Alpha preformation probability from Cluster Formation Model using AME-2020

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Introduction

Alpha decay, one of the most common decay modes of heavy and superheavy nuclei, has received a lot of attention since it can be used as a probe to examine unstable nuclei and it is the sole means to identify newly synthesized superheavy nuclei [1]. Recently, Cluster Formation Model (CFM), a quantum mechanical technique for determining preformation factor$P\alpha$ using binding energy differences of parent and daughter nuclei was presented, and it was successful in reproducing the microscopic calculation results for ^{212}Po [2]. Ahmed et al. successfully determine the α cluster preformation probability in even-even nuclei using this technique. Despite the fact that this has been expanded for odd-odd and odd A nuclei , as well as the study of α-decay, the analysis is limited to shell closures and does not reveal the relative stability of odd-N nuclei in comparison to their neighboring even-N nuclei. P.C. Sood et.al. [3] proposed a criterion for determining the relative longevity of odd-N nuclei in the actinide region as follows: *If three or more consecutive members of an isotopic sequence lying at or near the β-stability curve have α-emission as their dominant decay mode and if an intense favoured decay is available for the odd-N parent, then the odd-N member of the isotopic triad has generally a longer half-life than that of its even-N neighbour on either side, irrespective of Z being even or odd.* In this work, we will examine the alpha-cluster preformation factors for the actinide region to confirm the relative longevity of odd N nuclei compared to their even-N neighbors using experimental BEs from the atomic mass evaluation in AME2020 [4].

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Theoretical Framework

In CFM, a nucleus with energy E consists of a daughter nucleus and an alpha particle with a formation energy of $E_{f\alpha}$, the α preformation factor can be expressed as $P_\alpha = \frac{E_{f\alpha}}{E}$. The Formation Energy of Cluster $E_{f\alpha}$ for different nuclei type are given as follows [5]:

Case 1: For Even Z - Even N nuclei

$$E_{f\alpha} = 3B(A,Z) + B(A-4,Z-2)$$
$$-2B(A-1,Z-1) - 2B(A-1,Z)$$

Case 2: : For Even Z - Odd N nuclei

$$E_{f\alpha} = 3B(A-1,Z) + B(A-5,Z-2)$$
$$-2B(A-2,Z-1) - 2B(A-2,Z)$$

Case 3: For Odd Z - Even N nuclei

$$E_{f\alpha} = 3B(A-1,Z-1) + B(A-5,Z-3)$$
$$-2B(A-2,Z-2) - 2B(A-2,Z-1)$$

Case 4: For Odd Z - Odd N nuclei

$$E_{f\alpha} = 3B(A-2,Z-1) + B(A-6,Z-3)$$
$$-2B(A-3,Z-2) - 2B(A-3,Z-1)$$

By using these formulae, one can calculate P_α using experimental Binding energies, which are taken from the latest atomic mass evaluation in AME2020.

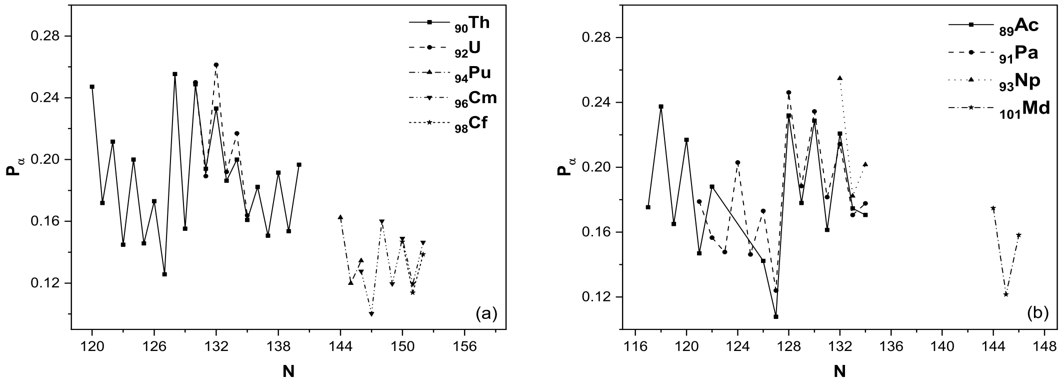

FIG. 1: Preformation factor versus Neutron Number for (a) even Z and (b) odd Z

Results and Discussion

The preformation factor, maintains an inverse correlation with the experimental half-life of a given nucleus, displaying a consistent trend in relation to the number of nucleons. Therefore, an increase in P_α values signifies reduced stability, while conversely, lower values indicate greater stability. Our focus is primarily on the Actinide region and specifically on the predominantly alpha decaying nuclei ($> 90\%$). Using the relevant formulas P_α for all beta stable nuclei are obtained. The average and standard deviation values of P_α for the four cases are shown in table I. It has been observed that average preformation factor for Even - Even and odd -odd nuclei is increased and σ value for Odd-Even and Odd-odd nuclei has decreased as compared to the calculations form AME-2016 [5]. It is clearly observed that the average value for odd -N nuclei is less than that of even-N nuclei. In fact, the odd-odd nuclei appear to have a lower preformation probability, indicating more stability in comparison to the expected norm. Data relevant for confirming the criteria established earlier [3] comprising isotopic triads have been graphically represented in fig.1. Notably, upon utilizing the most recent AME data, we have identified an additional isotopic triad involving ^{101}Md, a finding that was absent in the AME-2016 dataset. As an extension of this work, we would like to establish relationship between $t^{\alpha}_{1/2}$ and P_α similarly to that to Viola-Seaborg formula.

TABLE I: Comparison of the average $< P_\alpha >$ and standard deviation σ values of alpha preformation factor for different types of nuclei based on AME-2016 and AME-2020.

Z-N	No. of nuclei (n)		$< P_\alpha >$		σ	
	2016	2020	2016	2020	2016	2020
Even-Even	42	45	0.17	0.18	0.04	0.04
Even-Odd	25	29	0.15	0.15	0.03	0.04
Odd-Even	30	31	0.19	0.18	0.08	0.05
Odd-Odd	17	22	0.14	0.15	0.04	0.03

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