

Effect of deformations and orientations in ^{100}Sn daughter radioactivity

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Abstract

Based on the preformed cluster model (PCM), we have extended our earlier study to investigate the effects of nuclear deformations and orientations of nuclei in context of ground-state de-excitation of Xe to Gd parents, resulting in a doubly closed shell ^{100}Sn daughter and the complementary clusters. The comparison is also made with spherical choice of fragments to extract exclusive picture of the dynamics involved. Since PCM is based on collective clusterization picture, the preformation and penetration probabilities are shown to get modified considerably by inclusion of the quadrupole deformations (β_{2i}) alone, which in turn affects the decay half-lives of the clusters.

The phenomenon of cluster radioactivity is now well established on experimental as well as theoretical front, besides the familiar α , β and γ -emissions. The whole family of such decays consisting of light to heavy (^{14}C to ^{34}Si) clusters have been observed from various actinides (^{221}Fr to ^{242}Cm) in trans-lead region. In all these cases, the daughter nucleus is always ^{208}Pb (a doubly closed shell nucleus) or its neighboring nucleus and hence this phenomena has been termed in some literature as “lead radioactivity”. In order to explore the region of possible Sn radioactivity, Gupta and collaborators [1] studied the ground-state decays of neutron-deficient

$^{108-116}\text{Xe}$, $^{112-120}\text{Ba}$, $^{116-124}\text{Ce}$, $^{120-124}\text{Nd}$, $^{124-128}\text{Sm}$, and $^{128-132}\text{Gd}$ nuclei, and showed a clear preference for $A=4n$, α -nuclei, like ^4He , ^8Be , ^{12}C , etc. However, in their later work [2] carried out for neutron-rich isotopes, it was observed that non- α like clusters are preferred for decays into ^{132}Sn -daughter nucleus, though less probable than $A=4n$, α -nuclei clusters for the case of ^{100}Sn -daughter radioactivity. Since the shape of a nucleus provides an intuitive understanding of spatial density distribution, therefore, together with shell effects, it is expected that nuclear deformations and orientations should play an important role in the context of Sn radioactivity.

In the present work, we take up this study on the basis of preformed cluster model (PCM) [3] to analyze the influence of quadrupole deformations (β_{2i}) alongwith ‘optimum’ orientations (θ_i^{opt}) [4] on the behavior of possible fragmentation of Xe to Gd parents. The study is confined to only $N=Z$ parent nuclei, referring to ^{100}Sn as the daughter product. It is relevant to mention here that a majority of parents ^{108}Xe , ^{112}Ba , ^{116}Ce , ^{120}Nd , ^{124}Sm , and ^{128}Gd and their respective emitted clusters ^8Be , ^{12}C , ^{16}O , ^{20}Ne , ^{24}Mg and ^{28}Si considered here are deformed and hence the deformation effects seem indispensable, which were not analyzed explicitly in the earlier works [1, 2]. Because the PCM treats the fragmentation process in a collective clusterization approach, it is of great interest to see, in what way the deformation and orientation effects of the decay fragments influence the potential energy surfaces (PES) of these neutron-deficient nuclei.

The decay constant λ or the decay half-life $T_{1/2}$ in PCM is defined as

$$\lambda = \nu_0 P_0 P, \quad T_{1/2} = \frac{\ln 2}{\lambda}. \quad (1)$$

The clusters are assumed to be preborn in the parent nucleus with preformation probability P_0 , hit the barrier with impinging frequency ν_0 , and penetrate it with penetrability P . The structure information of the decaying nucleus is contained in P_0 via the fragmentation potential, defined as

$$V_R(\eta) = - \sum_{i=1}^2 \left[B_i(A_i, Z_i) \right] + V_C(R, Z_i, \beta_{\lambda i}, \theta_i) + V_P(R, A_i, \beta_{\lambda i}, \theta_i) \quad (2)$$

with B_i ($i=1,2$) as binding energies of two fragments and, V_C and V_P , respectively, as the Coulomb and nuclear proximity potentials for deformed and oriented nuclei. For details, we refer to ref. [3].

