Large-scale shell-model study of two-neutrino double beta decay in ^{82}Se

by

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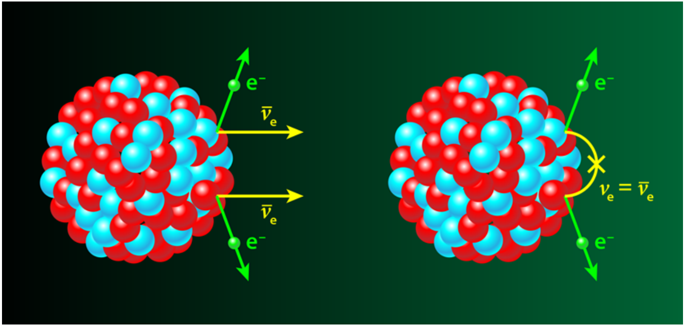
Introduction

- Double-beta decay (DBD) is the rarest radioactive weak interaction process and first introduced by Mayer as a nuclear disintegration.
- It can be classified by two major decay modes: two-neutrino (2ν) and neutrinoless (0ν) double beta decay.



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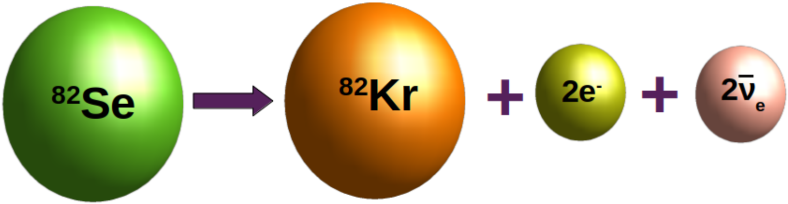
➤ The observation of $2\nu\beta\beta$ decay provides experimental evidence of the standard model of particle physics.



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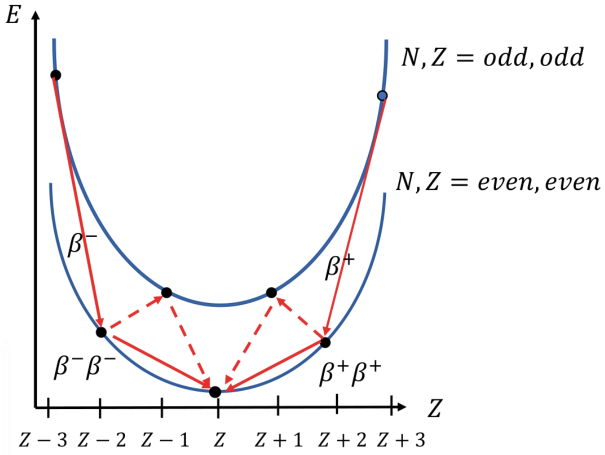

Figure: Mass parabola for isobaric nuclei with even atomic mass number.

Formalism

- The half-life for the $2\nu\beta\beta$ decay can be expressed as follows:

$$t_{1/2}^{2\nu} = \frac{1}{G^{2\nu} g_A^4 |M_{2\nu}|^2},$$

where $G^{(2\nu)}$ is the phase-space factor and g_A corresponds to axial-vector coupling strength. The nuclear matrix element (NME) $M_{2\nu}$ for $2\nu\beta\beta$ decay is given by

$$M_{2\nu} = \sum_k \frac{\langle 0_{g.s.}^{(f)} \| \sigma\tau^{\pm} \| 1_k^+ \rangle \langle 1_k^+ \| \sigma\tau^{\pm} \| 0_{g.s.}^{(i)} \rangle}{[\frac{1}{2} Q_{\beta\beta} + E(1_k^+) - M_i]/m_e + 1},$$

where m_e is the rest mass of the electron; $E(1_k^+) - M_i$ is the energy difference between the k^{th} intermediate 1^+ state and the g.s. of the initial nucleus; $0_{g.s.}^i (0_{g.s.}^f)$ is the g.s. of initial (final) nuclei; σ is the pauli matrix; $\tau^-(\tau^+)$ is the isospin lowering (raising) operator. $Q_{\beta\beta}$ (Q-value) is the energy released in the decay.

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➢ The reduced matrix element $\langle 0^{(f)}_{g.s.} \| \sigma\tau^{\pm} \| 1^{+}_{k} \rangle$ (or $\langle 1^{+}_{k} \| \sigma\tau^{\pm} \| 0^{(i)}_{g.s.} \rangle$) can be expressed as:

$$\langle J_f \| \sigma\tau^{\pm} \| J_i \rangle = \sum_{j_f j_i} \sqrt{3(2j_f + 1)}\delta_{l_i l_f} U(l_i s_i j_f 1, j_i s_f) D_{j_f j_i}.$$

Here, $U(l_i s_i j_f 1, j_i s_f)$ is the U coefficient, and j_i, l_i, and s_i (j_f, l_f, and s_f) are the total angular momentum, orbital angular momentum, and spin of initial (final) nucleonic state, respectively. $\delta_{l_i l_f}$ shows that for the allowed Gomow-Teller transition, the orbital angular momentum of the initial and final state nucleons must be equal.

