Occupation numbers and nuclear transition matrix elements of neutrinoless ββ decay within right-handed current mechanism

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Introduction

Besides the standard mass mechanism, the neutrinoless double beta (0νββ) decay is also possible with the coexistence of right-handed *V+A* and left-handed *V-A* currents. Specifically, the light and heavy Majorana neutrino exchange involving left and right handed currents within the left-right symmetric model (LRSM) can provide sharp limits on effective neutrino mass as well as effective coupling parameters of right-handed currents. The limits on these parameters are extracted from the observed experimental half-life limits of 0νββ decay by calculating the appropriate nuclear transition matrix elements (NTMEs). The extraction of accurate limits on these parameters depends on the reliability of NTMEs which is quite a challenging task due to non observation of 0νββ decay. The reliability of wave functions used to calculate NTMEs of 0νββ decay is tested by reproducing the experimentally extracted NTMEs $M_{2\nu}$ of 2νββ decay and other observed nuclear spectroscopic properties. Over the past years, the experimental sub-shell occupation numbers of ^{100}Mo, ^{100}Ru, ^{128,130}Te and ^{130}Xe nuclei have already been made available [1,2]. The reproduction of occupation numbers in addition to other available spectroscopic properties can play a crucial role in improving the reliability of model wave functions used in the calculation of NTMEs.

In the present work, we study the electron emitting $0\nu\beta^-\beta^-$ decay mode of ^{94,96}Zr, ^{100}Mo, ^{110}Pd, ^{128,130}Te and ^{150}Nd isotopes within mechanisms involving light Majorana neutrino mass and right-handed currents. The wave functions to calculate NTMEs are generated within projected Hartree-Fock-Bogoliubove (PHFB) model by using single particle energies (SPEs) derived from Woods-Saxon potential and four different parametrizaions of pairing plus multipolar effective two-body interaction adjusted to reproduce the available experimental sub-shell occupation numbers [3].

Formalism and Results

The inverse half-life of the $0\nu\beta^-\beta^-$ decay for $0^+\rightarrow 0^+$ transition is given by

$$\begin{aligned}[T^{0\nu}_{1/2}]^{-1} = {} & \left(\frac{<m_\nu>}{m_e}\right)^2 C_{mm} + \left(\frac{<m_\nu>}{m_e}\right) <\lambda> C_{m\lambda} \\ & + \left(\frac{<m_\nu>}{m_e}\right) <\eta> C_{m\eta} + <\lambda>^2 C_{\lambda\lambda} \\ & + <\eta>^2 C_{\eta\eta} + <\lambda><\eta> C_{\lambda\eta}\end{aligned} \quad (1)$$

where the nuclear structure factors C_{xy} are combinations of appropriate NTMEs $M^{(K)}$ and phase space factors. The $<m_\nu>$, $<\lambda>$ and $<\eta>$ are the effective light Majorana neutrino mass, the effective weak coupling of right-handed leptonic current with right-handed hadronic current and the effective weak coupling of right-handed leptonic current with left-handed hadronic current, respectively.

The Hamiltonian of the pairing plus multipolar effective two-body interaction used in the present work is given as

$$H = H_{s.p.} + V(P) + V(QQ) + V(HH) \quad (2)$$

The NTMEs $M^{(K)}$ of $0\nu\beta^-\beta^-$ decay have been calculated with four parametrizations of pairing plus multipolar effective two-body interaction and three parametrizations of short range correlations (SRC). The details about these parametrizations and method to fix them have been given in ref. [3] and references there in.

The SPEs and strengths of pairing and multipolar interactions are adjusted to reproduce the experimentally available sub-shell occupation numbers [1,2] and excitation energies E_{2^+} of 2^+ states of ^{100}Mo, ^{100}Ru, ^{128,130}Te and ^{130}Xe isotopes. In the rest of nuclei, the SPEs are scaled accordingly to reproduce the excitation energies E_{2^+} of 2^+ states. Employing four sets of HFB intrinsic wave functions, the deformation parameters β_2 of the nuclei under consideration are calculated and presented in Table 1.

Table 1: Theoretically calculated β_2 values along with their experimental values.

