vec{r})$ will appear (see [4], Eq. (22))

$$\mathrm{div}\ \vec{E}(\vec{r}) = 4\pi\rho_{\mathrm{e}}, \qquad E(r) = -\frac{4\pi}{3} enr, \qquad \vec{r} \equiv \vec{u}. \tag{8}$$

The strength of the mean electric field in [4]

$$|E(u)| = \frac{4e}{3a^3} u = E_{\mathrm{atom}}(a) \left(\frac{4}{3}\right) \frac{u}{a}, \qquad E_{\mathrm{atom}}(a) = e/a^2 \approx 5.1 \times 10^9\ \mathrm{V/cm} \tag{9}$$

was estimated by taking the mean electron number density at the position of the proton (see [4], Eqs. (24) and (26))

$$n\ (r=0) = \left|\Psi_{1\text{s}}(0)\right|^2 = 1/\pi a^3,$$

$$a \equiv r_{\text{B}} = \frac{\hbar^2}{m_{\text{e}}e^2} = 5.3\times 10^{-9}\text{cm}. \tag{10}$$

The next calculation of electric field was conducted in [4] basing on these formulas. From neutrons scattering experiments on palladium hydride follows that the amplitude of collective proton oscillations on palladium surface equals $\bar{u}_{\text{p}} \approx 2.2$ Å [4]. At such value $\bar{u}_{\text{p}}$ the mean electric field was estimated through Eq. (**??**) (see [4], Eq. (26)) and equals (see also [4], Eq. (27))

$$\left|E(r=\bar{u}_{\text{p}})\right| = E_{\text{atomic}}(a)\left(\frac{4}{3}\right)\frac{\bar{u}_{\text{p}}}{a} \approx 2.9\times 10^{10}\ \text{V/cm}. \tag{11}$$

It is incorrect estimation! The expression (**??**) is correct only for very small displacements $u \ll a$ and at $\bar{u}_{\text{p}} \ll a$ (see expression for $n\ (r=0)$ in (**??**))! If $\bar{u}_{\text{p}} > a$, we need to use the correct (screened) expression for mean electron number density at the position of the proton

$$\left|E(r\approx\bar{u}_{\text{p}})\right| = -\frac{4\pi}{3}er\left|\Psi_{1\text{s}}(r)\right|^2\bigg|_{\bar{u}_p} = -\frac{4e}{3a^3}\bar{u}_{\text{p}}\text{e}^{-2\bar{u}_{\text{p}}/\Lambda} = -E_{\text{atomic}}(a)\left(\frac{4}{3}\right)\frac{\bar{u}_{\text{p}}}{a}\text{e}^{-2\bar{u}_{\text{p}}/\Lambda}. \tag{12}$$

Here Λ is a radius of electron screening:

$$\Lambda_{\text{B}} = \hbar^2/m_{\text{e}}e^2 = 0.53\ \text{Å} \quad \text{(for atom)},$$

$$\Lambda_{\text{D}} = \sqrt{kT/4\pi\bar{n}e^2} \quad \text{(for classical electron gas)}, \tag{13}$$

$$\Lambda_{\text{TF}} = \sqrt{\varepsilon_{\text{F}}/3\pi\bar{n}e^2} \quad \text{(for degenerate electron gas)}.$$

In all metals (including Ni) $kT > \varepsilon_{\text{F}}$ and $\Lambda = \Lambda_{\text{TF}} \approx 0.6$ Å. At such parameters we have $|E(r\approx\bar{u}_{\text{p}})| \approx 2\times 10^7$ V/cm that is too low for the formation of heavy "dressed" electrons needed for inverse reaction of beta-decay (1).

2.2. Analysis of the action of variable nonuniform electric field of surface plasmon on electrons

According to the date of [3,4] the energy of ponderomotive interaction of electric field

$$\vec{E}(\vec{r},t) = \frac{1}{c}\frac{\partial\vec{A}(\vec{r},t)}{\partial t} = (\Omega/c)\vec{A}_0(\vec{r})\cos\Omega t \equiv \vec{E}_0(\vec{r})\cos\Omega t \tag{14}$$

