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# Neutrinoless DBD mechanisms and NMEs

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We discuss the light neutrino exchange mechanisms of the neutrinoless double beta decay in left-right symmetric seesaw models with right-handed gauge boson at TeV scale. It is found that there is a dominance of the conventional light neutrino Majorana neutrino mass mechanism over the momentum-dependent contribution to $0\nu\beta\beta$-decay involving final-state electrons with opposite helicities ($W_L$-$W_R$ exchange, the so called $\lambda$ mechanism).

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If the neutrinoless double beta decay process ($0\nu\beta\beta$-decay),

$$(A,Z) \rightarrow (A,Z+2) + 2e^- . \tag{1}$$

would be observed, it would not only prove that neutrinos are Majorana particles, but it would also provide a measurement of the neutrino mass, if the conventional light neutrino exchange mechanism generated by left-handed V-A weak currents is the dominant mechanism of this process.

The left-right symmetric theories provide a natural framework to understand the origin of neutrino Majorana masses. In this scenario, there are additional contributions to the $0\nu\beta\beta$-decay from both left-handed and right-handed currents via exchange of light and heavy neutrinos. It is assumed that mass of heavy vector boson $W_R$ might be around TeV - accessible at Large Hadron Collider.

The left-handed $\nu_{eL}$ and right-handed $\nu_{eR}$ electron neutrino eigenstates are a superposition of the light and heavy mass eigenstate Majorana neutrinos $\nu_j$ and $N_j$,

$$\nu_{eL} = \sum_{j=1}^{3} \left( U_{ej}\nu_{jL} + S_{ej}(N_{jR})^C \right), \quad \nu_{eR} = \sum_{j=1}^{3} \left( T^*_{ej}(\nu_{jL})^C + V^*_{ej}N_{jR} \right). \tag{2}$$

The $3 \times 3$ matrices $U, S, T, V$ represent the generalizations of the Pontecorvo-Maki-Nakagawa-Sakata matrix. They constitute the $6 \times 6$ unitary neutrino mixing matrix [1]

$$\mathscr{U} = \begin{pmatrix} U & S \\ T & V \end{pmatrix} = \begin{pmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & U_0 \end{pmatrix} \begin{pmatrix} A & R \\ S & B \end{pmatrix} \begin{pmatrix} V_0 & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{pmatrix}. \tag{3}$$

If masses of heavy neutrinos are above the TeV scale, the mixing angles responsible for mixing of light and heavy neutrinos are small. By neglecting the mixing between different generations of light and heavy neutrinos A, B, R and S matrices can be approximated as follows:

$$A \approx \mathbf{1}, \quad B \approx \mathbf{1}, \quad R \approx \frac{m_D}{m_{LNV}}\mathbf{1}, \quad S \approx -\frac{m_D}{m_{LNV}}\mathbf{1}. \tag{4}$$

Here, the Dirac mass $m_D$ represents energy scale of charge leptons and $m_{LNV}$ is the total lepton number violating scale, which corresponds to masses of heavy neutrinos. Since $V_0$ is unknown, it is common to assume that the structure of $V_0$ is the same one as $U_0 \equiv V_0$.

By considering only the exchange of light neutrinos and neglecting a possible mixing of light and heavy vector bosons, the $0\nu\beta\beta$-decay half-life can be written as [2]

$$\frac{1}{T^{0\nu}_{1/2}} = g_A^4 \, |M_{GT}|^2 \left\{ C_{mm} \, |\eta_\nu|^2 + C_{m\lambda} \, |\eta_\nu| \, |\eta_\lambda| \cos\psi + C_{\lambda\lambda} \, |\eta_\lambda|^2 \right\}. \tag{5}$$

