Analysis of decay half-lives of ^{208}Pb based clusters using different density and approaches

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Introduction

The study of cluster radioactivity, where a parent nucleus emits a cluster heavier than an alpha particle but lighter than a fission fragment, provides valuable insights into the structure and stability of nuclei. Among various theoretical approaches, the preformed cluster-decay model (PCM) [1] has emerged as a robust framework for predicting cluster decay half-lives and understanding decay characteristics. In the present work, we systematically investigate the cluster decay half-lives and their decay characteristics within the framework of PCM. Our primary focus is on the emission of clusters leading to the formation of doubly closed shell ^{208}Pb daughter nuclei, which serve as a benchmark due to their enhanced stability. The interaction potential between the emitted cluster and the daughter nucleus is calculated using a double-folding approach with the M3Y potential and semi-classical Skyrme Energy Density Formalism (SEDF) [2], incorporating densities derived from the two-parameter Fermi (2pF) [3] model and the Skyrme Hartree-Fock (SHF) [4] radial densities.

Our objective is to compare the phenomenological 2pF densities with the microscopic SHF densities to observe their impact on the calculated cluster decay half-lives. The penetration probability, which quantifies the likelihood of the cluster tunneling through the potential barrier, is derived using the Wentzel-Kramers-Brillouin (WKB) approximation. This method effectively captures quantum tunneling effects. The cluster's preformation probability (P_0) [5] is calculated using a phenomenological formula, further refining our understanding of decay. By systematically comparing the results obtained from the 2pF and SHF density models, this study aims to highlight the sensitivity of decay half-lives to different nuclear density inputs as well as theoretical formalism. This comparison emphasizes the importance of accurate density models in theoretical predictions, contributing to a deeper understanding of cluster decay mechanisms and aiding in exploring the nuclear landscape near the stability limits.

Theoretical Formalism

In the RMF framework [6], the cluster-daughter interaction potential is calculated using a double-folding procedure with the M3Y potential, incorporating nuclear densities from the 2pF and SHF models to assess their impact on decay half-lives. The double-folding approach is given as follows:

$$V_n(\vec{R}) = \int \rho_p(\vec{r}_p)\rho_t(\vec{r}_t)V_{eff}\left(|\vec{r}_p - \vec{r}_t + \vec{R}|\equiv r\right) d^3r_p d^3r_t. \qquad (1)$$

The interaction potential $V_N(R)$ used in SEDF [2] is given below:

$$V_N(R) = 2\pi\bar{R}\int H(\rho,\tau,j) - [H((\rho_1,\tau_1,j_1) + H((\rho_2,\tau_2,j_2] \qquad (2)$$

The decay constant and decay half-life is calculated within the PCM [1] as

$$T_{1/2} = \frac{\ln 2}{\lambda}, \qquad \lambda = \nu_0 P_0 P. \qquad (3)$$

The preformation probability (P_0) used in the above equation is calculated from Ref. [5]

Result and Discussions

The preformation probability (P_0) of a decaying system is closely related to its structural and decay properties, playing a crucial role in cluster decay from a parent nucleus. In this study, P_0 is calculated using a phenomenological formula referenced from Ref. [5]. The

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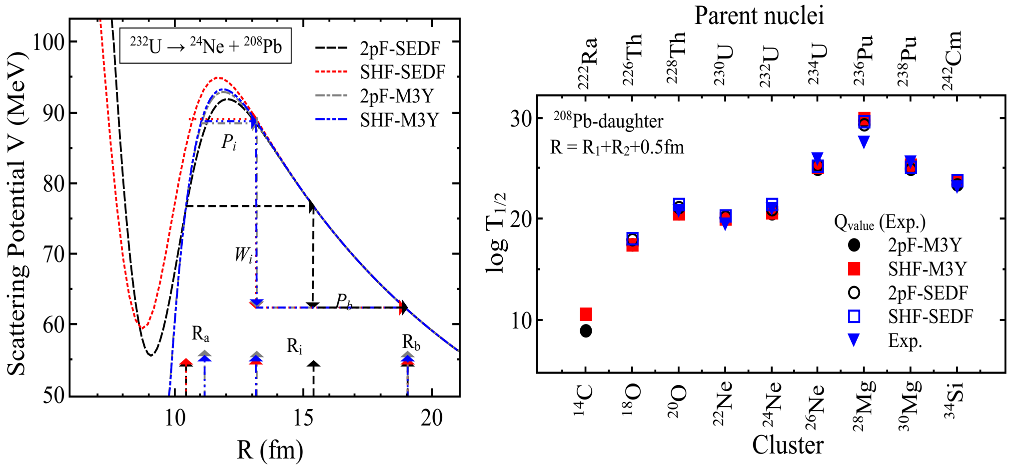

FIG. 1: (Color online) (a)The total interaction potential for an illustrative case of ^{232}U → ^{24}Ne+^{208}Pb, shown for the considered nuclear potentials at $\Delta R = 0.5$. (b) The decay half-life calculated using the Q_{values} taken from the experimental binding energies [1]

decay energies (Q_{values}), taken from Moller *et al.* [1], are essential inputs for the potential energy landscape, which are then utilized in the Preformed Clusterdecay Model (PCM) to compute the half-lives of experimentally observed clusters. Our results indicate that a neck-length $\Delta R = 0.5$ fm is optimal for describing elongated nuclear configurations. The calculations presented here are specifically for spherical clusters and ^{208}Pb daughter nuclei, providing a focused analysis of the impact of structural assumptions on the predicted half-lives.

Fig. 1(a) illustrates the scattering potential for 2pF and Skyrme Hartree-Fock (SHF) radial densities using M3Y and SEDF interaction potentials. The scattering curves shows that the M3Y results are consistent across the two densities. In contrast, the SEDF potential exhibits slight variations in barrier characteristics depending on the density used. This difference highlights the sensitivity of the scattering potential to the underlying nuclear interactions and density inputs, emphasizing the nuanced behavior of the nuclear potential landscape in predicting cluster emission. Additionally, Fig. 1(b) presents the logarithmic profile of half-lives for different clusters when paired with the fixed ^{208}Pb daughter nucleus. Notably, the calculated half-lives based on experimental binding energies reveal deviations when comparing results across different potentials. Our calculations, limited to spherical choice of nuclei using the M3Y potential, reveal deviations between the calculated and experimental half-lives [1], as demonstrated in Fig. 1(b). These deviations, though measurable, have comparable standard deviations when using different nuclear potentials, underscoring the robustness of the approach. While the present work is confined to spherical cases, future research aims to expand the framework to include deformation effects using Skyrme densities within the PCM, which could provide further insights into the role of nuclear shape on the cluster decay process.

References

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