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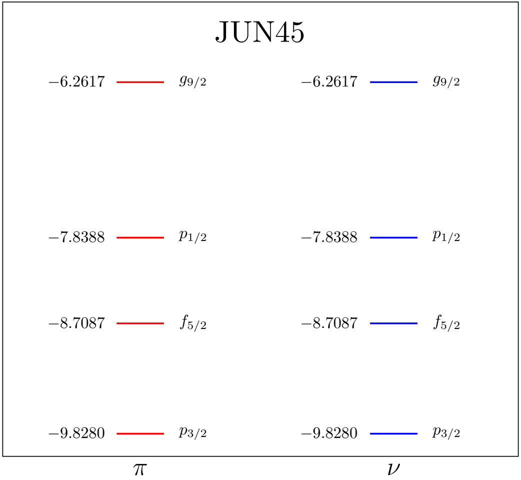
- The one-body transition densities $D_{j_f j_i}$ can be expressed as:

$$D_{j_f j_i} = \frac{\langle f || a^\dagger_{j_f} a_{j_i} || i \rangle}{\sqrt{2\delta_j + 1}},$$

where $a^\dagger_{j_f}$ (a_{j_i}) is nucleon-creation (annihilation) operator, and δ_j represents the changing of the angular momentum.

- The shell-model studies have been conducted using jun45 interaction for the study of $2\nu\beta\beta$ decay in ^{82}Se. This interaction consists of the $0f_{5/2}1p0g_{9/2}$ proton and neutron orbitals.

Model Space



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Results

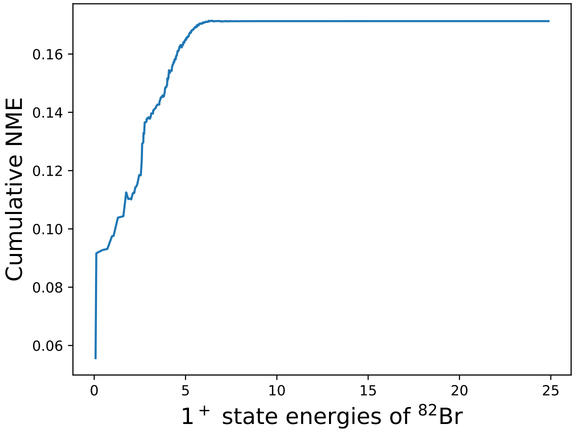

Figure: Cumulative $2\nu\beta\beta$ NME ($M_{2\nu}$) for ^{82}Se as a function of excitation energy (in MeV) of the intermediate 1^+ states in ^{82}Br.

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$$t_{1/2}^{2\nu} = \frac{1}{G^{2\nu} g_A^4 |M_{2\nu}|^2}, \qquad M_{2\nu} = \sum_k \frac{\langle 0_{g.s.}^{(f)} \| \sigma\tau^{\pm} \| 1_k^+ \rangle \langle 1_k^+ \| \sigma\tau^{\pm} \| 0_{g.s.}^{(i)} \rangle}{[\frac{1}{2} Q_{\beta\beta} + E(1_k^+) - M_i]/m_e + 1}$$

Table: Shell-model calculated $2\nu\beta\beta$ NMEs and the extracted half-life for ^{82}Se.

Isotope	$\lvert M_{2\nu} \rvert$	$G^{2\nu}$ (yr^{-1})	g_A^{eff}	Calculated $t_{1/2}^{2\nu}$ (yr)	Experimental/Recommended (Average) value of $t_{1/2}^{2\nu}$ (yr)
^{82}Se	0.1713	150.31×10^{-20}	0.76	0.68×10^{20}	$0.87^{+0.02}_{-0.01} \times 10^{20}$

- ➢ Adv. High Energy Phys. 2016, 7486712 (2016).
- ➢ Front. Phys. 5, 55 (2017).
- ➢ Universe 6, 159 (2020).

Summary and Conclusions

- In the present work, large-scale shell-model calculation was carried out for the study of $2\nu\beta\beta$-decay of the medium-mass nucleus ^{82}Se.

- The cumulative $M_{2\nu}$ curve shows that it saturates after a particular intermediate 1^+ state.

- The calculated half-life of $2\nu\beta\beta$-decaying nucleus ^{82}Se is in good agreement with the experimental data.

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Thank You for your attention!