Uncertainties in nuclear transition matrix elements of neutrinoless positron double beta decay within PHFB model

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Introduction

One of the most important achievements of the last decade is the discovery of neutrino mass. The mass and nature of neutrinos can be determined from the analysis of observational data obtained from three complementary experiments, namely single-β decay, neutrino oscillation and neutrinoless double beta $(\beta\beta)_{0\nu}$ decay. The observation of $(\beta\beta)_{0\nu}$ decay implies non-zero mass of Majorana neutrinos.

The $(\beta\beta)_{0\nu}$ decay can proceed through double-electron emission $(\beta^-\beta^-)$, double-positron emission $(\beta^+\beta^+)$, electron-positron conversion $(\varepsilon\beta^+)$, double-electron capture $(\varepsilon\varepsilon)$, single and double Majoron emissions. The $\beta^+\beta^+$, $\varepsilon\beta^+$ and $\varepsilon\varepsilon$ processes are energetically competing and we shall refer to them as $e^+\beta\beta$ modes. The $(\beta\beta)_{0\nu}$ decay is possible in any gauge theoretical model which violates the conservation of lepton number. Limits on various gauge theoretical parameters can be extracted from the observed experimental limits on half-lives $T_{1/2}^{0\nu}$ by calculating the appropriate nuclear transition matrix elements (NTMEs).

In order to extract gauge-theoretical parameters accurately, one requires reliable calculation of NTMEs. However, there is a large variation in the calculated NTMEs in different nuclear models. The uncertainty in NTMEs is mainly due to different approaches employed in the existing theoretical calculations. In the absence of any general guiding principles, the models use different model spaces and different effective interactions.

In the present work, we restrict ourselves to $(\beta^+\beta^+)_{0\nu}$ and $(\varepsilon\beta^+)_{0\nu}$ modes of ^{96}Ru, ^{102}Pd, ^{106}Cd, ^{124}Xe, ^{130}Ba and ^{156}Dy isotopes for the $0^+\rightarrow0^+$ transition. The projected Hartree-Fock Bogoliubov (PHFB) model, in conjunction with the pairing plus quadrupole-quadrupole (*PQQ*) interaction, has been successfully applied to study the $(e^+\beta\beta)_{2\nu}$ as well as $(\beta^+\beta^+)_{0\nu}$ and $(\varepsilon\beta^+)_{0\nu}$ modes [1-4]. Four different parameterizations of the pairing plus multipole Hamiltonian are used to calculate NTMEs and their average values as well as standard deviations are estimated. Subsequently, the latter are employed to obtain upper and lower limits on the effective mass of light and heavy Majorana neutrinos, respectively.

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 already given in Refs. [1-4]. The Hamiltonian of the effective two-body interaction used in the present work is given as

$$H = H_{s.p.} + V(P) + V(QQ) + V(HH) \qquad (1)$$

where $H_{s.p.}$, $V(P)$, $V(QQ)$ and $V(HH)$ denote the single particle Hamiltonian, pairing, quadrupole-quadrupole and hexadecapole-hexadecapole parts of the effective two-body interaction. The relative magnitudes of the parameters of the *HH* part are calculated from a relation

$$\chi_4 \;=\; 0.4884\chi_2 A^{-2/3} b^{-4} \qquad (3)$$

with b=1.0032 $A^{1/6}$, suggested by Bohr and Mottelson [5]. The parameters for the T = 1 case are approximately half of their T = 0 counter parts.

The following two procedures have been adopted to fix the strengths of like and unlike components of the *QQ* interaction without and with the *V*(*HH*). In the first procedure, the strengths of like particle components are taken as $\chi_{pp} = \chi_{nn}$=0.0105 MeV b^{-4} and the strength of *pn* component χ_{pn} is varied so as to reproduce the E_2^+ of considered nuclei as closely as possible. We call these parametrizations as *PQQ*1 and *PQQHH*1, respectively. In the second procedure, we use the condition $\chi_{pp}= \chi_{nn}=\chi_{pn}/2$ and the experimental E_2^+ is reproduced. These parametrizations are denoted as *PQQ*2 and *PQQHH*2, respectively.

Results and discussions

Some preliminary results of the calculated NTMEs $M_{0\nu}$ as well as M_{0N} of $(\beta^+\beta^+)_{0\nu}$ and $(\varepsilon\beta^+)_{0\nu}$ modes for light and heavy neutrino exchange with the four parametrizations, namely *PQQ*1, *PQQ*2, *PQQHH*1 and *PQQHH*2 are presented in Table 1.

Table 1: Calculated NTMEs $M_{0\nu}$ and M_{0N} of ^{96}Ru and ^{130}Ba in the PHFB model.

Nuclei		$M_{0\nu}$	M_{0N}
^{96}Ru	*PQQ*1	4.550	132.39
	PQQHH1	4.526	132.68
	*PQQ*2	4.583	133.16
	PQQHH2	4.486	131.39
^{130}Ba	*PQQ*1	3.395	108.45
	PQQHH1	2.707	99.250
	*PQQ*2	2.769	91.516
	PQQHH2	1.398	58.414

By adding the hexadecapolar correlations to the standard *PQQ* interaction, the NTMEs $M_{0\nu}$ and M_{0N} get reduced by approximately 0.5 – 20.3 % and 0.2 – 8.5 %, respectively. Considering all the four parametrizations *PQQ*1, *PQQ*2, *PQQHH*1 and *PQQHH*2, the NTMEs $M_{0\nu}$ and M_{0N} for the light and the heavy neutrino exchange get reduced by approximately 0.5 – 59 % and 0.2 – 46 %, respectively. The work is in progress and the detailed results will be presented in the symposium.

Conclusions

To summarize, we employ the PHFB model using *PQQ* and *PQQHH* type of effective two-body interaction to construct the HFB wave functions of parent and daughter nuclei undergoing $e^+\beta\beta$ modes. Subsequently, we employ the same wave functions to study the $(\beta^+\beta^+)_{0\nu}$ and $(\varepsilon\beta^+)_{0\nu}$ modes of considered nuclei. Using the four parametrizations within PHFB model, there is a significant variation in the NTMEs $M_{0\nu}$ and M_{0N}. It is observed that the inclusion of hexadecapole interaction has substantial effect on the NTMEs of $(\beta^+\beta^+)_{0\nu}$ and $(\varepsilon\beta^+)_{0\nu}$ modes.

Acknowledgement

This work has been financially supported by DST, India vide grant no. SR/S2/HEP-13/2006.

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