(generated by plasma oscillation of protons situated on metal surface) with electron

$$W_{\text{pond}}(\vec{r},t) = \sqrt{m_{\text{e}}^2c^4 + e^2c^2|\vec{E}(\vec{r},t)|^2/\Omega^2} - m_{\text{e}}c^2 \tag{15}$$

is much greater then the binding energy

$$W_{\text{coulomb}} = -Ze^2\text{e}^{-r/a}/r \tag{16}$$

of electron with nucleus and equals

$$W_{\text{pond}}^{(\max)} \approx 1\,\text{MeV}.$$

Action of spatially nonuniform periodic ponderomotive force on electrons

$$\vec{F}_{\text{pond}}(\vec{r},t) = -\nabla W_{\text{pond}}(\vec{r},t) = -\frac{(ec/\Omega)^2\nabla|\vec{E}(\vec{r},t)|^2}{2\sqrt{m_e^2c^4 + e^2c^2|\vec{E}(\vec{r},t)|^2/\Omega^2}}, \tag{17}$$

which is synchronised with variable electric field $\vec{E}(\vec{r},t)$, leads to their acceleration and expulsion from the area of increasing field. Such effect is used at the formation of a bunch of relativistic electrons with energy $T_e \geq 100\,\text{MeV}$ at the action of femtosecond laser pulse on a solid-state matrix. In this case the increase of electron energy $W_e = \gamma m_e c^2$ is connected with the increase of relativistic momentum

$$p_e = \sqrt{\gamma^2 - 1}\, m_e c$$

instead of formation of "dressed up" electron with $W_e = \tilde{m}_e c^2$ and low momentum $p_e \ll m_e c$.

The alternative effect of increase of effective mass of this electron $m_e \to \tilde{m}_e$ without acceleration (without increase of electron momentum) at ponderomotive nonlinear interaction with electric field (effect of "dressed up" electron) is possible only in the case of completely spatial-homogeneous variable field $\vec{E}(\vec{r},t) \equiv \vec{E}(t)$, when there is no pushing out force and

$$\vec{F}_{\text{pond}} \sim \nabla|\vec{E}(\vec{r},t)|^2 \equiv 0. \tag{18}$$

However in considered model of surface plasmon the field

$$\vec{E}(\vec{r},t) \approx \vec{e}_x E_0 \mathrm{e}^{-x/l} \cos\Omega t, \qquad l \approx n_p^{1/3} \tag{19}$$

is extremely nonuniform and localized in very thin surface layer (see Fig. 1).

Hence, the main result of ponderomotive action of strong nonuniform variable electric field $\vec{E}(\vec{r},t)$ of surface plasmon is the acceleration of both free conduction electrons and coupled atom electrons.

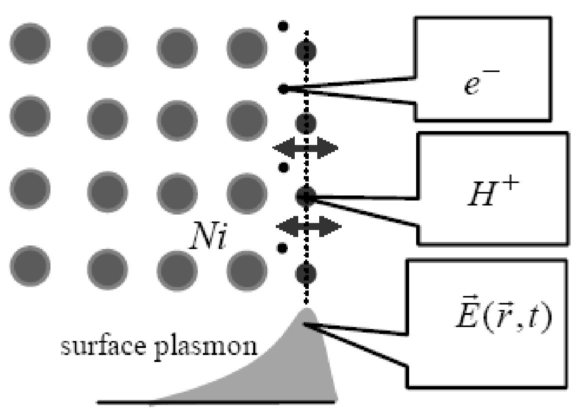

Figure 1. The model and space structure of surface plasmon.

2.3. Analysis of effectiveness of neutron production by inverse reaction of beta-decay at ponderomotive action of variable electric field of surface plasmon.

Let us consider the efficiency of inverse reaction of beta-decay $\tilde{e}^- p \rightarrow n\nu$ taking into account the formation of such accelerated relativistic electrons.

Mean free path of these fast electrons in relation to the process of inverse reaction of beta-decay $\tilde{e}^- p \rightarrow n\nu$ is

$$\left\langle l_{\tilde{e}^- p \rightarrow n\nu} \right\rangle \approx \langle v \rangle \, \tau_{\tilde{e}^- p \rightarrow n\nu}. \tag{20}$$

Here

$$\tau_{\tilde{e}^- p \rightarrow n\nu} = 1/\,\Gamma_{\tilde{e}^- p \rightarrow n\nu}$$

is the duration of return beta-decay reaction (see [3], Eqs. (29) and (30)),

$$\Gamma(\tilde{e}^- p \rightarrow n\nu) \approx (G_F m_e^2 c/\hbar^3)^2 (m_e c^2/\hbar) \left(\frac{\tilde{m}_e - \Delta}{\Delta} \right)^2 \approx 1.2 \times 10^{-3} \, (\beta - \beta_0)^2 \, s^{-1},$$

$$\beta = \tilde{m}_e / m_e, \qquad \Delta = M_n - M_p \approx 1.3 \, \mathrm{MeV/c^2} \tag{21}$$

is the probability of return beta-decay reaction.

From the other hand the same mean free path may be written

$$\left\langle l_{\tilde{e}^- p \rightarrow n\nu} \right\rangle \approx 1/\sigma_{\tilde{e}^- p \rightarrow n\nu} n_t \tag{22}$$

using the cross-section $\sigma_{\tilde{e}^- p \rightarrow n\nu}$ of $\tilde{e}^- p \rightarrow n\nu$ reaction and total concentration n_t of atoms (nuclei) in a target.

