Effect of nuclear surface polarization in the cluster-radioactivity of ^{223}Ac and ^{231}Pa parents

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Introduction

Adamian et. al [1] have suggested a polynomial for the understanding of nuclear surface polarization effect of rare earth elements and actinides. It was observed that the diffuseness along the main deformation axis tends to reduce as the nucleus becomes more and more deformed, while the opposite is seen along the other axis. The effect of angle dependent diffuseness is perceived to be more pronounced in the actinides than the elements of aforementioned region.

In the present work, the role of angular dependence in diffuseness parameter is investigated in reference to the ground state decay of actinide parents such as ^{231}Ac and ^{223}Pa. The calculations have been performed within the framework of preformed cluster model (PCM) [2] using the Proximity potential-77 [3], for the choice of fragments having quadrupole (β_2) deformations and optimum orientations (θ_i^{opt}). Importantly, the explicit role of nuclear surface polarization is examined by analyzing the fragmentation potential and the half-lives with and without incorporating the θ-dependence in the nuclear diffuseness parameter b.

Theory

The decay half-life time $T_{1/2}$ in Preformed Cluster Model (PCM) is defined as

$$T_{1/2} = \frac{ln2}{\lambda}, \quad \lambda = \nu_0 P_0 P \tag{1}$$

Here, P_0 and P represent the preformation probability and barrier penetrability of the fragments. ν_0 is the barrier assault frequency $\sim 10^{21} s^{-1}$ taken for the cluster decay.

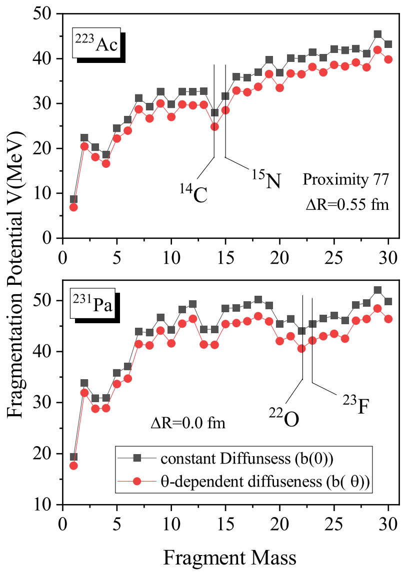

FIG. 1: Upper and lower panel shows the variation of fragmentation potential V (MeV) of ^{223}Ac and ^{231}Pa parents respectively with and without using the θ-dependence in the nuclear diffuseness parameter b. The deformations are included upto β_2.

The structure information of the decaying nucleus is contained in P_0 via the fragmentation potential V and is defined as

$$V = -\sum_{i=1}^{2}[B_i(A_i, Z_i)] + V_C(R, Z_i, \beta_{\lambda i}, \theta_i) + V_P(R, A_i, \beta_{\lambda i}, \theta_i). \tag{2}$$

Here, $B_i(A_i, Z_i)$ is the ground state binding energy [4]. V_C and V_N are respectively, the Coulomb and nuclear proximity potentials for deformed and oriented nuclei.

The nuclear proximity potential V_P is given by

$$V_p(A_i, \beta_{\lambda i}, \theta_i) = 4\pi\bar{R}\gamma b(0)\Phi(s_0). \qquad (3)$$

Here, $\overline{R}$ is the mean curvature radius of the reaction partners. $\phi(s_0)$ is the universal function defined in terms of minimum separation distance s_0. γ is the surface energy coefficient. b(0) is the diffuseness of the nuclear surface given by

$$b(0) = \left[\pi/2\sqrt{3}\ln 9\right]_{t_{10-90}} \qquad (4)$$

where t_{10-90} is the thickness of the surface where the density profile changes from 90% to 10%. The value of diffuseness is usually taken as b(0)$\sim$0.99 fm. For the Actinide region, the dependence of diffuseness b(0) on angle θ is given by [1] as,

$$b(\theta) = b(0) + \Delta b(\theta). \qquad (5)$$

with $\Delta b(\theta)$=0.45$\sin^2\theta - 0.4\sin^3\theta$. Here b(0) is the constant surface diffuseness.

Calculations and Results

Fig.1 is plotted with an aim to explore the effect of nuclear surface polarization in the cluster radioactivity of actinide parents such as ^{223}Ac and ^{231}Pa. In the previous work [2] based on the cluster radioactivity, constant diffuseness parameter b(0) was used, however the present study is extended by incorporating angle-dependent diffuseness b(θ). In the Fig.1, the comparison of fragmentation potential V (MeV) is analyzed with constant diffuseness and with angle-dependent diffuseness parameters. It is observed that the structure of potential energy surface (PES) exhibit similarity regardless of the b(0) and b(θ) parameters. One can clearly see from the figure that for both the parent nuclei, lower fragmentation potential is obtained with angle-dependent diffuseness and hence indicate an interesting case of investigation. Note that we are interested only in those minima of fragmentation potential whose experimental half life is given. The experimentally observed clusters in the decay of ^{223}Ac and ^{231}Pa emitters are ^{14}C, ^{15}N and ^{23}F respectively (marked by horizontal line in Fig.1). We get a localized minima for ^{22}O in lower panel of Fig.1, so the same is also marked and the corresponding half life is predicted.

TABLE I: PCM calculated logarithmic half-lives $\log_{10}T_{1/2}$ with b(0) and b(θ) parameters and experimental available data [5].

Decay channel	$log_{10}T_{1/2}$ (s)		Expt. [5]
	b(0)	b(θ)	(s)
^{223}Ac→^{14}C+^{209}Bi	16.2	15.2	12.6
^{223}Ac→^{15}N+^{208}Pb	18.69	17.2	>14.76
^{231}Pa→^{22}O+^{209}Bi	30.9	30.3	–
^{231}Pa→^{23}F+^{208}Pb	26.6	25.5	26.0

The half lives $log_{10}T_{1/2}$ of aforementioned clusters are calculated using the PCM as shown in Table I. It is evident from Table that $log_{10}T_{1/2}$ of clusters emitting from considered parents are influenced by the nuclear surface polarization component as relatively lower half lives are obtained with b(θ) in comparison to constant diffuseness parameter. However, the theoretically calculated half lives find nice comparison with experimentally available $log_{10}T_{1/2}$ for both b(θ) and b(0) cases.

In order to get the clear description of surface polarization on ground state phenomena, the above study will be extended to complete actinide and lanthanide regions in near future.

This work is supported under DST WISE-Post-Doctoral Fellowship (WISE-PDF) (File No. DST/WISE-PDF/PM-22/2023) and DST-SERB for grant no. CRG/2021/001144.

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