Nuclei	e_{eff}	Theory	Exp. [4]
^{94}Zr	0.5	0.0996±0.0316	0.090±0.010
^{94}Mo	0.6	0.1600±0.0010	0.1509±0.0015
^{96}Zr	0.5	0.0840±0.0020	0.080±0.017
^{96}Mo	0.4	0.1749±0.0019	0.1720±0.0016
^{100}Mo	0.6	0.2452±0.0005	0.2309±0.0022
^{100}Ru	0.4	0.2206±0.0027	0.2148±0.0011
^{110}Pd	0.5	0.2453±0.0092	0.257±0.006
^{110}Cd	0.5	0.1848±0.0065	0.1770±0.0039
^{128}Te	0.6	0.1389±0.0011	0.1363±0.0011
^{128}Xe	0.5	0.1838±0.0022	0.1836±0.0049
^{130}Te	0.5	0.1106±0.0065	0.1184±0.0014
^{130}Xe	0.5	0.1686±0.0061	0.169±0.007
^{150}Nd	0.5	0.2811±0.0009	0.2853±0.0021
^{150}Sm	0.4	0.2240±0.0036	0.1931±0.0021

The reliability of wave functions has been further tested by calculating the average NTMEs $M_{2\nu}$ (Table 2) for the $0^+ \rightarrow 0^+$ transition of $2\nu\beta^-\beta^-$ decay and comparing them with the available experimental data [6].

Table 2: Theoretically calculated average NTMEs $M_{2\nu}$ along with experimental values [5].

Nuclei	$M_{2\nu}$ (Theo.)	$M_{2\nu}$ (Exp.)
^{94}Zr	-	0.091±0.019
^{96}Zr	0.080±0.004	0.068±0.002
^{100}Mo	0.185±0.005	0.159±0.006
^{110}Pd	-	0.138±0.019
^{128}Te	0.043±0.003	0.052±0.008
^{130}Te	0.0293±0.0009	0.096±0.007
^{150}Nd	0.055±0.003	0.047±0.004

Subsequently, nuclear structure factors C_{xy} are calculated. It is noticed that NTMEs $M^{(K)}$ calculated with wave functions having adjusted experimental occupation numbers are in general reduced in comparison to those calculated without adjustment of occupation numbers. Using the average nuclear structure factors, on-axis limits on $<m_\nu>$, $<\lambda>$ and $<\eta>$ are extracted from the observed half-life limits of $0\nu\beta^-\beta^-$ decay of ^{94,96}Zr, ^{100}Mo, ^{110}Pd, ^{128,130}Te and ^{150}Nd isotopes and presented in Table 3.

Table 3: Extracted limits on $<m_\nu>$, $<\lambda>$ and $<\eta>$ for $0\nu\beta^-\beta^-$ decay.

Nuclei	$<m_\nu>$	$<\lambda>$	$<\eta>$
^{94}Zr	8.55×10^{2}	2.17×10^{-3}	1.11×10^{-5}
^{96}Zr	9.60	8.19×10^{-6}	1.28×10^{-7}
^{100}Mo	0.45	4.21×10^{-7}	6.41×10^{-9}
^{110}Pd	1.29×10^{3}	1.84×10^{-3}	1.78×10^{-5}
^{128}Te	3.95	1.28×10^{-5}	4.85×10^{-8}
^{130}Te	0.17	2.00×10^{-7}	2.53×10^{-9}
^{150}Nd	3.73	3.22×10^{-6}	6.04×10^{-8}

It is observed from Table 3 that the most stringent limits are obtained for ^{130}Te nuclei.

Conclusions

To summarize, we have calculated the sub-shell occupation numbers, yrast spectra, deformation parameter and $M_{2\nu}$ of potential nuclei for $0\nu\beta^-\beta^-$ decay within PHFB model. After getting an overall agreement between the calculated and observed properties, NTMEs $M^{(K)}$ of $0\nu\beta^-\beta^-$ decay within mechanisms involving light Majorana neutrino mass and right-handed currents have been calculated and limits on $<m_\nu>$, $<\lambda>$ and $<\eta>$ are extracted. It is observed that NTMEs $M^{(K)}$ calculated with wave functions having adjusted experimental occupation numbers are in general reduced.

References

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