Two-neutrino Double Beta Decay of ^{76}Ge and ^{82}Se within Deformed Hartree-Fock Model

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Introduction

After the successful observation of two-neutrino double beta decay (DBD) for about 10 nuclei, there is a continuous efforts to improve the reliability and accuracy in evaluation of nuclear transition matrix elements (NTMEs). In spite of enormous progress in the field still there is lack of understandings to correctly describe second-order weak interaction processes like double beta transition. In addition to the initial and final nuclear states, it is necessary to have extensive knowledge about the complete set of the states of odd-odd intermediate nucleus. This stimulates the nuclear physics community to entreat different models and nuclear structure scenarios for solving the problem.

Over the last decades the deformed Hartree-Fock (DHF) model along with Surface- delta (SDI) interaction has been applied successfully to reproduce the nuclear spectroscopic properties [1]. A reasonable agreement between the calculated and observed spectroscopic properties makes us confident to employ the DHF wave functions to the study of double beta decay. Moreover, in our model, the deformation and pairing degrees of freedom are treated on equal footing which is desirable for studying DBD as most of the DBD nuclei are deformed and all of them are even-even type.

Here we have used the DHF model to study the two-neutrino double beta decay of ^{76}Ge and ^{82}Se.

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Theoretical Formalism

The axially deformed states are obtained by solving deformed Hartree-Fock equations in a self-consistance iterative process. Because of mixing in single particle orbits, as a consequance of taking into account the residual interaction, the HF configurations are superposition of states of good angular momentum. The states of good angular momentum can be extracted by means of angular momentum projection operator. In general, the projected states are not orthogonal. We orthonormalise them using following equation

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

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

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

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

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

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.

Results and Discussion

In our calculation, we have considered ^{56}Ni as spherical inert core and the valance space spans the $1p_{3/2}$, $0f_{5/2}$, $1p_{1/2}$, $0g_{9/2}$, $0d_{5/2}$,

TABLE I: Experimental limit on half-lives and corresponding extracted matrix elements $M_{2\nu}$ along with theoretically calculated values for $\beta^-\beta^-$ decay of ^{76}Ge and ^{82}Se for $0^+_{gs} \rightarrow 0^+_{gs}$ transition. The number corresponding to (a) and (b) are calculated for g_A =1.254 and 1.0 respectively. '*' denotes the present calculations.

Isotope	Expt $T_{1/2}$[Ref.] in yr	$M_{2\nu}$[Expt]	Model [Ref.]	$M_{2\nu}$ [Theo.]	Theo. $T_{1/2}$ in yr
^{76}Ge	$1.74^{+0.18}_{-0.16} \pm 0.01 \times 10^{21}$[2]	(a) $0.0665^{+0.0035}_{-0.0034}$	DHF*	0.0818	(a) 1.19×10^{21}
		(b) $0.1046^{+0.0055}_{-0.0053}$			(b) 2.94×10^{21}
	$0.9\pm0.1 \times 10^{21}$[3]	(a) $0.0925^{+0.0056}_{-0.0047}$	QRPA[7]	0.083	(a) 1.12×10^{21}
		(b) $0.1455^{+0.0088}_{-0.0074}$			(b)2.77×10^{21}
	Average value: $1.5\pm0.1 \times 10^{21}$[4]	(a) $0.0716^{+0.0025}_{-0.0023}$	SM[8]	0.0715	(a) 1.5×10^{21}
		(b) $0.1126^{+0.0039}_{-0.0036}$			(b) 3.46×10^{21}
^{82}Se	$0.96^{+0.1}_{-0.1} \pm 0.03 \times 10^{20}$[5]	(a) $0.0492^{+0.0037}_{-0.0031}$	DHF*	0.0516	(a) 0.86×10^{20}
		(b) $0.0773^{+0.0058}_{-0.0049}$			(b) 2.13×10^{20}
	$1.08^{+0.26}_{-0.06} \times 10^{20}$[6]	(a) $0.0464^{+0.0013}_{-0.0047}$	QRPA[9]	0.072	(a) 4.5×10^{19}
		(b) $0.0729^{+0.0020}_{-0.0074}$			(b) 1.11×10^{20}
	Average value: $0.92\pm0.07 \times 10^{20}$[4]	(a) $0.0503^{+0.0020}_{-0.0018}$	SM[8]	0.084	(a) 3.3×10^{19}
		(b) $0.0791^{+0.0031}_{-0.0028}$			(b) 8.15×10^{19}

$0g_{7/2}$, $0d_{3/2}$, $2s_{1/2}$ and $0h_{11/2}$ orbits both for protons neutrons with single particle energies 0.0, 0.78, 1.88, 4.44, 8.88, 11.47, 10.73, 12.21 and 13.69 MeV respectively. We have taken a reasonably large model space which is more effective in reproducing the observed quenching of NTMEs.

We have used the prolate HF solutions to calculate the energy spectra and electromagnetic moments for initial, final and intermediate nuclei except for ^{82}Kr. For this nucleus the prolate and oblate solutions are degenerate, therefore we have performed the shape-mixing calculation. A fairly good agreement between theoretical and experimental results is obtained. Subsequently, we employ the same wave functions to obtain the NTMEs for DBD processes. The calculated matrix elements and half-life of the transitions are depicted in Table I. The phase-space factors of Ref. [10] are used in this calculations.

Conclusion

To summarize, we employ the DHF model to construct the wave functions of parent, daughter and intermediate nuclei undergoing $\beta\beta$ decay. The overall agreement between the calculated and observed yrast spectra as well as electromagnetic properties of the nuclei suggests that the DHF wave functions are quite reliable. Subsequently, we employ the same wave functions to study the $\beta\beta$ decay of considered nuclei.

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