Study of Majoron accompanied neutrinoless double beta decay

R. Chandra[1],* K. Chaturvedi[2], Yash Kaur Singh[1], T. K. Yadav[1], P. K. Rath[3] and P. K. Raina[4]

[1] Department of Applied Physics, Babasaheb Bhimrao Ambedkar University, Lucknow - 226025, INDIA
[2] Department of Physics, Bundelkhand University, Jhansi – 284128, INDIA
[3]Department of Physics, University of Lucknow, Lucknow, 226007, INDIA
[4] Department of Physics, IIT Ropar, Nangal Road, Rupnagar, Punjab – 140001, INDIA
** email: ramesh.luphy@gmail.com*

Introduction

In the last decade, the confirmation of neutrino flavor oscillations and the reported observation of neutrinoless double beta $(\beta\beta)_{0\nu}$ decay have together played an extremely inspirational role in the advancement of a vast amount of experimental as well as theoretical studies on nuclear double-*β* decay in general and $(\beta\beta)_{0\nu}$ decay in particular [1,2].

In the left-right symmetric model [3,4], the possible mechanisms of $(\beta^-\beta^-)_{0\nu}$ decay are the exchange of left handed light as well as heavy Majorana neutrinos and the exchange of right handed heavy Majorana neutrinos. Alternatively, the occurrence of lepton number violating Majoron accompanied $(\beta\beta)_{0\nu}$ decay is also a possibility. The Majorons, in a general sense, are massless or light bosons carrying leptonic charge L. The existence of Majorons can play a crucial role in many areas namely Physics beyond the Standard Model, history of early universe, evolution of steller objects, supernovae astrophysics and the solar neutrino problem.

Following Bamert et al. [5], the nine different Majoron models are summarized in Table 1:

Table 1: Nine Majoron models according to Bamert et al. [5].

Mode	**Case**	**n**	**L**	$\mathbf{M_\alpha}$
$\beta\beta\phi$	IB	1	0	M_F-M_{GT}
$\beta\beta\phi$	IC	1	0	M_F-M_{GT}
$\beta\beta\phi$	IIB	1	-2	M_F-M_{GT}
$\beta\beta\phi$	IIC	3	-2	M_{CR}
$\beta\beta\phi$	IIF	3	-2	M_{CR}
$\beta\beta\phi\phi$	ID	3	0	$M_{F\omega2}$-$M_{GT\omega2}$
$\beta\beta\phi\phi$	IE	3	0	$M_{F\omega2}$-$M_{GT\omega2}$
$\beta\beta\phi\phi$	IID	3	-1	$M_{F\omega2}$-$M_{GT\omega2}$
$\beta\beta\phi\phi$	IIE	7	-1	$M_{F\omega2}$-$M_{GT\omega2}$

It can be noticed from Table 1 that the proposed Majoron models can be broadly classified as single Majoron emission $(\beta\beta\phi)_{0\nu}$ and double Majoron emission $(\beta\beta\phi\phi)_{0\nu}$ depending upon the number of Majorons emitted. In table 1, n, L and M_α denote the spectral index of the sum energy spectrum, leptonic charge and nuclear transition matrix elements (NTMEs), respectively.

The projected Hartree-Fock Bogoliubov (PHFB) model in conjunction with pairing plus quadrupole-quadrupole (PQQ) interaction has been successfully applied to study the $(\beta\beta)_{0\nu}$ decay as well as classical Majoron models i.e. the case IB, IC and IIB [6]. In the present case we apply the same model to calculate the NTMEs of rest of the Majoron models i.e. the case IIC, IIF, ID, IE, IID and IIE.