Here, $M_{GT}$ is the Gamow-Teller matrix element and the coefficients $C_I$ (I = $mm$, $m\lambda$ and $\lambda\lambda$) are combinations of products of nuclear matrix elements and phase-space factors, which explicit form is given in [2]. The absolute values of the effective lepton number violating parameters $\eta_\nu$ ($m_{\beta\beta}$ mechanism) and $\eta_\lambda$ ($\lambda$ mechanism) are given by

$$\begin{aligned} |\eta_\nu| &= \frac{m_{\beta\beta}}{m_e} = \left| \sum_{j=1}^{3} U^2_{ej} \frac{m_j}{m_e} \right| = \frac{m_D}{m_{LNV}} \frac{m_D}{m_e} \left| \sum_{j=1}^{3} U^2_{ej} \frac{m_j m_{LNV}}{m_D^2} \right| \approx \frac{m_D^2}{m_{LNV} m_e}, \\ |\eta_\lambda| &= \left( \frac{M_{W_L}}{M_{W_R}} \right)^2 | \sum_{j=1}^{3} U_{ej} T^*_{ej} | \approx \left( \frac{M_{W_L}}{M_{W_R}} \right)^2 \frac{m_D}{m_{LNV}}. \end{aligned} \tag{6}$$

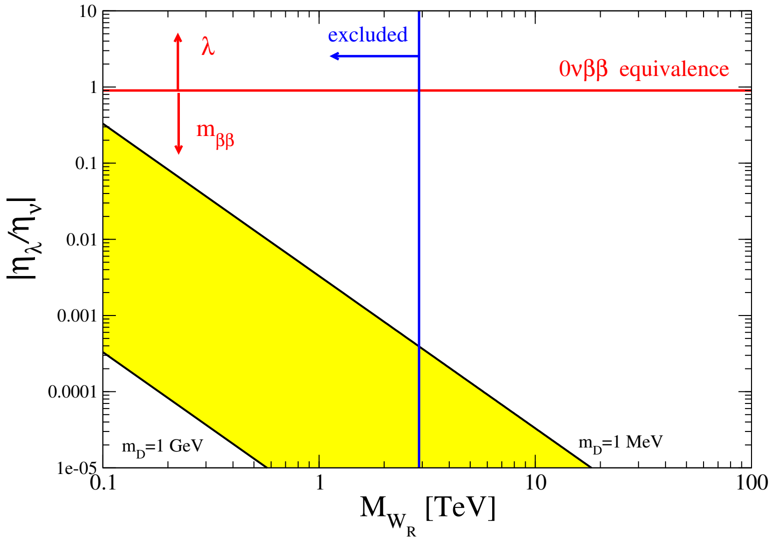

**Figure 1:** (Color online) The allowed range of values for the ratio $|\eta_\lambda/\eta_\nu|$ as a function of the mass of the heavy vector boson $M_{W_R}$. The line of the $0\nu\beta\beta$ equivalence corresponds to the case of equal importance of both $m_{\beta\beta}$ and $\lambda$ mechanisms in the $0\nu\beta\beta$-decay rate.

$\psi$ is their relative phase. Here, it is assumed $|\sum_{j=1}^{3} U_{ej}^2 m_j| m_{LNV}/m_D^2 \approx 1$, i.e., there is no anomaly cancellation among terms, which constitute $\eta_\nu$. $m_e$ is the mass of electron and $M_{W_L}$ ($M_{W_R}$) is the mass of light (heavy) vector boson. $g_A$ is the axial-vector coupling constant.
In Fig. 1 the ratio $|\eta_\lambda/\eta_\nu|$ is plotted as function of $M_{W_R}$. For the Dirac mass we assume 1 MeV $< m_D <$ 1 GeV. By using the present limit on $M_{W_R}$ we see that the $\lambda$ mechanism is excluded as the dominant mechanism of the $0\nu\beta\beta$-decay.

In summary, the left-right symmetric model scenario of the $0\nu\beta\beta$-decay was discussed by assuming the seesaw and the lepton number violation at the TeV scale. By making viable assumptions and using the current constraints on mass of heavy vector boson we conclude that the dominance of the $\lambda$ mechanism is practically excluded. Thus, there is a chance that the observation of the $0\nu\beta\beta$-decay will allow to determine the absolute neutrino mass scale of light neutrinos.

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