Half-lives of Proton Emission and Alpha Decay

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Introduction

Understanding the half-lives of proton emission and alpha decay is important to understand nuclear structure near the proton drip line.

Relativistic continuum Hartree-Bogoliubov (RCHB) theory was developed to predict both exotic and stable nuclei by incorporating continuum effects into the self-consistent Hartree-Bogoliubov framework [1]. As an extension of the RCHB, Deformed relativistic Hartree-Boboliubov theory in continuum (DRHBc) was developed, which takes axial degrees of freedom into account [2-4].

In this study, we calculate the proton emission half-lives of $71 \leq Z \leq 83$ nuclei predicted by DRHBc, using the semiclassical WKB approximation. We compare our results with available experimental data as well as previous calculations from RCHB [5], and discuss the differences. Finally, we calculate the alpha-decay half-lives of proton-emitting nuclei, where possible, and compare them with the corresponding proton emission half-lives.

WKB Framework

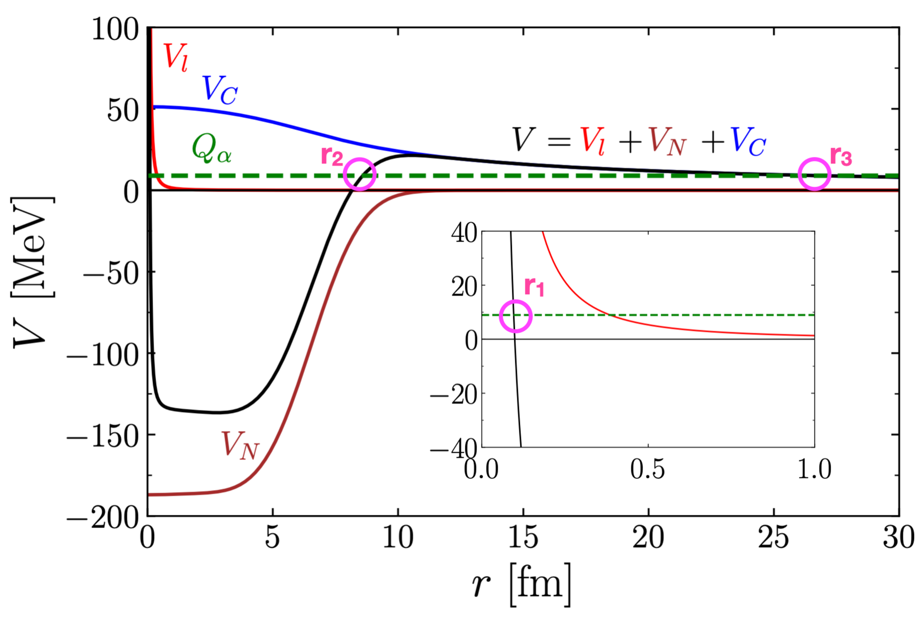

Fig. 1. Potential between daughter particle and a particle [6]. In WKB approximation framework, the half-live is calculated by considering the probability that the particles are formed and penetrates the Coulomb barrier. The time scale of the half-life is determined by the particle penetration probability of Coulomb barrier from r_2 to r_3.

Formulae

$$T = \hbar \ln 2/\Gamma$$

$$\Gamma = P_x N_f(k) \frac{\hbar^2}{4\mu} P_{\text{penetration}}(k)$$

$$k = \sqrt{\frac{2\mu}{\hbar^2}|Q - (V_l + \boxed{V_N + V_C})}$$

DRHBc or RCHB

In proton emission, the V_N is the nuclear potential of parent nucleus and P_x is the spectroscopic factor (S_p). We estimate S_p by decomposing the wave function into spherical components [7].

In alpha decay, the V_N is the nucleus-nucleus double-folding potential and P_x is the probability of the alpha particle formation in the parent nucleus (P_α). We estimate P_α by adopting cluster formation model $P_\alpha = P_\alpha(E_b)$ [8,9].