Theoretical framework

The details about the model space, single particle energies, *PQQ* type of effective two-body interaction and the procedure to fix its parameters have been given in Rath et al. [6] and references there in. In the approximation of light neutrino mass, the inverse half-life formula for Majoron emitting $(\beta\beta)_{0\nu}$ decay is given by [7]

$$\left[T_{1/2}^{(0\nu\phi)}(0^+ \to 0^+)\right]^{-1} = \left|\langle g_\alpha \rangle\right|^m \left|M_\alpha\right|^2 G_{\beta\beta\alpha}$$

with m=2 for $(\beta\beta\phi)_{0\nu}$ and m=4 for $(\beta\beta\phi\phi)_{0\nu}$ decay modes. Here $\langle g_\alpha \rangle$ and $G_{\beta\beta\alpha}$ denote the effective Majoron-neutrino coupling constant and phase space factors, respectively. The index α indicates that effective Majoron-neutrino coupling constant, NTMEs and phase space factors are different for different Majoron models. In closure approximation the NTMEs M_α are defined as

$$M_\alpha = \sum_{n,m} \left\langle 0_F^+ \left\| O_{\alpha,nm} \tau_n^+ \tau_m^+ \right\| 0_I^+ \right\rangle$$

The required nuclear transition operators are given by Hirsch et al. [7].

Results and discussions

We have calculated the NTMEs involved in different Majoron models listed in Table 1 using PHFB wave functions. Further, the NTMEs have been calculated by considering the finite size of nucleon (F) and Jastrow type of short range correlations (SRC) with Miller-Spencer, Argonne V18 and CD-Bonn NN potentials for the Majoron accompanied $(\beta\beta)_{0\nu}$ decay of ^{94,96}Zr, ^{98,100}Mo, ^{104}Ru, ^{110}Pd, ^{128,130}Te and ^{150}Nd isotopes for the $0^+ \rightarrow 0^+$ transition. The results are presented in Table 2 for the case of ^{100}Mo.

Table 2: Calculated NTMEs M_α of Majoron accompanied $(\beta\beta)_{0\nu}$ decay of ^{100}Mo in the PHFB model using PQQ type of two-body interaction.

M_α	**F**	**F+SRC**		
		SRC1	**SRC2**	**SRC3**
M_F	1.3662	1.2026	1.3667	1.4128
M_{GT}	-5.5167	-4.7220	-5.4265	-5.6564
M_{CR}	-0.2078	-0.1802	-0.2071	-0.2148
$M_{F\omega 2}$	0.0012	0.0011	0.0012	0.0012
$M_{GT\omega 2}$	-0.0058	-0.0056	-0.0059	-0.0059

In Table 2, SRC1, SRC2 and SRC3 denote the Jastrow type of short range correlations (SRC) with Miller-Spencer, Argonne V18 and CD-Bonn NN potentials, respectively. The calculation of NTMEs for rest of the nuclei stated above along with the extracted limits on effective Majoron-neutrino coupling will be presented in the symposium.

Conclusions

To summarize, we study the Majoron accompanied $(\beta\beta)_{0\nu}$ decay of ^{94,96}Zr, ^{98,100}Mo, ^{104}Ru, ^{110}Pd, ^{128,130}Te and ^{150}Nd isotopes for the $0^+ \rightarrow 0^+$ transition within PHFB model using pairing plus quadrupole-quadrupole type of two-body effective interaction and calculate the appropriate NTMEs of nine different Majoron models for extracting the effective Majoron-neutrino coupling from available half-life limits.

References

[1] F. T. Avignone III, S. R. Elliott, and J. Engel, Rev. Mod. Phys. 80, 481 (2008).

[2] J. D. Vergados, H. Ejiri, and F. Simkovic, Rep. Prog. Phys. 75, 106301 (2012).

[3] M. Doi and T. Kotani, Prog. Theor. Phys. 89, 139 (1993).

[4] M. Hirsch, H. V. Klapdor-Kleingrothaus, and O. Panella, Phys. Lett. B 374, 7 (1996).

[5] P. Bamert, C. P. Burgess and R. N. Mohapatra, Nucl. Phys. B 449, 25 (1995)

[6] P. K. Rath, R. Chandra, K. Chaturvedi, P. Lohani, P. K. Raina, and J. G. Hirsch, Phys. Rev. C 88, 064322 (2013).

[7] M. Hirsch, H. V. Klapdor-Kleingrothaus, S. G. Kovalenko and H. Pas, Phys. Lett. B 372, 8 (1996).