Single State Dominance in Two-Neutrino Double Beta decay

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Introduction

The nuclear double beta($\beta\beta$) decay has long been recognized as a sensitive tool to test the mass and the nature (Dirac or Majorana) of neutrino, lepton number conservation and weak interactions involving right-hand currents. The 2ν $\beta\beta$ decay is consistent with the Standard Model (SM) and has been observed in ten nuclei [1]. On the other hand, $0\nu\beta\beta$ decay, forbidden in the SM, is yet to be confirmed experimentally. $2\nu\beta\beta$ decay gives the opportunity to test the nuclear structure models to calculate nuclear matrix elements, necessary for neutrino Majorana mass estimation.

Single State Dominance (SSD) hypothesis [2] conjectured that, for those $2\nu\beta\beta$ transitions where the ground state of the intermediate nucleus is a $J^\pi=1^+$ state, the matrix element for $2\nu\beta\beta$ decay could be dominated by GT transitions through this state. If the SSD hypothesis is confirmed, the half-lives for $2\nu\beta\beta$ decay could be determined from single-β and electron capture (EC) measurements. From theoretical point of view, the possible realization of the SSD hypothesis for the ground-state to ground-state transitions would lead to simplification in the theoretical description of the intermediate nucleus, since only the lowest 1^+ wavefunction has to be calculated.

Here, we describe the 2ν $\beta^\pm\beta^\pm$/ β^+EC/ ECEC transitions within a self-consistent mean field model, namely, Deformed Hartree-Fock (DHF) model. There are only few attempts made earlier to study SSD in $2\nu\beta\beta$ decay [3].

Theoretical Formalism

The axially deformed states are obtained by solving deformed Hartree-Fock equations in an iterative process. The states of good J can be extracted by means of angular momentum projection operator. In general, the projected states are not orthogonal. We orthonormalise them using following equation

$$\sum_{K'}(H^J_{KK'} - E_J N^J_{KK'})b^J_{K'} = 0 \quad . \qquad (1)$$

The inverse half-life of the 2ν $\beta\beta$ decay for the $0^+ \rightarrow 0^+$ transition is given by

$$[T^{2\nu}_{1/2}(0^+ \rightarrow 0^+)]^{-1} = G_{2\nu} \left|M_{2\nu}\right|^2 \quad , \qquad (2)$$

where $G_{2\nu}$ is the integrated kinematical factor. The nuclear transition matrix element (NTME) $M_{2\nu}$, which is a model dependent quantity, is given by

$$M_{2\nu} = \sum_N \frac{\langle 0^+_F||\sigma\tau^\pm||1^+_N\rangle\langle 1^+_N||\sigma\tau^\pm||0^+_I\rangle}{E_N - (E_I + E_F)/2} \quad , \qquad (3)$$

where $|0^+_I\rangle$, $|0^+_F\rangle$ and $|1^+_N\rangle$ are initial, final and virtual intermediate states respectively. The quantity $E_I(E_F)$ is the energy of initial (final) states. For detail formalism see Ref. [4].

Results and Discussions

In the present work we have analyzed neutrino emitting modes of double beta decay for some nuclei which fulfil SSD hypothesis. In

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TABLE I: The double Gamow-Teller matrix element $M^{2\nu}_{DGT}$ and corresponding half-life $T^{2\nu}_{1/2}$ for $0^+_{gs} \rightarrow 0^+_{gs}$ transition of 2ν $\beta^-\beta^-$ decay for nuclei with SSD characteristics. Case A: Extracted from single-β and electron-capture decay. Case B: Calculated values by considering only the first 1^+ state of intermediate nuclei. Experimental values are taken from [1].

Nucleus	Case	log ft_{EC}	log ft_{β^-}	$M^{2\nu}_{DGT}$(SSD)	$T^{2\nu}_{1/2}$(SSD)	$T^{2\nu}_{1/2}$ (exp.)
^{100}Mo	A	4.29	4.59	0.19	5.0×10^{18}	
	B	4.06	4.25	0.23	2.05×10^{18}	
						$7.1\pm0.4\times 10^{18}$
^{110}Pd	A	4.08	4.66	0.19	1.2×10^{20}	
	B	3.96	4.47	0.18	0.78×10^{20}	
						$>6.0\times 10^{16}$
^{116}Cd	A	4.39	4.66	0.16	1.1×10^{19}	
	B	4.35	4.91	0.09	1.76×10^{19}	
						$2.8\pm0.2\times 10^{19}$

order to test the validity of SSD hypothesis, the matrix elements are extracted from log ft values corresponding to single-β and electron-capture decay [5]. The DGT matrix element for $2\nu\beta\beta$ decay within SSD hypothesis is obtained by:

$$M^{2\nu}_{DGT}(SSD) = \frac{1}{\sqrt{ft_{EC}ft_{\beta^-}}}\frac{6D}{g_A^2(Q_{\beta}\text{-}Q_{EC})}\ , \tag{4}$$

where $D = 6147$ β-decay constant and $g_A = 1.25$ is the axial-vector coupling strength. In accordance with the matrix element 4, the SSD hypothesis is realized within DHF calculation by restricting the summation of Eq. 3 to the first 1^+ state of intermediate nuclei.

Table I shows the matrix elements and corresponding half-life within SSD hypothesis for ^{100}Mo, ^{110}Pd and ^{116}Cd nuclei. Comparison with available experimental result is also made.

Within DHF model, considering only the lowest 1^+ state of intermediate nucleus in calculation of nuclear matrix elements, we have predicted the half-lives as 3.5×10^{22} yrs and 6.1×10^{21} yrs with $g_A = 1.25$ for $2\nu ECEC$ transitions in ^{78}Kr and ^{106}Cd, respectively.

Conclusions

Here, we have studied $2\nu\beta\beta$ nuclear matrix element within self-consistent Deformed Hartree-Fock method with special interest of SSD in some potential candidates. These results will help in analysis of NEMO3 data to test SSD hypothesis for ^{100}Mo and ^{116}Cd nuclei. If observed, it will simplify not only the theoretical description of intermediate nuclei but also the experimental estimation of $2\nu\beta\beta$ half-life.

Acknowledgements

Authors gratefully acknowledge the financial support from the Council for Scientific and Industrial Research (CSIR), New Delhi, Govt. of India through project No. 03(1216)/12/EMR-II dated 13.05.2012.

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