Results

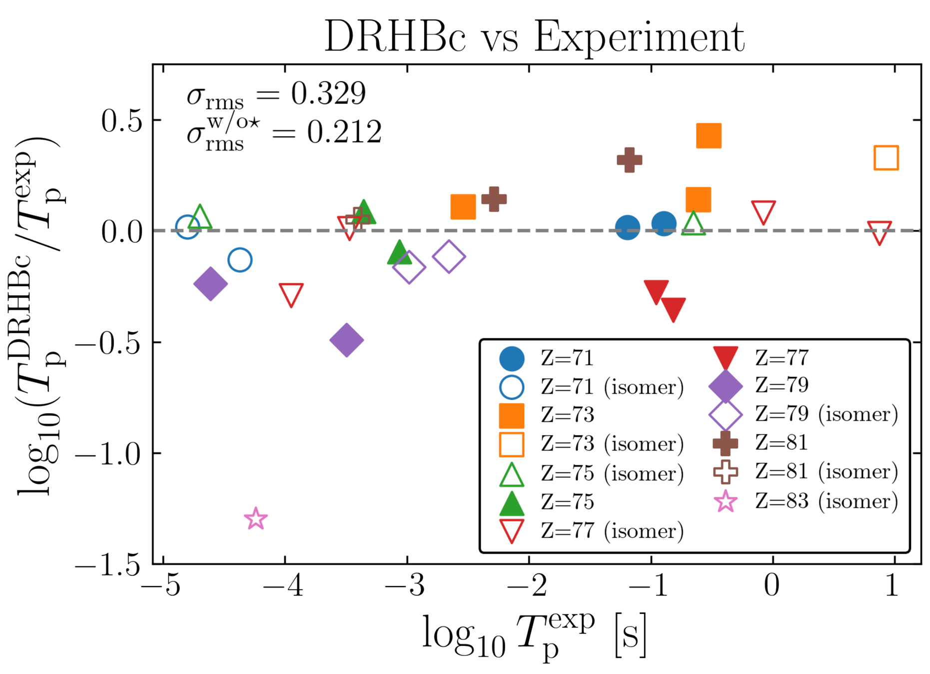

Fig. 2. Comparison of proton emission half-lives between DRHBc and experimental data [10]. Except ^{185m}Bi, the differences are all below 0.55.

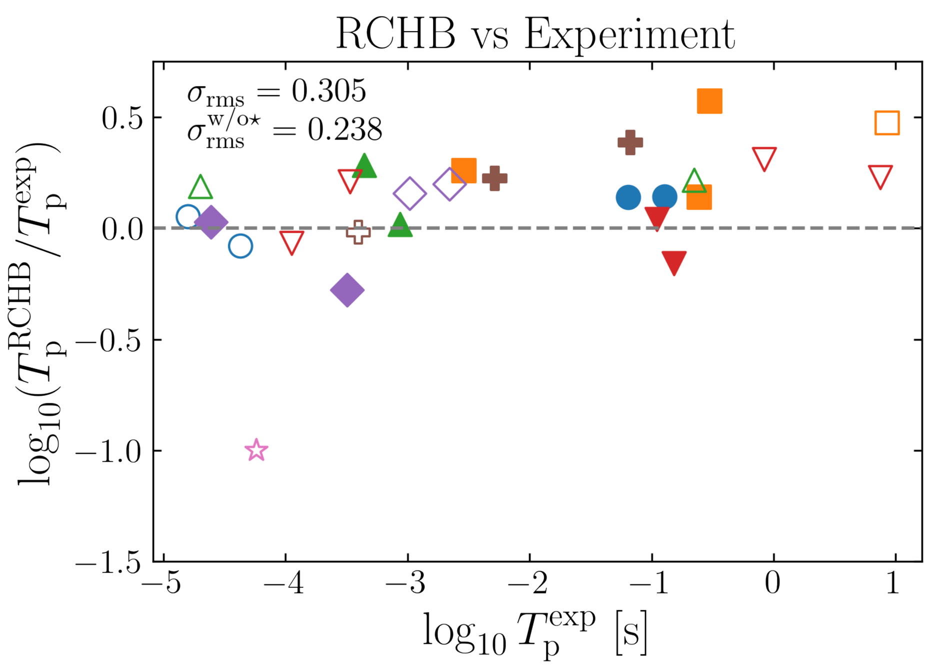

Fig. 3. Comparison of proton emission half-lives between RCHB and experimental data.