From the last equations follows the following expression for cross-section $\sigma_{\tilde{e}^- p \rightarrow n\nu}$ of return beta-decay reaction with the participation of fast electron with averaged velocity $\langle v \rangle$

$$\sigma_{\tilde{e}^- p \rightarrow n\nu} \approx \Gamma_{\tilde{e}^- p \rightarrow n\nu} / n \langle v \rangle \approx \left\{ 1.2 \times 10^{-3} \, (\beta - \beta_0)^2 \,/ n \langle v \rangle \right\} \, \mathrm{cm}^2. \tag{23}$$

For typical parameters $n_t \approx 3 \times 10^{22} \, \mathrm{cm}^{-3}$, $\langle v \rangle \approx c/3 = 10^{10}$ cm/s, $\beta - \beta_0 \approx 0.5$ we have the final values for cross-section

$$\sigma_{\tilde{e}^- p \rightarrow n\nu} \approx \Gamma_{\tilde{e}^- p \rightarrow n\nu} / n \langle v \rangle \approx 10^{-36} \, \mathrm{cm}^2 = 10^{-12} \, \mathrm{bn} \tag{24}$$

and mean free path of these fast electrons

$$\langle l_{\tilde{e}^- p \rightarrow n\nu} \rangle \approx 3 \times 10^{13} \, \mathrm{cm} \tag{25}$$

in relation to the process of inverse reaction of beta-decay.

This cross-section of neutronization is by $10^{14} - 10^{15}$ times less then the cross-section

$$\sigma_{\text{ion.rad.loss}} = 1/n_t \left\langle l_{\text{ion.rad.loss}} \right\rangle \tag{26}$$

of ionization and radiative loss (including ionization and excitation of atoms of target and X-ray bremsstrahlung).

In particular for electron with the energy about 0.8 MeV the mean free path and cross-section of ionization and radiative loss in Ni or Pd matrix are equal

$$\left\langle l_{\text{ion.rad.loss}} \right\rangle \approx 1 - 2 \text{ mm}, \tag{27}$$

$$\sigma_{\text{ion.rad.loss}} \approx (3 - 1.5) \times 10^{-22}\,\text{cm}^{-2} = 300 - 150\ \text{bn}. \tag{28}$$

In the result at surface density of heavy electron–proton pairs $N/S = 10^{16}\text{cm}^{-2}$ the maximal possible rate of neutron production on a metal hydride surface is much lower then it was presented in [4] (see Eq. (31) where $\tilde{w}(\tilde{\text{e}}^-\text{p} \to \text{n}\nu) \approx 10^{13}\text{cm}^{-2}\text{s}^{-1}$ at $\beta - \beta_0 \approx 0.5$) and equals to very low value

$$\tilde{w}(\tilde{\text{e}}^-\text{p} \to \text{n}\nu) \approx 10^{13}\,(\beta - \beta_0)^2\,\frac{\left\langle l_{\tilde{\text{e}}^-\text{p}\to\text{n}\nu}\right\rangle}{\left\langle l_{\text{ion.loss}}\right\rangle}\text{cm}^{-2}\text{s}^{-1} \le 0.03\ \ \text{cm}^{-2}\text{s}^{-1}. \tag{29}$$

2.4. The problem of additional localized energy for the generation of heavy electrons

According to Fermi theory of weak interaction the rate of $\tilde{\text{e}}^-\text{p} \to \text{n}\nu$ reaction is the following (see [3], Eqs. (29) and (30))

$$\Gamma(\tilde{\text{e}}^-\text{p} \to \text{n}\nu) \approx (\frac{G_\text{F} m_\text{e}^2 c}{\hbar^3})^2 (m_\text{e}c^2/\hbar)\left(\frac{\tilde{m}_\text{e} - \Delta}{\Delta}\right)^2 \approx 7 \times 10^{-3}\left(\frac{\tilde{m}_\text{e} - \Delta}{\Delta}\right)^2 \text{s}^{-1} \approx 1.2 \times 10^{-3}\,(\beta - \beta_0)^2\,\text{s}^{-1}. \tag{30}$$

At surface density of heavy electron–proton pairs $N/S = 10^{16}\text{cm}^{-2}$ [4] the rate of weak neutron production on a metal hydride surface is (see [4], Eq.(31))

$$\tilde{w}(\tilde{\text{e}}^-\text{p} \to \text{n}\nu) \approx 1.2 \times 10^{13}\,(\beta - \beta_0)^2\,\text{cm}^{-2}\text{s}^{-1}. \tag{31}$$

