Influence of the deformation and shape coexistence on lifetime estimates in Ru isotopic chain

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Introduction

β-decay half-life is an indicator of the shape-phase transition in an atomic nucleus as it is sensitive to the shell structure near the Fermi levels arising as a consequence of the interplay between the single particle energies and collective degrees of freedom. Nuclear deformation and shape transitions thus are expected to impact the β-decay properties, in particular, the half-life estimates. The nuclei between Z = 40 and Z = 50 are characterized by a strong competition between various oblate, prolate, spherical shapes, giving rise to shape instabilities leading to coexisting nuclear shapes as well as sudden shape transitions in isotopic chains [1, 2]. β-decay half-life is one of the most experimentally accessible physical quantities for RI beam facilities and plays a decisive role in determining the time scale of the r-process nucleosynthesis [3]. Observed short half-lives around A = 110 region speed up the r-matter flow [4] and make this region particularly more interesting to study impact of deformation on β-decay lifetimes especially for astrophysically intriguing Ru isotopes that have a special significance in astrophysical processes and our understanding of solar system formation [5].

Brief description of the work

We investigate the ground state shape evolution of the entire Ru isotopic chain from proton drip line to neutron drip line which have been known to exhibit a variety of structural transitions that may impact the decay mechanisms. We employ Nilsson Strutinsky Method (NSM) [8] and the Relativistic Mean Field (RMF) Model using the NL3* parameter [7] to trace the energy minima with respect to Nilsson deformation parameters (β_2, γ) to evaluate nuclear deformation and shapes and identify shape coexisting nuclei. Then we compute the β decay half−lives for nuclei showcasing the shape coexistence from both the NSM and RMF Models.

Results and Discussion

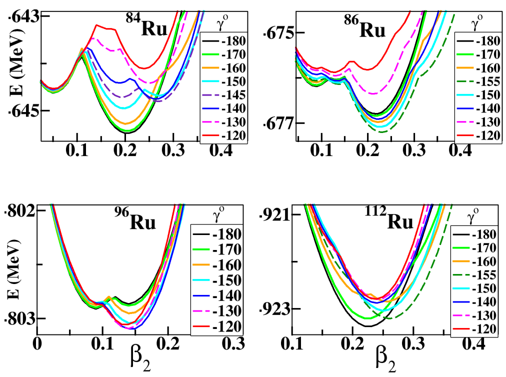

FIG. 1: Energy minima vs β and γ showing Ru isotopes exhibiting shape coexistence

The entire isotopic range of Ru is well deformed with the predominant oblate shapes along with some triaxial shapes; with prolate minima primarily seen near the shell closure N = 50 and neutron drip-line. Fig. 1 shows two energy minima for few Ru isotopes exhibiting shape coexistence w.r.t. β_2 and γ.

Although our calculated values of quadrupole deformation β_2 around this region [8] are seen to match experimental values well,

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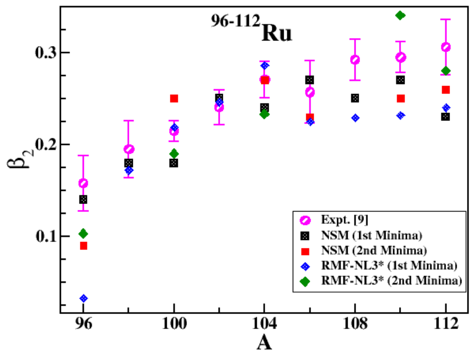

FIG. 2: Deformation β_2 corresponding to first and second E minima for Ru isotopes.

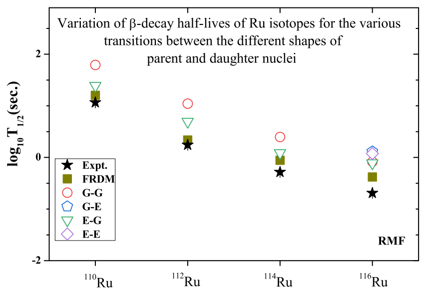

FIG. 3: β-decay half-lives for selected shape coexisting Ru nuclei for various transitions.

it is interesting to note from Fig. 2, that the experimental values [9] of β_2 are closer to those corresponding to second minima in shape coexisting ^{104}Ru and ^{112}Ru isotopes, where the first (lowest) minima lies comparatively further. This uncommon observation suggests the possibility that these nuclei may spend some time in a second minima state during measurements before it eventually decays or transitions to the ground state associated with the first minima. This assumption is strongly supported by the β-decay half-lives calculations. Half-lives for transitions involving second minima of either parent or daughter nuclei lie closer to experimental values than those calculated from the first minima or the ground states as seen in Fig. 3 for Ru isotopes in some shape coexisting nuclei along with values obtained from FRDM model for comparison.

Conclusion

This shows that for the coexisting states, the deformation as well as β decay half-lives evaluated using second minima state are better matched to observations than those obtained from the first minima in few cases where they do not match well with the predicted ground states. This region of Z = 40-50 known to have well deformed states with rapid shape phase transitions and shape coexistence shows an influence of the shape coexistence on decay properties. This indicates the importance of structural influences on stability, lifetimes and decay mechanisms which further emphasises the requirement for more elaborate work in this area experimentally as well as theoretically.

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References

[1] M. Hukkanen et al., Phys. Rev. C **108**, 064315(2023).
[2] R. Rodríguez-Guzmán et al., Physics Letters B, **Vol. 691**, Issue 4 (2010).
[3] S. Nishimura, Beta-gamma spectroscopy at RIBF, Prog. Theor. Exp. Phys. Vol. **2012**, Issue 1 03C006 (2012).
[4] S. Nishimura et al. , Phys. Rev. Lett. **106**, 052502 (2011).
[5] N. Dauphas et al., Earth & Planetary Science Letters, **Vol. 226**, Issues 3–4, (2004).
[6] M. Aggarwal, Phys. Rev., **C 89**, 024325 (2014).
[7] G. Saxena et al. Phys. Lett., **B 775**, 126 (2017).
[8] Mamta Aggarwal et. al., Nucl. Phys. **A 1044** 122843 (2024).
[9] S. Raman et al., At. Data Nucl. Data Tables **78** (2001) 1.