Dynamics of competing α and cluster radioactive decays within the collective clusterization approach

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Introduction

Cluster radioactivity is the phenomena of heavy radioactive parent nuclei emitting clusters (heavier than alpha particle, α), spontaneously. Sandulescu et al. theoretically found it in 1980 [1], and Rose and Jones empirically confirmed it in 1984 [2], for the ^{223}Ra nucleus from which ^{14}C cluster was formed. In other words, it is the process of a cluster forming in the mother nuclei and then passing over the barrier. The daughter nuclei in these decays are always ^{208}Pb or nuclei that are close by. The model that we utilize to explain the decay process theoretically is Gupta and collaborators' Preformation Cluster Decay Models (PCM) [3-5] based on Quantum Mechanical Fragmentation Theory (QMFT) [6-8]. Previous research [3-5] have used PCM to study the influence of deformations and orientations in the radioactivity of the ^{208}Pb-daugther cluster. Now, in this study, we explore the competing aspects of alpha radioactivity and ^{208}Pb daughter cluster radioactivity using fragmentation potential, preformation probability, scattering potential, and penetration probability in the decay of radioactive nuclei ^{222}Ra, ^{226}Th, ^{228}Th, ^{231}Pa, ^{230}U, and ^{232}U systems with always ^{208}Pb as daughter and ^{14}C, ^{18}O, ^{20}O, ^{23}F, ^{22}Ne, and ^{24}Ne cluster nuclei emitted correspondingly.

Methodology

The PCM uses the collective coordinates of mass and charge asymmetries as η_A and η_z based on QMFT. In terms of these collective coordinates, the decay half-life $T_{1/2}$, or the decay constant defined as

$$\lambda = \frac{ln2}{T_{1/2}} = v_0 P_0 P \qquad (1)$$

here v_0 is the assault frequency, P_0 corresponds to cluster preformation probability and P the barrier penetrability.

$$P = exp\left[-\frac{2}{\hbar}\int_{R_a}^{R_a}\{2\mu[V(R)-Q_{eff}]\}^{1/2}dR\right] \qquad (2)$$

P_0 is solution of the stationary Schrödinger equation in η co-ordinate

$$\left\{-\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}+V(\eta)\right\}\psi^{\nu}(\eta) = E^{\upsilon}\psi^{\nu}(\eta) \qquad (3)$$

which on normalization is given as

$$P_0 = |\psi_R^{\upsilon}(A_2)|^2\frac{2}{A}\sqrt{B_{\eta\eta}}(A_2) \qquad (4)$$

The fragmentation potential $V(\eta)$ in eq (3) is calculated as the sum of Coulomb potential (V_C), the nuclear proximity potential (V_P) and the ground state binding energies of two nuclei as:

$$V(\eta) = \sum_{i=1}^{2}[B_i(A_i, Z_i)] + V_c + V_p \qquad (5)$$

Results and Discussions

The fragmentation potential for ^{228}Th is shown in Fig. 1. Here the decay of α cluster is more minimized in comparison to the ^{20}O cluster.

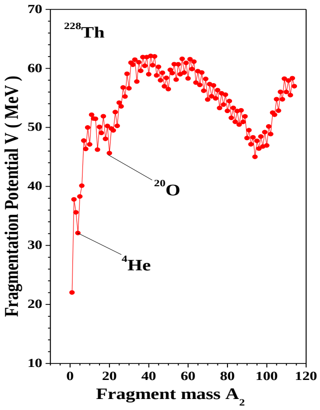

Fig. 1. *The variation of fragmentation potential with fragment mass A_2 for spontaneous decay of ^{228}Th parent nucleus.*

Fig. 2 presents the comparison between the calculated data for the P_0 values for α and ^{208}Pb daughter decays of the chosen nuclei revealed that the value of P_0 for doubly magic ^{208}Pb daughter decay is quite smaller in comparison to α cluster decay. Fig. 3 gives the collective picture of penetration probability, P, which is the comparison between the calculated data for the P for α decay and ^{208}Pb daughter decay. Penetration probability is found to be quite small for doubly magic ^{208}Pb daughter decay of ^{226}Th with comparison to α cluster decay, which has minimum P for ^{222}Ra, ^{228}Th, ^{230}U and ^{232}U in comparison to ^{208}Pb daughter decay. Penetration probability has approximately same value for ^{231}Pa.

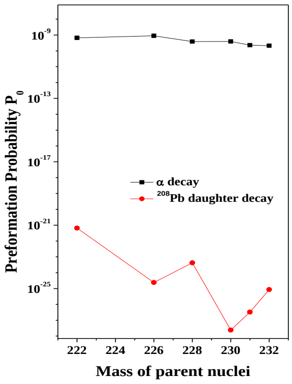

Fig. 2 *The variation of P_0 and mass of the parent nuclei for α and ^{208}Pb daughter decay.*

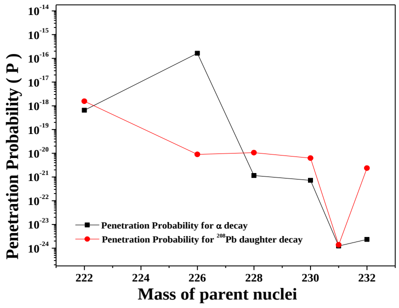

Fig. 3 *The variation of P and mass of the parent nuclei for α decay and ^{208}Pb daughter decay.*

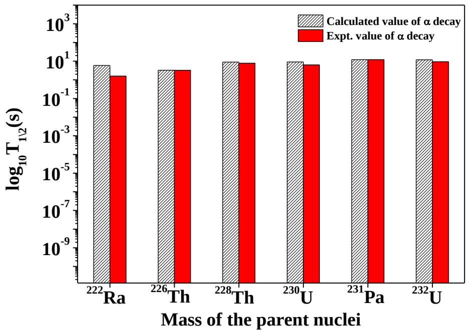

Fig. 4. *The variation of calculated and experimental logarithm half-lives with mass of the parent nuclei, for α-decay.*

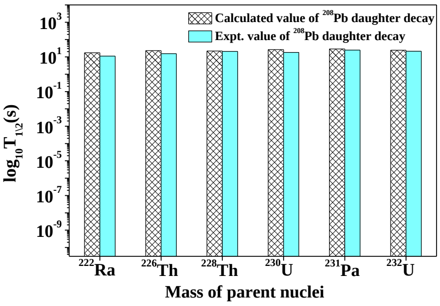

Fig. 5 *Same as Figure 4 but for the doubly magic ^{208}Pb daughter decay.*

Fig. 4 and Fig. 5 gives the comparison between the calculated and experimental logarithm half-lives for α decay and ^{208}Pb daughter decay, respectively, in good agreement for all the chosen nuclei.

The PCM calculated data has a fair comparison with the experimental data for both α cluster decay and ^{208}Pb daughter decay are further improved with the inculcation of the deformation and orientation effects of the nuclei, particularly for the α cluster decays. The results for the latter case are available with the inclusion of orientation effects [3].

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