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β-β Decay with Majorana Neutrino as Possible Reason for the Lack of Solar Neutrinos

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Abstract. A new mechanism is considered which could contribute to the lack of Solar neutrinos. If neutrino is a Majorana particle ($\tilde{\nu}_e = \nu_e$) and its mass $m_\nu \neq 0$ or/and right-handed admixtures exist in the weak interactions, the β–β decay between the pairs of single β emitters without emission of neutrinos is possible. The estimations of the effective neutrino mass which could twice decrease the emission rate of Solar ^{8}B and ^{7}Be neutrinos give however the value of $\langle m_\nu \rangle$ more than 10^4–10^7 GeV which is in contradiction with experimental limits $\langle m_\nu \rangle \leq$ 1–4 eV founded in direct experiments devoted to search for neutrinoless double beta decay of atomic nuclei.

Key words: Solar neutrinos. — Neutrino mass. — β–β decay.

The phehomenon of neutrinoless β–β decay between the pairs of single β emitters was considered for the first time by A.F. Pacheco [1]. If neutrino is a Majorana particle ($\tilde{\nu}_e = \nu_e$) and its mass $m_\nu \neq 0$ and/or right-handed admixtures contribute to the weak interaction, the process is possible when virtual antineutrino emitted in β^- decay of one nucleus may be absorbed as neutrino in another nucleus in neighbourhood provoking also its β^- decay:

$$\begin{gathered}(A_1,Z_1) \to (A_1,Z_1+1)+e^-+\tilde{\nu}_e \\ \nu_e+(A_2,Z_2) \to (A_2,Z_2+1)+e^-.\end{gathered} \tag{1}$$

The nonzero neutrino mass or right-handed admixtures are required to flip the neutrino helicity and make possible the second reaction in (1). Analogous equations can be written also for two β^+ emitters or for one β^- and one β^+ nuclei (electron capture instead β^+ decay is possible too). As a result of the process (1), only electrons – no neutrinos – will be emitted with energy $E(e_1)+E(e_2)=Q(\beta_1)+Q(\beta_2)$, where $Q(\beta)$ is energy released in β decay.

The neutrinoless β–β decay between the pairs of single β emitters is analogous to the neutrinoless double beta ($\beta\beta$) decay of atomic nuclei (see [2]). In both of them d-quarks are transformed to u-quarks (as regards (1)). However in $\beta\beta$ decay the quarks are located in one or different nucleons of the same nucleus (Δ-isobar or two-nucleon mechanism) whereas in β–β

decay – in different nuclei. In fact, the (A_1,Z_1) and (A_2,Z_2) nuclei of (1) can be located not in the same sample but in different objects bringing into being the interaction of a given nucleus with the whole Universe (or, for the case of nonzero m_ν, with its part limited by Yukava radius). Theoretically it could cause the unavoidable electron background in superlow-background experiments devoted to search fo rare and forbidden processes (such as $0\nu\beta\beta$ decay).

As in process (1) only electrons are emitted, it is interesting to consider this phenomenon in connection with the puzzle of the lack of Solar neutrinos which have to be emitted, in particular, in β^+ decay of ^8B:

$$^8B \;\rightarrow\; ^8Be + e^+ + \nu_e. \tag{2}$$

In accordance with [3], the observed in experiments flux of neutrinos generated in process (2) is at least two times less than its theoretical value.

Probability of neutrinoless β-β decay between two nuclei $\Gamma \sim \langle m_\nu \rangle^2/D^2$, where $\langle m_\nu \rangle$ is an effective value of neutrino mass, D - distance between the nuclei [1]. In the sample with N_β nuclei the full rate of β–β processes is proportional to the number of pairs $\Lambda \sim N_{pair} \cdot \langle m_\nu \rangle^2/R^2$, where R – an effective radius of the sample. Since $N_{pair} \sim N_\beta^2 \sim R^6$, so $\Lambda \sim N_\beta^{4/3} \langle m_\nu \rangle^2$ and in a big sample the process of β–β decay could be non-negligible.

To estimate the value of $\langle m_\nu \rangle$ which is needed for decreasing two times the neutrino emission rate, we use the formula (4) in [1] for Γ modificated for the case of two different nuclei (A_i, Z_i), (A_j, Z_j) anchored on the distance D_{ij}:

$$\Gamma_{ij} = \frac{\gamma_{ij}}{D_{ij}^2} = \frac{\pi (ln2)^2 \langle m_\nu \rangle^2}{16 m^5} \cdot \frac{H_i H_j f_{ij}}{(ft)_i (ft)_j} \cdot \frac{1}{D_{ij}^2}, \tag{3}$$

where m is the mass of electron, $H_i = 2\pi\alpha Z_i'/(1 - \exp(-2\pi\alpha Z_i'))$ – Coulomb correction factor, $Z_i' = \mp(Z_i \mp 1)$ – atomic number of daughter nucleus created in $\beta^\pm$ decay, $f_{ij} = t_{ij}(t_{ij}^4 + 10t_{ij}^3 + 40t_{ij}^2 + 60t_{ij} + 30)/30$, $t_{ij} = (Q_i + Q_j)/m$, Q_i – maximal energy of neutrino available in decay of (A_i, Z_i), $\alpha = 1/137.036$.

