Nuclear transition matrix elements of neutrinoless double beta decay including V+A current

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Introduction

The study of neutrinoless double beta (0νββ) decay has far reaching consequences in the panorama of lepton number violating processes. Over the past years, the theoretical studies devoted to the calculation of NTMEs have been excellently reviewed in refs. [1,2,3] and references there in. In 0νββ decay, the emission of a neutrino from one nucleon and its absorption by another nucleon implies the Majorana nature of neutrinos with finite mass. The 0νββ decay is not necessarily linked with the exchange of neutrino between two nucleons but is also possible with the simultaneous existence of right-handed V+A and left-handed V-A currents. In the present work, we consider the electron emitting $0\nu\beta^-\beta^-$ decay mode.

The $0\nu\beta^-\beta^-$ decay has not been observed so far and present status for the search of this particular mode has been given in refs. [4,5]. The nuclear models predict half-lives $T_{1/2}^{0\nu}$ of $0\nu\beta^-\beta^-$ decay assuming certain value of neutrino mass or conversely, limits on various lepton number violating gauge-theoretical parameters are extracted from the observed experimental half-life limits by calculating the appropriate NTMEs.

In the present work, our aim is to calculate the NTMEs of $0\nu\beta^-\beta^-$ decay of some nuclei in the mass range A=90-150 for the $0^+\rightarrow0^+$ transition within mechanisms involving the light Majorana neutrino, and right handed V+A current and to extract limits on the effective light Majorana neutrino mass $<m_\nu>$, the effective weak coupling of right-handed leptonic current with right-handed hadronic current $<\lambda>$ and the effective weak coupling of right-handed leptonic current with left-handed hadronic current $<\eta>$ from the observed limit on half-life $T_{1/2}^{0\nu}$.

Theoretical framework

Using approximation of Doi *et al*. [6,7] and Tomoda [8], the inverse half-life of the $0\nu\beta^-\beta^-$ decay for $0^+\rightarrow0^+$ transition is given by

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

and the nuclear structure factors C_{xy} are given as

$$\begin{aligned}C_{mm} &= G_{01}\left|M^{0\nu}\right|^2 \\ C_{m\lambda} &= M^{0\nu}(G_{04}M_{1+} - G_{03}M_{2-}) \\ C_{m\eta} &= M^{0\nu}(G_{03}M_{2+} - G_{04}M_{1-} - G_{05}M_P + G_{06}M_R) \\ C_{\lambda\lambda} &= G_{02}\left|M_{2-}\right|^2 - \frac{2}{9}G_{03}(M_{1+}M_{2-}) + \frac{1}{9}G_{04}\left|M_{1+}\right|^2 \\ C_{\eta\eta} &= G_{02}\left|M_{2+}\right|^2 - \frac{2}{9}G_{03}(M_{1-}M_{2+}) + \frac{1}{9}G_{04}\left|M_{1-}\right|^2 \\ &\quad - G_{07}(M_P M_R) + G_{08}\left|M_P\right|^2 + G_{09}\left|M_R\right|^2 \\ C_{\lambda\eta} &= -2G_{02}(M_{2+}M_{2-}) \\ &\quad + \frac{2}{9}G_{03}(M_{2+}M_{1+} + M_{2-}M_{1-}) \\ &\quad - \frac{2}{9}G_{04}(M_{1-}M_{1+})\end{aligned} \quad (2)$$

where the combinations of NTMEs, $M^{0\nu}$ and $M_{i\pm}$ (i=1,2) are defined as

$$\begin{aligned}M^{0\nu} &= M_{GT} - M_F + M_T \\ M_{1\pm} &= M_{qGT} - 6M_{qT} \pm 3M_{qF} \\ M_{2\pm} &= M_{\omega GT} \pm M_{\omega F} - \frac{1}{9}M_{1\mp}\end{aligned} \quad (3)$$

The values of $M^{0\nu}$ have been taken from [9] reevaluated at g_A=1.2701. The phase space factors are taken from ref. [10] reevaluated at g_A=1.2701.