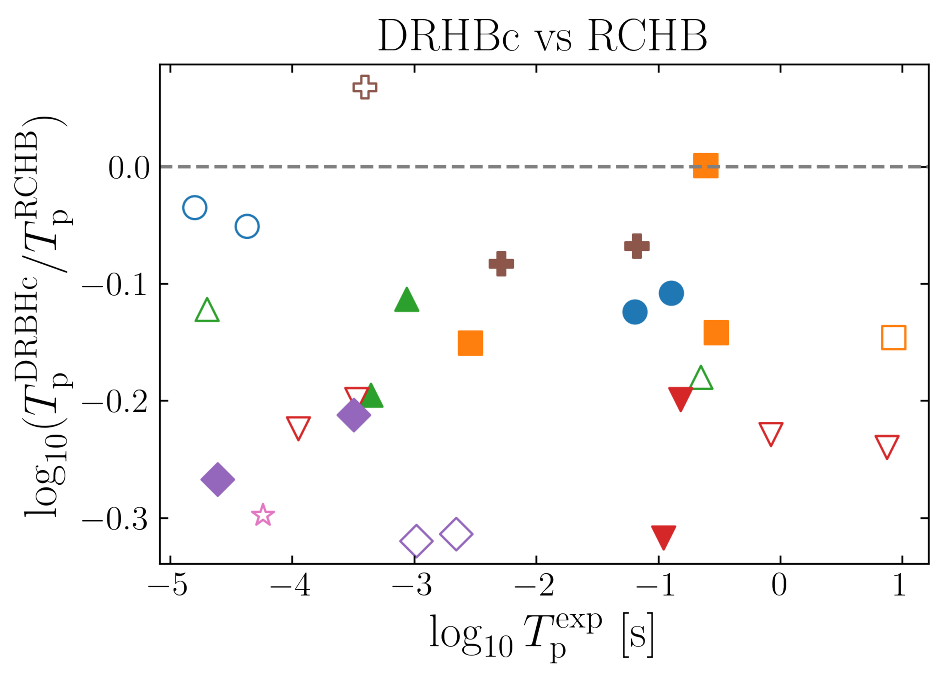

Fig. 4. Comparison of proton emission half-lives between DRHBc and RCHB. Half-lives calculated with DRHBc are shorter than those with RCHB.

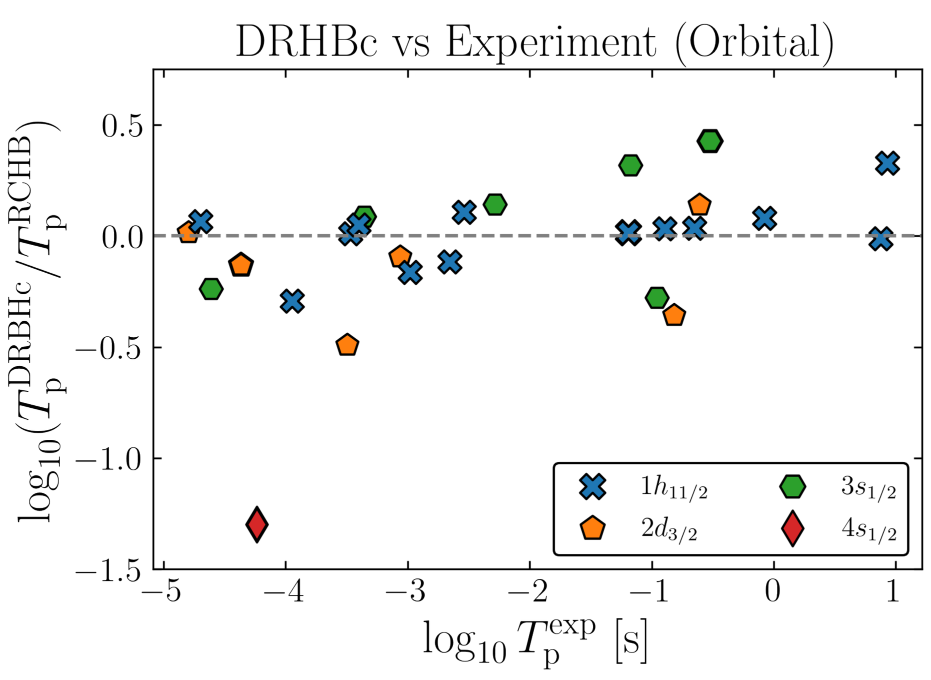

Fig. 5. Same as Fig. 2, but the markers are distinguished by color and shape according to the emitted proton orbital.

