Effects of oriented nuclei on the competing features of alpha and ^{14}C cluster decays of even–even $^{216-226}$Ra parent nuclei within preformed cluster decay model

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Introduction

Even after more than four decades of the discovery of a ^{14}C cluster emission from a ^{223}Ra nucleus in 1984 by Rose and Jones [1] on the basis of Sandulescu et al's theoretical predictions in 1980 [2] and subsequent extensive explorations, the phenomenon of cluster radioactivity (CR) is still in vogue. This fact is quite evident from the studies [3] which call for the experimental investigation of ^{92,94}Sr CR of super heavy nuclei ^{300,302}120 predicted to have a branching ratio relative to α decay of -0.10 and 0.49, respectively. The study emphasize that such decay modes must be explored in competition with α decay.

Before entering exotic domains of super heavy nuclei, the preformed cluster decay model (PCM) based on the quantum mechanical fragmentation theory (QMFT) [4–6], is employed to analyze the competing aspects of α and ^{14}C cluster emissions from even-even $^{216-226}$Ra nuclides. The objective is to understand the role of shell structure, effects of oriented nuclei and other competing aspects of these decay mechanisms through the lens of QMFT based PCM. The corresponding preformation probability P_0 values for the binary fragmentation are calculated, and the WKB penetration probability P is used to determine the half-life of the parent nucleus for these decay processes. The results indicate that α-decay is dominant across all parent nuclei, studied here, with ^{14}C emissions presenting interesting chase. Evidently, this quest is, particularly, vigorous in the case of ^{222}Ra, where the daughter nucleus is the doubly magic ^{208}Pb for ^{14}C cluster emission. Moreover, we have also explored the deformation and orientation effects in these decay processes.

Methodology

The PCM [4–6] uses the dynamical collective coordinates of mass and charge asymmetries η and η_z on the basis of quantum mechanical fragmentation theory. The decay constant in PCM is defined as

$$\lambda = \nu_0 P_0 P \qquad (1)$$

$$T_{1/2} = ln2/\lambda \qquad (2)$$

Here, ν_0 is the impinging frequency with which the cluster hits the barrier. P is the barrier penetrability and P_0 is cluster preformation probability which refer, to the R and η-motions, respectively. Then, for all the clusters P_0 is

$$P_0(A_i) = \mid \psi(\eta(A_i)) \mid^2 \frac{2}{A}\sqrt{B_{\eta\eta}} \qquad (3)$$

given by solution of stationary Schrodinger eqn. in η co-ordinate. The fragmentation potential $V_R(\eta)$ is calculated as the sum of Coulomb interaction, the nuclear proximity potential and the ground state binding energies of two nuclei.

Results and Discussions

Fig. 1 a) and b), respectively, present results for the fragmentation potential and P_0

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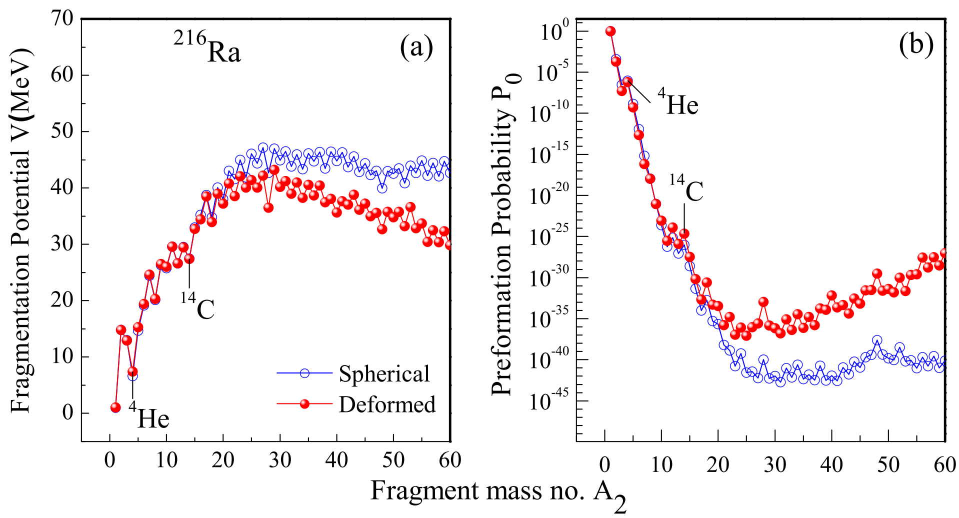

FIG. 1: (a) Fragmentation potential and (b) P_0 as a function of mass of the emitted fragments for the g.s. decay of ^{216}Ra for the spherical case and with the deformation and orientation effects included.

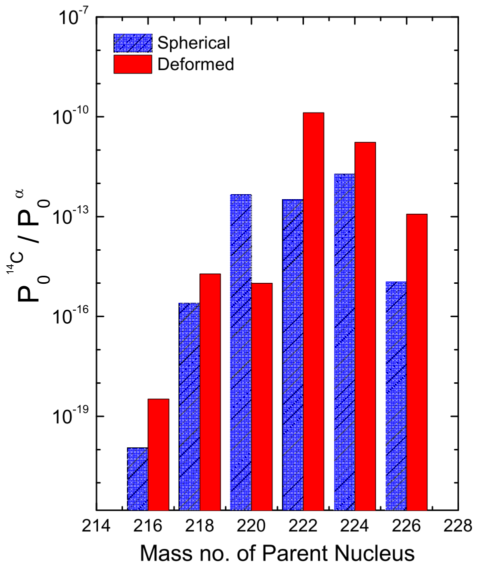

FIG. 2: The ratio ${P_0}^{^{14}C}/{P_0}^{\alpha}$ of P_0 value of ^{14}C cluster and α emissions from Ra isotopes.

of the fragments in the decay of ^{216}Ra for the spherical considerations and with the deformation and orientation (non-compact) effects included. Though, the deformation values for the emissions under study are quite low and α and ^{208}Pb are spherical nuclei. However, as evident from these figures the collective clusterization process affects their preformation while competing with other decaying deformed nuclei.

Fig. 2 shows that with the inclusion of deformation and orientation effects, the P_0 values for the ^{14}C cluster emission show significant increase, particularly, for the ^{222}Ra parent nucleus, in comparison to the spherical case among all the chosen isotopes of Ra. Moreover, the higher preformation probability value for the ^{222}Ra, corresponding to the doubly magic ^{208}Pb daughter among the ^{14}C emitters, underscores the crucial role of nuclear structure in determining emission probabilities. Within PCM, it will be interesting to explore other competing aspects like penetrability of these preformed fragments along with the interaction barrier characteristics. The findings are in line with the available experimental data [7]. Further work is in progress.

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