Double Beta Decay Study of Some Nuclei in the Mass Range $A = 76$ to 150 within the Deformed Hartree-Fock Model

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Introduction

The nuclear double beta($\beta\beta$) decay is a rare second order weak transition between two isobars having even Z -even N configuration and differing in nuclear charge by two units. It 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. There are two modes of $\beta\beta$ decay, namely two neutrino double beta ($2\nu\beta\beta$) decay and neutrinoless double beta ($0\nu\beta\beta$) decay.

This thesis describes the study of 2ν $\beta^-\beta^-$ transition as well as 2ν $\beta^+\beta^+$/ β^+EC/ ECEC transitions of some nuclei in the mass range $A = 76$ to $A = 150$ within a self-consistent mean field model namely, Deformed Hartree-Fock (DHF) model. Our aim is to study the double beta decay not isolatedly but together with the other observed nuclear phenomena. This is in accordance with the basic philosophy of nuclear many body theory, which is to explain all observed property of nuclei in a coherent manner.

Theoretical Formalism

The axially deformed states are obtained by solving deformed Hartree-Fock equations in an iterative process. Because of mixing in single particle orbits, the HF configurations are superposition of states of good angular momentum (J). The states of good J can be extracted by means of J 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

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

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.

Results and Discussions

A. Spectroscopic Study of Double Beta Decay Nuclei

Here, our aim is to obtain the reliable nuclear wave functions which will later be employed to calculate double beta decay observables. We test the quality of the wave functions obtained in our calculations by comparing the shapes and deformations of the nuclei and spectroscopic properties with available experimental results.

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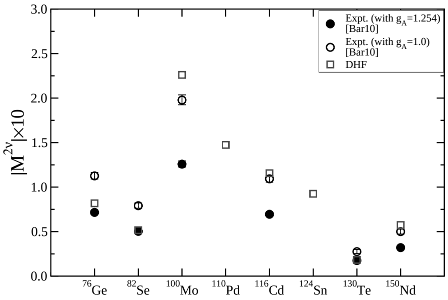

FIG. 1: Comparison of presently calculated NTMEs with available experimental results for $2\nu\beta^-\beta^-$ decay of ^{76}Ge, ^{82}Se, ^{100}Mo, ^{110}Pd, ^{124}Sn, ^{130}Te and ^{150}Nd nuclei. Experimental matrix elements are taken from Ref. [1].

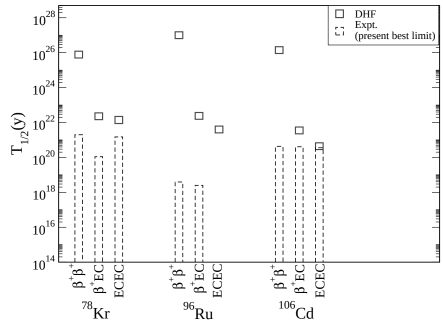

FIG. 2: Comparison of theoretical predicted half-lives with experimental best limits for 2ν $\beta^+\beta^+$/ β^+EC/ ECEC modes of ^{78}Kr, ^{96}Ru and ^{106}Cd. The calculated half-lives represented by boxes are range of half-life calculated with $g_A = 1.254$ and $g_A = 1.0$. The experimental results are taken from Refs.[2, 3].

B. $2\nu\beta^-\beta^-$ Decay of ^{76}Ge, ^{82}Se, ^{100}Mo, ^{110}Pd, ^{124}Sn, ^{130}Te and ^{150}Nd

We calculate the NTMEs of $2\nu\beta^-\beta^-$ decay for $0^+ \to 0^+$ transition in 2n-mechanism for the nuclei ^{76}Ge, ^{82}Se, ^{100}Mo, ^{110}Pd, ^{124}Sn, ^{130}Te and ^{150}Nd. The predicted half-lives are compared with the available experimental results as well as with other theoretical model calculations. The calculated NTMEs are compared with the values extracted from experimental half-lives and shown in Fig. 1.

C. 2ν $\beta^+\beta^+$/ β^+EC/ ECEC Decay of ^{78}Kr, ^{96}Ru and ^{106}Cd

We use the reliable wave-functions obtained earlier to calculate NTMEs and half-lives for 2ν $\beta^+\beta^+$/ β^+EC/ ECEC modes of ^{78}Kr, ^{96}Ru and ^{106}Cd. Calculated values are compared with the best experimental limits for these nuclei in Fig. 2.

Conclusions

This thesis aims to study the 2ν $\beta\beta$ decay of some nuclei in the mass range A=76 to 150 within the deformed Hartree-Fock (DHF) model using surface delta residual interaction. The overall reasonable agreement between the calculated spectroscopic properties and observed data makes us confident about the quality of the wave functions obtained in our calculations. Subsequently, we calculate reliable nuclear transition matrix elements (NTMEs) $M^{2\nu}$ and half-lives $T^{2\nu}_{1/2}$ of $2\nu\beta\beta$ decay and the results are compared with the other existing theoretical calculations as well as available experimental results. It was noticed that the validity of the nuclear models cannot be uniquely established due to large variations in NTMEs calculated using different models as well as uncertainty in g_A.

References

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