Double Beta Decay Half Lives for A=60-90 Nuclei in DSM

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Introduction

Double-β decay (DBD) is a rare weak-interaction process in which two identical nucleons inside the nucleus undergo decay with or without emission of neutrinos and they are denoted by 2νβ$^−$$^−$ and 0νβ$^−$$^−$ respectively. In addition, nuclei can also decay by positron DBD and here three modes β$^+$$^+$$^β$EC and ECEC are possible (hereafter, these three are called e$^+$$^+$$^DBD$). Observation of 0νβ$^−$$^−$ (also 0νe$^+$$^DBD$) is important as this gives neutrino mass.The current status of DSM results is presented here.

Formalism

Half-life for 0νβ$^−$$^−$ for the 0$^+_1$ ground state (gs) of a initial even-even nucleus decay to the 0$^+_1$ gs of the final even-even nucleus, with a few approximations [5], is given by

$$[T_{1/2}^{0\nu}(0^+_1 \rightarrow 0^+_1)]^{-1} = G^{0\nu}|M^{0\nu}|^2 \frac{\langle m_\nu \rangle^2}{m_e^2};$$

$$M^{0\nu} = M^{0\nu}_G - \frac{g_V^2}{g_A} M^{0\nu}_A$$

$$= \langle 0^+_1 || O(2 : 0\nu) || 0^+_1 \rangle,$$

$$O(2 : 0\nu) = \sum_{a,b} \mathcal{H}(r_{ab}, \overline{E}) \tau_a^+ \tau_b^+ \left( \sigma_a \cdot \sigma_b - \frac{g_V}{g_A} \right),$$

$$\mathcal{H}(r_{ab}, \overline{E}) \rightarrow \mathcal{H}_{eff}(r_{ab}, \overline{E})$$

$$= \frac{R}{r_{ab}} \exp \left( -\frac{3\overline{E}}{2hc} r_{ab} \right)$$

$$\times [1 - \exp(-\gamma_1 r_{ab}^2) (1 - \gamma_2 r_{ab}^2) ]^2.$$ (1)

In (1), $M^{0\nu}$ is NTME and $\langle m_\nu \rangle$ is the average neutrino mass. The $G^{0\nu}$ are phase space integrals and tabulations for them are available in Ref. [6]. The $g_A$ and $g_V$ are the weak axial-vector and vector coupling constants (we use $g_A/g_V=1$). The $\mathcal{H}_{eff}(r_{ab}, \overline{E})$ is the ‘neutrino potential’ with short range correlations incorporated. The parameters $\gamma_1 = 1.1 \text{ fm}^{-2}$, $\gamma_2 = 0.68 \text{ fm}^{-2}$, $R = 1.2 A^{1/3}$ fm, $\overline{E} = 1.12 A^{1/2}$ MeV, $r_{ab}$ in fm and $hc = 197.327 \text{ MeV fm}$. Calculation of the two-body matrix elements of the 0\nu transition operator $O(2 : 0\nu)$ involves Talmi integrals and Brody-Moshinsky brackets. Here we also need the oscillator length parameter $b = \sqrt{\hbar/m_\omega} \sim 0.9 A^{1/6}$ fm. Half-life for the 2νβ$^−$$^−$ for $0^+ \rightarrow 0^+$ transi-

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the DSM half-lives for $74^\text{Sr}$ lives are close to those from QRPA. Similarly, were published in [9] and the calculated half-lives for the $\nu\beta^-\beta^-$ decay and we have obtained $M^{2\nu} = 0.23$ while QRPA gives $0.13 - 0.16$ and expt’l value is 0.06. At present we are making calculations using much larger number of intrinsic states and changing $1g_{9/2}$ energy. We also plan to use the new interaction JUN45 [8].

For $2\nu e^+\text{DBD}$, the DSM results for $78^\text{Kr}$ were published in [9] and the calculated half-lives are close to those from QRPA. Similarly the DSM half-lives for $74^\text{Se}$ were published in [10] and there no results from other models for this nucleus. The half-life for the EC mode is $\sim 10^{26}$ yr and it should be possible to observe this in future experiments. We have recently performed calculations for $84^\text{Sr}$ (here also there no published results) [11] and the calculated half-lives for the $\beta^+\text{EC}$ and ECEC modes are $10^{26}$ yr and $\sim 4 \times 10^{24}$ yr respectively. Here $1g_{9/2}$ has to be lowered close to $2p_{1/2}$ orbit. In [3], a first attempt has been made to calculate half-lives for $^{84}\text{Zn}$. For $0\nu\beta^-\beta^-$ decay we have performed first calculations using DSM (with $\sim 10$ intrinsic states for band mixing) for $76^\text{Ge}$ and $82^\text{Se}$ and also $0\nu e^+\text{DBD}$ for $^{84}\text{Sr}$. Our results for $76^\text{Ge}$ and $82^\text{Se}$ differ by a factor of 2 to 3 in comparison to shell model and QRPA results. More detailed (with much larger number of intrinsic states) calculations are under way by relaxing the various approximations that gave Eq. (1) and also using JUN45 interaction. After testing the success of these calculations, we will consider the other nuclei in Table 1.

#### Results and Discussion

Calculations of NTME using DSM in $f_5/2p_{3/2}$ space with a modified Kuo interaction have been carried out for several of the nuclei in Table 1. The results are as follows.

DSM results for $2\nu\beta^-\beta^-$ in $76^\text{Ge}$ were reported in [7]. We made a first DSM calculation using $\sim 10$ intrinsic states in band mixing for $82^\text{Se}$ decay and we have obtained $M^{2\nu} = 0.23$ while QRPA gives $0.13 - 0.16$ and expt’l value is 0.06. At present we are making calculations using much larger number of intrinsic states and changing $1g_{9/2}$ energy. We also plan to use the new interaction JUN45 [8].

For $2\nu e^+\text{DBD}$, the DSM results for $78^\text{Kr}$ were published in [9] and the calculated half-lives are close to those from QRPA. Similarly the DSM half-lives for $74^\text{Se}$ were published in [10] and there no results from other models for this nucleus. The half-life for the ECEC mode is $\sim 10^{26}$ yr and it should be possible to observe this in future experiments. We have recently performed calculations for $84^\text{Sr}$ (here also there no published results) [11] and the calculated half-lives for the $\beta^+\text{EC}$ and ECEC modes are $10^{26}$ yr and $\sim 4 \times 10^{24}$ yr respectively. Here $1g_{9/2}$ has to be lowered close to $2p_{1/2}$ orbit. In [3], a first attempt has been made to calculate half-lives for $^{84}\text{Zn}$.

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#### References