Results and discussions

The NTMEs M_α have been calculated employing projected Hartree-Fock-Bogoliubov (PHFB) model with four parametrizations of pairing plus multipolar effective two-body interaction, namely PQQ1, PQQHH1, PQQ2 and PQQHH2 and three parametrizations of short range correlations (SRC) due to Miller-Spencer parametrization (SRC1), Argonne NN (SRC2) and CD-Bonn potentials (SRC3) including finite size (F) of nucleons. The details about these parametrizations and method to fix them have been given in ref. [11] and references there in. Due to paucity of space we present the results of only ^{96}Zr and ^{150}Nd nuclei for PQQ1 parametrization in Table 1.

Table 1: Theoretically calculated NTMEs M_α ($\alpha=\omega F,qF,\omega GT,qGT,qT,P,R$) of $0\nu\beta^-\beta^-$ decay for the $0^+\to0^+$ transition in PQQ1 parametrization.

Nuclei	NTME	F+SRC		
		SRC1	SRC2	SRC3
^{96}Zr	$M_{\omega F}$	0.425	0.496	0.517
	M_{qF}	0.496	0.542	0.547
	$M_{\omega GT}$	-2.054	-2.429	-2.553
	M_{qGT}	-2.651	-2.957	-3.005
	M_{qT}	0.074	0.073	0.073
	M_P	2.169	2.325	2.341
	M_R	-1.211	-1.967	-2.472
^{150}Nd	$M_{\omega F}$	0.475	0.537	0.554
	M_{qF}	0.632	0.674	0.678
	$M_{\omega GT}$	-2.164	-2.496	-2.602
	M_{qGT}	-3.013	-3.293	-3.334
	M_{qT}	0.043	0.043	0.043
	M_P	0.319	0.380	0.387
	M_R	-1.309	-2.103	-2.620

Subsequently, nuclear structure factors C_{xy} are calculated using appropriate NTMEs M_α and phase space factors. Using the average nuclear structure factors, on-axis limits on $\langle m_\nu \rangle$, $\langle\lambda\rangle$ and $\langle\eta\rangle$ are extracted from the observed limits on half-lives $T_{1/2}^{0\nu}$ =9.2×10^{21} [12] and 2.0×10^{22} [13] for ^{96}Zr and ^{150}Nd, respectively. The extracted limits on $\langle m_\nu \rangle$, $\langle\lambda\rangle$ and $\langle\eta\rangle$ for ^{96}Zr (^{150}Nd) are 10.92 eV (3.88 eV), 8.26×10^{-6} (2.94×10^{-6}) and 9.68×10^{-8} (4.61×10^{-8}), respectively.

Conclusions

Using HFB wave functions generated with PQQ1 parametrization of pairing plus multipolar type of effective two body interaction, and three different parametrizations of SRC, the NTMEs $M_{\omega F,qF}$, $M_{\omega GT,qGT}$, M_{qT}, M_P, and M_R of $0\nu\beta^-\beta^-$ decay for the $0^+\to0^+$ transition have been calculated for ^{96}Zr and ^{150}Nd nuclei. Limits obtained for the case of ^{150}Nd nuclei are more stringent.

References

[1] J. Suhonen, O. Civitarese, Phys. Rep. **300**, 123 (1998).
[2] A. Faessler and F. Simkovic, J. Phys. G **24**, 2139 (1998).
[3] J. Engel and J. Menéndez, Rep. Prog. Phys. **80**, 046301 (2017).
[4] Reyco Henning, Reviews in Physics 1, **29**, (2016).
[5] I. Ostrovskiy, Modern Physics Letters A, **31**, 1630017 (2016).
[6] M. Doi, T. Kotoni and E. Takasugi, Prog. Theor. Phys. Suppl. **83**, 1 (1985).
[7] M. Doi and T. Kotani, Prog. Theor. Phys., **89**, 139 (1993).
[8] T. Tomoda, Rep. Prog. Phys. 54, 53 (1991).
[9] P. K. Rath, R. Chandra, K. Chaturvedi, P. Lohani, P. K. Raina, and J. G. Hirsch, Phys. Rev. C **88**, 064322 (2013).
[10] D. Štefánik, R. Dvornický, F. Šimkovic, and P. Vogel, Phys. Rev. C **92**, 055502 (2015).
[11] P. K. Rath, R. Chandra, K. Chaturvedi, P. K. Raina, and J. G. Hirsch, Phys. Rev. C. **82**, 064310 (2010).
[12] J. Argyriades et al. Nucl. Phys. A **847**, 168,(2010).
[13] R. Arnold et al. Phys. Rev. D **94**, 072003 (2016).