Correlations in the nuclear transition matrix elements of $(\beta\beta)_{0\nu}$ decay within PHFB model

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Introduction

The neturinoless double beta $(\beta\beta)_{0\nu}$ decay is one of the potential keys to open the window for physics beyond standard model of electroweak unification (SM) as it violates the lepton number conservation. In order to get the absolute mass and unfold the nature of neutrinos i.e. Dirac or Majorana, the $(\beta\beta)_{0\nu}$ decay is the natural choice theoretically as well as experimentally [1,2]. The $(\beta\beta)_{0\nu}$ has not been observed experimentally and only limits on half-lives are available. The neutrino mass and other gauge theoretical parameters can be extracted from the available half-life limits using appropriate nuclear transition matrix elements (NTMEs) and accurately calculable phase space factors of $(\beta\beta)_{0\nu}$ decay. The accuracy of these extracted gauge theoretical parameters highly depends on the reliability of NTMEs of $(\beta\beta)_{0\nu}$ decay. The NTME $M^{0\nu}$ is a model dependent quantity and in the absence of experimental data the calculation of the $M^{0\nu}$ of $(\beta\beta)_{0\nu}$ decay is a formidable task. The two-neutrino double beta $(\beta\beta)_{2\nu}$ decay has been observed experimentally for twelve nuclei [3] and experimental NTMEs $M_{2\nu}$ for this mode are available. In practice, the reliability of $M^{0\nu}$ for $(\beta\beta)_{0\nu}$ decay is tested by reproducing the experimentally extracted $M_{2\nu}$ of $(\beta\beta)_{2\nu}$ decay as both the modes involve same set of wave functions.

The NTMEs $M^{0\nu}$ are mainly calculated in three types of models namely, shell-model, quasiparticle random phase approximation (QRPA) and alternative models along with their several variants and extensions [4,5]. It is found that there is a large uncertainty in the values of $M^{0\nu}$ calculated in these models. Even the NTMEs calculated in the same type of generic model have noticeable uncertainty. There are several reasons for the observed uncertainty in NTMEs. There is no specific prescription in practice to fix the two basic ingredients of any nuclear model i.e. the model space and appropriate effective two-body interaction. Generally, different model space and different effective interactions are used in models. Further, even for the same model space the basic approach to fix the parameters of effective two-body interactions is different. Moreover, the choice of axial vector coupling constant g_A and short range correlations also contribute to uncertainty in the NTMEs. Faessler et al. [6] has shown the importance of correlated nuclear matrix elements uncertainties within QRPA model in comparing the decay rates of $(\beta\beta)_{0\nu}$ decay for different nuclei.

The projected Hartree-Fock Bogoliubov (PHFB) model has been successfully employed to study the $(\beta\beta)_{0\nu}$ decay (see [7] and references therein). In the present work we establish correlations between NTMEs $M^{0\nu}$ of ^{96}Zr, ^{100}Mo, ^{110}Pd, ^{128,130}Te and ^{150}Nd calculated within PHFB model.

Theoretical framework

In the approximation of light Majorona neutrinos, the inverse half-life of $(\beta\beta)_{0\nu}$ decay for $0^+\to0^+$ transition is given by [8],

$$\left[T_{1/2}^{0\nu}\right]^{-1} = \left(\frac{\langle m_\nu\rangle}{m_e}\right)^2 G_{01}\left|\left(M_{GT}^{0\nu} - M_F^{0\nu}\right)\right|^2 \quad (1)$$

where G_{01} is the phase space factor which can be calculated exactly and the NTMEs are given by

$$M_k = \Sigma\left\langle 0_F^+\left\|O_{k,nm}\tau_n^+\tau_m^+\right\|0_I^+\right\rangle \quad (2)$$

with

$$O_F = \left(\frac{g_V}{g_A}\right)^2 H(r_{12}), \qquad O_{GT} = \sigma_1.\sigma_2 H(r_{12}) \quad (3)$$

Results and discussions

The model space, single particle energies (SPE's), parameters of the pairing plus multipole (PQQHH) type of effective two-body interaction have been already given in Ref. [9]. The effective Hamiltonian used in the present work is given as

$$H = H_{s.p.} + V(P) + V(QQ) + V(HH) \quad (4)$$

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. We use four parametrizations of effective two-body interaction namely, PQQ1, PQQHH1, PQQ2 and PQQHH2. The details about these parametrizations and method to fix them have been provided in our earlier work [10]. Further, the NTMEs have been calculated by considering the finite size of nucleon and Jastrow type of short range correlations with Miller-Spencer, Argonne V18 and CD-Bonn NN potentials. Hence, with four parametrizations and three short range correlations we have a set of twelve NTMEs for each nucleus.

Following Faessler et al. [6], the associated covariance matrx is given as

$$\mathrm{cov}(n_i,n_j) = \rho_{ij}\sigma_i\sigma_j$$

where diagonal elements coincide with the variances σ_i^2, n_i is matrix element, σ_I is the error and ρ_{ij} is the correlation. Here, we analyze the correlation between NTMEs of ^{96}Zr, ^{100}Mo, ^{110}Pd, ^{128,130}Te and ^{150}Nd nuclei calculated within PHFB model. The results are given in Table 1.

Table 1: Correlation matrix ρ_{ij} between NTMEs $M^{0\nu}$ of $(\beta\beta)_{0\nu}$ decay of ^{96}Zr, ^{100}Mo, ^{110}Pd, ^{128,130}Te and ^{150}Nd nuclei calculated within PHFB model.

	Correlation matrix ρ_{ij}					
	^{96}Zr	**^{100}Mo**	**^{110}Pd**	**^{128}Te**	**^{130}Te**	**^{150}Nd**
^{96}Zr	1.00					
^{100}Mo	0.86	1.00				
^{110}Pd	0.74	0.82	1.00			
^{128}Te	0.52	0.44	0.40	1.00		
^{130}Te	0.70	0.90	0.96	0.34	1.00	
^{150}Nd	0.53	0.80	0.92	0.20	0.97	1.00

It is observed from Table 1 that there is a positive correlation between NTMEs of $(\beta\beta)_{0\nu}$ decay of two or more nuclei within PHFB model. The detailed results will be presented in the symposium.

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