For formation of such surface density of heavy (“dressed up”) electrons we need additional density of:

localized specific surface energy

$$W/S \ge (\tilde{m}_\text{e} - m_\text{e})\,c^2(N/S) \ge 10^{16}\,\text{MeV/cm}^2 \approx 2 \times 10^3\,\text{J/cm}^2, \tag{32}$$

localized specific volume energy

$$(W/S)\,n_\text{p}^{1/3} \ge 10^{24}\,\text{MeV/cm}^3 \approx 10^{11}\,\text{J/cm}^3, \tag{33}$$

localized specific surface power

$$P/S \approx \tilde{w}\,(\tilde{\text{e}}^-\text{p} \to \text{n}\nu)(\tilde{m}_\text{e} - m_\text{e})\,c^2 \approx 2 \times 10^{13}\,\text{MeV/cm}^2 \approx 3\ \ \text{W/cm}^2 \tag{34}$$

and localized specific volume power

$$(P/S)\,n_\text{p}^{1/3} \approx 10^{21}\,\text{MeV/cm}^3 \approx 3 \times 10^8\,\text{W/cm}^3. \tag{35}$$

There are no sources of such concentrated energy and power on the surface of metal hydride!

Decrease of total proton mass (including the mass of proton electrostatic field) cannot be the source of this energy because in such case the conditions of inverse reaction of beta-decay (1) cannot be satisfied.

At the same time the thermal energy of these N/S surface hydrogen atoms is only

$$(3kT/2)N/S \le\ 4 \times 10^{-5}\,\text{J/cm}^{-2}. \tag{36}$$

The real maximally possible total number of heavy electron–proton pairs with additional energy

$$E \ge (\tilde{m} - m)\,c^2 \ge 0.8\,\text{MeV}$$

at averaged (thermal) energy

$$kT \approx 0.025 - 0.075 \text{ eV} \quad (T = 300 - 900\,\text{K})$$

of each proton in considered system is very small and equals

$$N^*/N = \int_{(\tilde{m}-m)c^2}^{\infty} \frac{1}{kT} \mathrm{e}^{-E/kT} \mathrm{d}E = \mathrm{e}^{-(\tilde{m}-m)c^2/kT} \approx (10^{-14000000} - 10^{-4500000}) \to 0, \quad N^*/S \to 0. \tag{37}$$

Such negligible quantity of surface concentration of heavy electron–proton pairs N^*/S does not allow to explain observable effects.

3. Summary

The carried out analysis has shown that Widom–Larsen theory, which is connected with the inverse reaction of beta-decay in variable electric field of surface plasmon in metal hydride, is unsuitable for the description and explanation of Rossi experiments in metal hydrides.

Authors of works [3–7] have not considered very essential features of interaction of electrons with a strong nonuniform field of surface high-frequency plasmon in condensed matters. Result of such interaction is acceleration of electrons due to action of ponderomotive force and formation of "fast heavy electrons", instead of formation of "slow heavy electrons", that is possible only in uniform high-frequency field.

Such accelerated (relativistic) electrons spend the own energy not for initiation of inverse reaction of beta-decay in target but to electromagnetic radiating processes and generation of bremsstrahlung. Such result directly follows from comparison of cross-sections of bremsstrahlung

$$\sigma_{\text{ion.rad. loss}} \approx 300 - 150\,\text{bn}$$

and inverse reaction of beta-decay

$$\sigma_{\tilde{\mathrm{e}}^- \mathrm{p} \to \mathrm{n}\nu} \approx 10^{-12}\,\text{bn}$$

for these "fast heavy electrons"

Such method of realization of inverse reaction of beta-decay may be effective in the area of action of uniform plane electromagnetic waves [9] of very high intensity

$$J \geq c|E_0^{(\max)}|^2/4\pi \approx 10^{20}\,\text{W/cm}^2 \tag{38}$$

in uniform substance. Such intensities are reached in experiments with femtosecond laser pulses. Unfortunately, electromagnetic fields of such squeezed optical laser pulses are very nonuniform. In this case at interaction of these pulses with any substance appearing of pushing out ponderomotive force and formation of relativistic electrons take place (e.g. [10]).

The same effect of electrons acceleration takes place at interaction of external soft electromagnetic waves (e.g. action of IR laser) with metal surface. In this case the surface electromagnetic field will be nonuniform because of total reflection. From the other hand, in the case of action of stationary radiation of hypothetical X-ray and gamma-ray lasers [11] on thin layer, process of surface reflection is absent, electromagnetic field would be close to uniform and it would be no effect of acceleration.

In our opinion the most optimal method of optimization of LENR is connected with the formation of correlated states of interacting particles in nonstationary potential wells without the increase of total energy of these particles. This mechanism provides the great increase of very small subbarrier transparency (by $10^{40} - 10^{100}$ and more times [12–15]) and can be efficiently applied to different nonstationary experiments (e.g. [16–20] and Rossi–Focardi experiments [1,2]).

Additional analysis of application of Widom–Larsen theory to LENR phenomena is presented in [21].

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