Full rate of β–β decay in homogenous globe with radius R is:

$$\Lambda_{ij} = \frac{9}{4R^2} N_{pair} \gamma_{ij}, \tag{4}$$

where $N_{pair} = N_i N_j$ for $i \neq j$ and $N_i(N_i - 1)/2$ for $i = j$, N_i – the number of nuclei (A_i, Z_i) in the globe. Supposing that the Sun is approximately homogenous in the deepest layers where fusion occurs, we have the formula for the rate of β–β decay within the Sun:

$$\Lambda_{ij} = 3.2 \cdot 10^{-76} \cdot \left(\frac{\langle m_\nu \rangle}{1eV} \right)^2 \left(\frac{R}{R_\odot} \right)^{-2} N_{pair} \chi_i \chi_j f_{ij} \qquad (1/sec), \tag{5}$$

where $\chi_i = H_i/(ft)_i$ depends on properties of the nucleus (A_i, Z_i) only, whereas f_{ij} depends on properties of both the nuclei. The formula (5) allows to calculate the rates of neutrinoless β–β process between the pairs of existing within the Sun active nuclei. This quantities are presented in the Table. The values of Q_i and $(ft)_i$ were taken from [5], $R=0.1\ R_\odot$ was restricted [3], and N_i was calculated using the data [3] about the rates of (A_i, Z_i) decay:

$$N_i = (dN_i/dt)T_{1/2}/\ln 2 = \Omega(\nu_i)T_{1/2}/\ln 2,$$

where $\Omega(\nu_i)$ – theoretical value of flux of i-th neutrinos [3]. The values of $\Lambda_{ij}/\langle m_\nu\rangle^2$ for ^{13}N (Q_i=1190 keV), ^{15}O (1723 and 2754 keV) and ^{17}F (1739 keV) were calculated also and were found to be equal to 10^4–10^5 $s^{-1}\cdot eV^{-2}$ for β–β decay with ^{7}Be and less than 1.0 $s^{-1}\cdot eV^{-2}$ – with ^{8}B.

We can see from the Table, that the maximal contribution in decreasing the boron neutrinos' flux is determined by β–β decay between ^{8}B and ^{7}Be: $\Lambda = 60\langle m_\nu(eV)\rangle^2$ 1/sec. For the decreasing two times the theoretical rate of the ^{8}B neutrino emission we need therefore to take the value of $\langle m_\nu\rangle = 1.2\cdot 10^7$ GeV. For decreasing two times the flux in neutrino monoline of 862 keV from ^{7}Be K-capture (theoretical rate $1.3\cdot 10^{37}$ 1/sec) we have to take the value of $\langle m_\nu\rangle = 2.6\cdot 10^4$ GeV.

Required values of neutrino mass are in manifest contradiction with experimental limits on $\langle m_\nu\rangle$ from direct experiments to search for neutrinoless double beta decay of ^{76}Ge [6], ^{116}Cd [7], ^{136}Xe [8], and ^{150}Nd [9]: $\langle m_\nu\rangle < 1...4$ eV.

So, the neutrinoless β–β decay within the Sun could not give a considerable contribution to the lack of Solar neutrinos. Nevertheless it could play more important role in more compact and dense astronomical objects (such as pre-Supernova core) and in stellar nucleosynthesis.

Nucleus	Q_i, keV	lg ft	N_i	^{7}Be 384	^{7}Be 862	^{8}B 331	^{8}B 14018
^{7}Be	384	3.5	$8.8\cdot 10^{43}$	$2.5\cdot 10^8$	$1.5\cdot 10^9$	–	21
^{7}Be	862	3.3	$8.8\cdot 10^{43}$	$1.5\cdot 10^9$	$6.7\cdot 10^9$	1.1	39
^{8}B	331	2.9	$1.8\cdot 10^{34}$	–	1.1	–	–
^{8}B	14018	5.7	$1.8\cdot 10^{34}$	21	39	–	–

Table 1: $\Lambda_{ij}/\langle m_\nu\rangle^2$, $s^{-1}\cdot eV^{-2}$. Values less than 1.0 are not showed.

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