β^+/EC - decay half-life study of sd space nuclei using shell model

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Introduction

The nuclear shell model has been successful in the description of various aspects of nuclear structure and beta decay probabilities of exotic nuclei [1, 2]. The nuclear structure study of $N = Z$ nuclei in the nuclear chart are very interesting because these nuclei show several phenomena such as shape coexistence along the $N = Z$ line and the role of pairing correlation of neutron and proton [3]. Proton-rich nuclei hold a pivotal role in astrophysics, particularly in processes like nucleosynthesis within stars. Motivated with the recent experimental data [4] of β^+/EC - decay half-lives in sd space nuclei, we have reported a comprehensive β^+/EC - decay study using nuclear shell model (SM) in the present work. The USDB [5] and SDNN [6] effective interactions have been used for the shell model calculations in sd model space. The shell model code NuShellX@MSU [7] is used for the diagonalization of energy matrices.

The SM results of β^+/EC - decay half-lives, excitation energies, Q-values, logft values, and branching fractions are discussed and compared with the available experimental data. The calculated β^+/EC - decay half-lives, excitation energies, Q-values, logft values, and branching fractions are in a good agreement with the available experimental data.

β - decay formalism

In β-decay processes the atomic number Z changes by one unit while the mass number A of the parent nucleus remains unchanged.

The total decay half-life of a combined β^+ and electron-capture (EC) transition is given by

$$f_0 t_{1/2} = \left[f_0^{(+)} + f_0^{(EC)}\right] t_{1/2} = \frac{\kappa}{[g_A^2 * B(GT) + B(F)]}, \quad (1)$$

where, g_A (= 1.270) represents the axial-vector coupling constant of the weak interactions and f_0 is the phase-space factor (or Fermi integral). The latest updated value of κ is

$$\kappa \equiv \frac{2\pi^3 \hbar^7 ln2}{m_e^5 c^4 (G_F cos\theta_C)^2} = 6289s, \quad (2)$$

where, the θ_C is the Cabibbo angle. The Fermi reduced transition probability $B(F)$ is given by

$$B(F) \equiv \frac{g_V^2}{2J_i + 1} |M_F|^2, \quad (3)$$

where, g_V (= 1.0) represents the vector coupling constant of the weak interaction and M_F is the Fermi matrix element.

The Gamow-Teller reduced transition probability $B(GT)$ is given by

$$B(GT) = \langle \sigma\tau \rangle^2. \quad (4)$$

In the above expression, the nuclear matrix element for the Gamow-Teller operator is given by

$$\langle \sigma\tau \rangle = \frac{\langle f || \sum_k \sigma^k \tau_\pm^k || i \rangle}{\sqrt{2J_i + 1}}, \quad (5)$$

where initial and final states are represented by the quantum numbers i and f, respectively.

For $\beta^\mp$ decay, the phase-space factor is given by

$$f_0^{(+)} = \int_1^{E_0} F_0(-Z_f, \epsilon) p\epsilon (E_0 - \epsilon)^2 \, d\epsilon, \quad (6)$$

where, F_0 is called Fermi function and

$$\epsilon \equiv \frac{E_e}{m_e c^2}, E_0 \equiv \frac{E_i - E_f}{m_e c^2}, p \equiv \sqrt{\epsilon^2 - 1}, \quad (7)$$

where E_e is the total energy of the emitted electron/positron and E_i and E_f are the energies of the initial and final nuclear state. The log$ft \equiv \log_{10}(f_0 t_{1/2}[s])$. The total half-life related to partial half-life (t_i) of the daughter state i using the following expression:

$$t_{1/2} = \left(\sum_i \frac{1}{t_i} \right)^{-1}. \quad (8)$$

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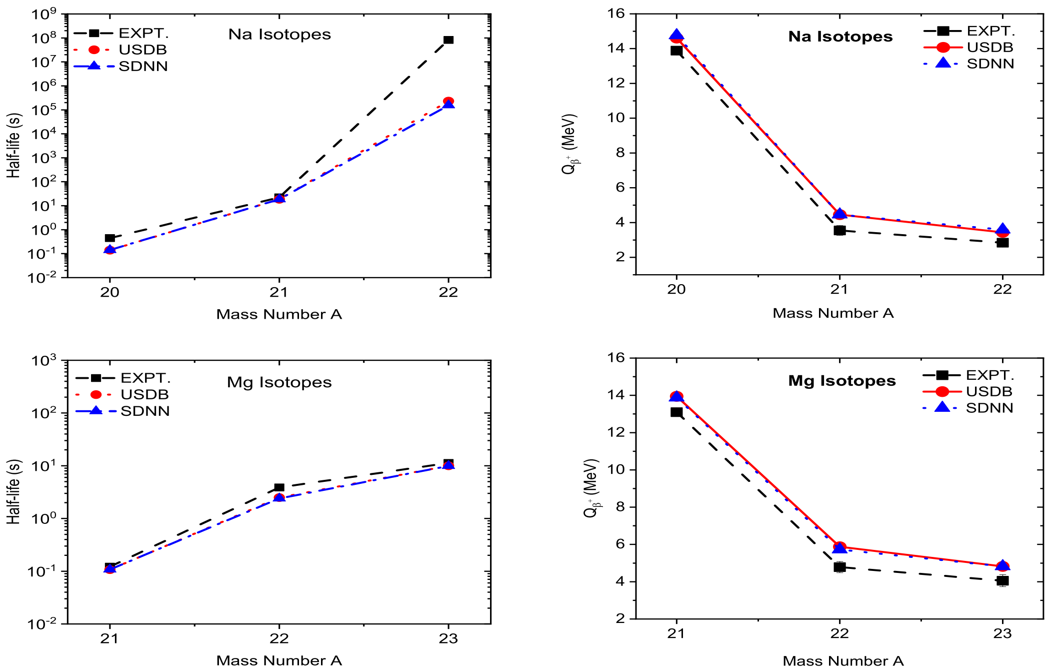

FIG. 1: The theoretical and experimental β^+/EC- decay half-life and Q values versus mass number A of the concerned nuclei for Na and Mg isotopes.

The branching ratio b_r is related to partial half-life t_i and the total half-life $t_{1/2}$ of the allowed β-decay as

$$t_i = \frac{t_{1/2}}{b_r}. \tag{9}$$

Results and Discussion

The experimental data with theoretical shell-model results of β^+/EC-decay half-lives are compared in left panel of the fig.1, while the Q-values are compared in right panel. As from fig.1, the half-life of Na and Mg isotopes increase with increase mass number while the Q-values decrease with increase mass number. The theoretical shell-model results of excitation energies and β^+-decay properties like logft values, branching percentages of Na and Mg nuclei of *sd* shell are compared between theoretical and experimental data. The shell model results for *sd* shell nuclei are in good agreement with the experimental data for excitation energies, logft values, and the branching ratios, except for few cases where the theoretical results deviate from the experimental data. During the meeting, we will present the results of the remaining *sd* shell nuclei.

Surender acknowledges financial support from BHU for his PhD thesis work. V. Kumar acknowledges financial support from IoE Seed Grant BHU (R/Dev/D/IoE/Seed Grant-II/2021-22/39960).

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