Theoretical Investigation of Probable Decay Modes in Superheavy Nuclei from Z=121-126

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Introduction

α-decay has played a crucial role in advancing the understanding of nuclear physics. As a dominant decay mode in superheavy nuclei, α-decay holds significant importance in experimental studies. The heaviest element synthesized to date, Oganesson (^{294}Og, Z = 118), was produced via α-decay [1], and ongoing research continues to explore heavier elements. Notably, the experimentally observed decay chain of ^{293}Lv [2] and theoretical predictions of α-decay properties for superheavy elements up to Z = 126 [3] provide strong evidence supporting the possibility of detecting nuclei with atomic numbers as high as 126.

In this work, the α-decay half-lives for the nuclei $^{291-339}$121, $^{294-338}$122, $^{297-339}$123, $^{300-338}$124, $^{303-339}$125, and $^{306-338}$126 have been studied using the New Modified Tagepera and Nurmia (NMTN) formula [4], recently modified by us to achieve more accurate α-decay half-life calculations. The disintegration energies (Q-values) are computed utilizing the Relativistic Mean Field (RMF) theory with the NL3 force parameter set. Investigating the competition among decay modes is critical for assessing the potential synthesis of new isotopes. Therefore, the α-decay mode has been compared with spontaneous fission (SF), for which the Modified Bio formula (MBF) [5] is employed. In the low neutron number region, the α-decay mode is clearly dominant. However, in the medium neutron range, a strong competition between α-decay and SF arises, with SF occasionally becoming the dominant decay mode in the higher neutron number.

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Formalism

The NMTN formula for α-decay is represented as:

$$log_{10}T_{1/2} = a\sqrt{\mu}(Z_dQ^{-1/2} - Z_d^{2/3}) + b + c\sqrt{l(l+1)} + d\sqrt{I(I+1)} + h$$

Here, μ and I represent the reduced mass and isospin of the parent nucleus, respectively. The angular momentum carried away by the α-particle is denoted by l, while Z_d is the proton number of the daughter nucleus. The coefficients a, b, c, and d take values of 0.7988, -18.3048, 0.3041, and -3.0399, respectively. The parameter h is assigned a value of 0 for even-even nuclei and 0.1198 for odd-mass number nuclei. These coefficients were obtained by fitting 349 experimental data from NUBASE2020 [6] which leads to RMSE value 0.4172.

For SF, the MBF formula is:

$$log_{10}T_{1/2} = a + b\left(\frac{Z^2}{(1-kl^2)A}\right) + c\left(\frac{Z^2}{(1-kl^2)A}\right)^2 + dE_{s+p}$$

The value of k is 2.6 and E_{s+p} is denote the shell plus pairing correction energy.

Results and discussion

The α-decay half-lives primarily depend on the Q-values , which are calculated using the binding energies of the parent and daughter nuclei. These binding energies are determined through the RMF theory with the NL3 force

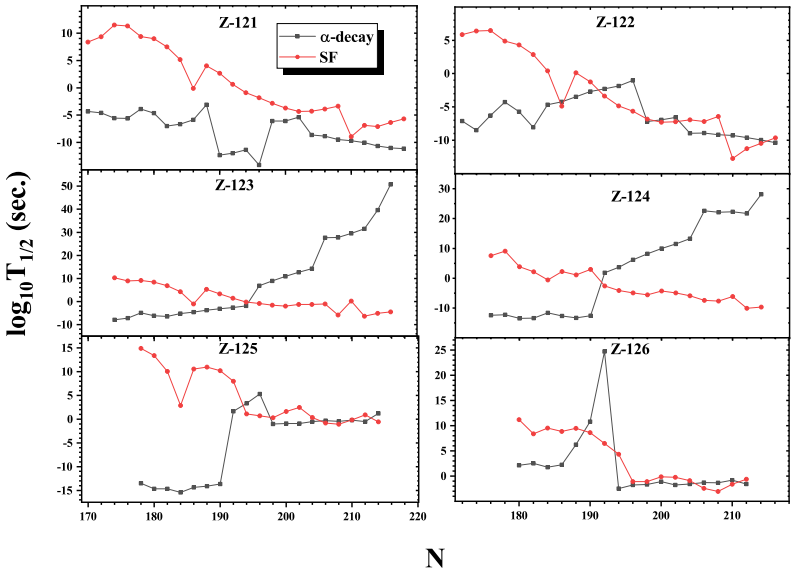

FIG. 1: Comparison of α-decay and the SF half-lives for the isotopes $^{291-339}121$, $^{294-338}122$, $^{297-339}123$, $^{300-338}124$, $^{303-339}125$, and $^{306-338}126$.

parameter set. The l are derived using the selection rules outlined in [7], with spin-parities taken from Ref. [8].

We have systematically analyzed the logarithmic half-lives of α-decay for a wide range of superheavy isotopes, including $^{291-339}121$, $^{294-338}122$, $^{297-339}123$, $^{300-338}124$, $^{303-339}125$, and $^{306-338}126$, using the NMTN formula. These half-lives are compared with those of spontaneous fission (SF), as illustrated in Fig. 1. It is evident from this figure that for all six proton numbers (Z), α-decay is the dominant decay mode at lower neutron numbers (N), as its half-lives are significantly shorter than those of SF.

In the mid-range of neutron numbers, the half-lives of α-decay become comparable to those of SF. As we move toward higher neutron numbers, SF increasingly becomes the dominant decay mode, with α-decay half-lives showing a marked increase. A particularly notable case is observed for $Z = 126$ at $N = 192$, where the α-decay half-life rises sharply due to lower Q-values. This increased α-decay half-life is a clear signature of magicity at neutron number $N = 192$, which has also been speculated in some of the theoretical works [9]. This comprehensive study provides valuable insights into the decay properties of superheavy nuclei, offering a crucial reference point for future research in this area.

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