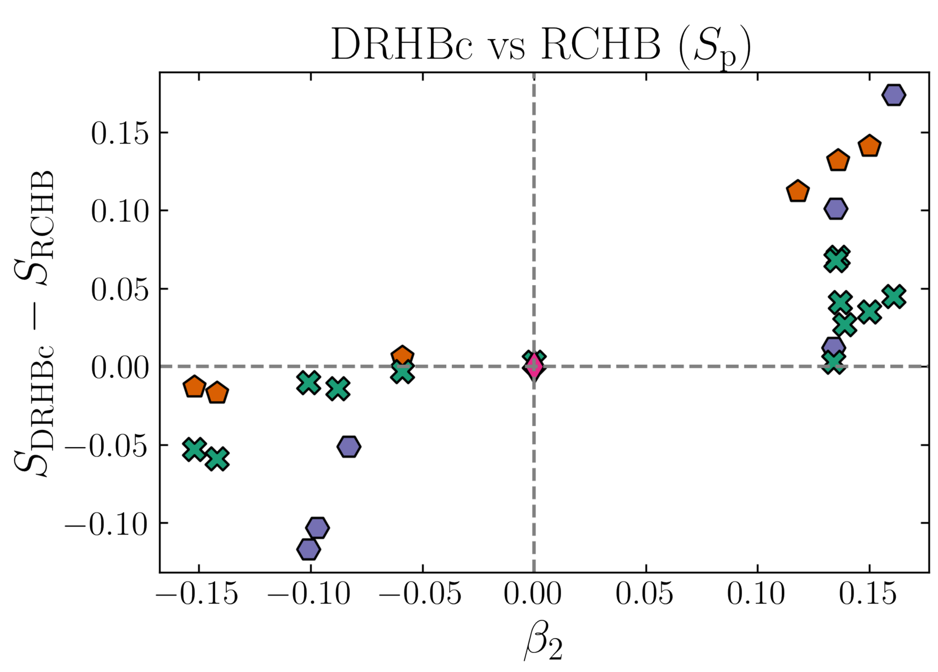

Fig. 6. Comparison of predicted spectroscopic factor from DRHBc and RCHB.

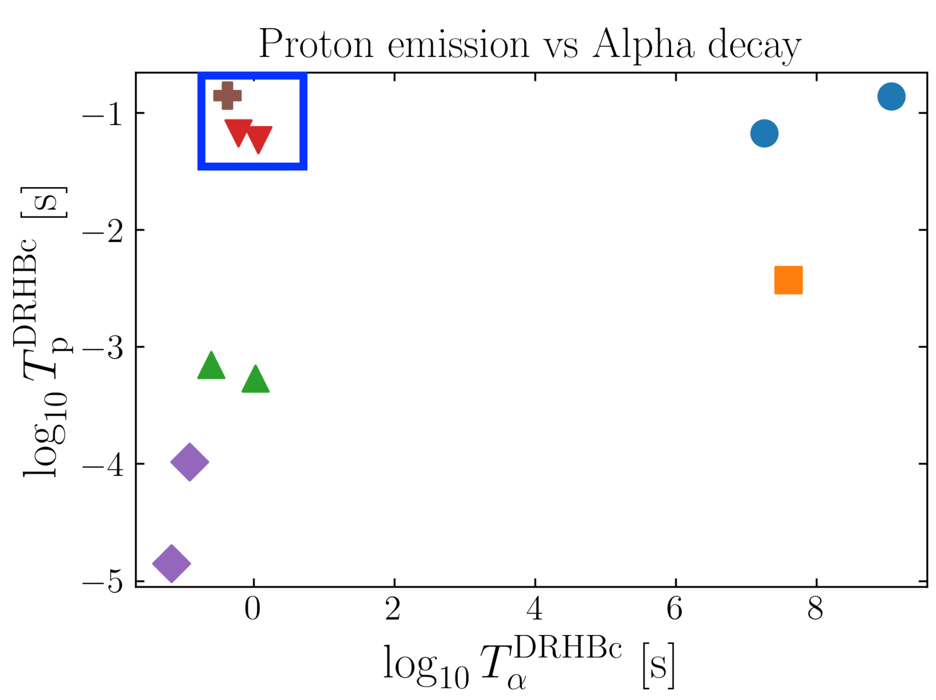

Fig. 7. Half-lives of proton emission vs alpha decay in DRHBc. The half-lives of ^{166,167}Ir and ^{177}Tl are comparable, as highlighted in the blue box.

Discussion

- Our results also show good agreement with experimental data for isomer states.
- Except for ^{185m}Bi (empty star marker), the half-lives with DRHBc agree better with experimental data than those with RCHB.
- The spectroscopic factor $S_p = 1$ of ^{185m}Bi ($4s_{1/2}$) may contribute to the discrepancy between calculated and experimental half-lives.
- The half-lives with DRHBc are shorter than those with RCHB.
- The calculated half-lives tend to be overestimated at large experimental values, possibly implying that the decay width is underestimated at small values.
- When comparing S_p, it tends to be higher for nuclei with a prolate shape ($\beta_2 > 0$).
- For the selected nuclei, proton emission is generally more dominant than alpha decay, except for ^{166,167}Ir and ^{177}Tl.

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