Figure 1(a) illustrates the mass fragmentation potential, minimized in charge coordinate, as a function of the cluster mass for the considered parents. The effects of deformations up to quadrupole (β_{2i}), in reference to

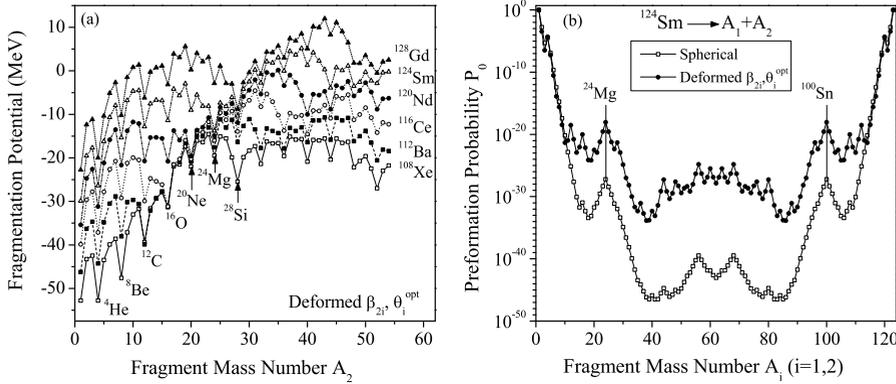


Figure 1: (a) Fragmentation potential for different $N=Z$ parents. (b) Preformation probability P_0 for decay of ^{124}Sm with spherical and deformed configurations.

“optimum” orientation of the cold decay process [4], are duly incorporated in the calculations. For a comprehensive analysis, the calculations have been performed at the touching configuration to estimate the possible existence of the most probable cluster emitted with doubly magic daughter ^{100}Sn . We notice from fig. 1(a) that, even after inclusion of the deformation and orientation effects, potential energy minima occur only at $A_2=4n$, which are alpha-like clusters ^4He to ^{28}Si , although the magnitudes of the fragmentation potential are quite different for different $N=Z$ parents. This observation is in contrast to $A_2 \neq 4n$, non-alpha like clusters emitted for the case of cluster decays of radioactive nuclei with Pb or its neighboring nuclei as the daughter product.

Since, both deformations and orientations are found [3] to have significant effect on decay half-lives investigated in trans-lead region, we explore the same here in the trans-tin region. Figure 1(b) presents our calculations of preformation probability P_0 for the illustrative decay of ^{124}Sm , using spherical as well as β_2 -deformed choice of fragments. We find that inclusion of deformation and orientation effects of decay fragments changes the relative preformation probability P_0 , quite significantly. Interestingly, the emergence of ^{24}Mg cluster in fig. 1(b), corresponding to doubly closed shell ^{100}Sn daughter, seems more probable for deformed configuration in the fragmentation of ^{124}Sm . Similarly, the barrier position as well as its height (not shown here) also get modified with inclusion of deformations, thereby affecting the barrier penetrability P accordingly.

Figure 2 shows the calculated preformation probabilities, penetrabilities and logarithms of half-life times for clusters referring to minima in fragmen-

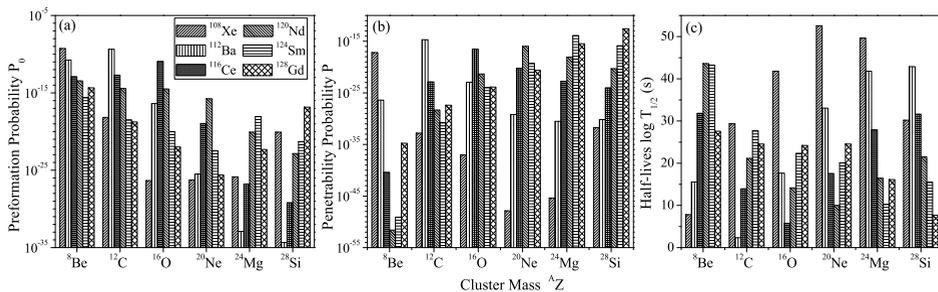


Figure 2: Calculated (a) P_0 , (b) P , and (c) $\log T_{1/2}$, for ${}^8\text{Be}$ to ${}^{28}\text{Si}$ clusters emitted from different $N=Z$ parents. The deformation effects are included upto β_2 .

tation potentials of all the considered $N=Z$ parents. Knowing that, in PCM, $T_{1/2}$ exhibits a combined effect of both P_0 and P (ν_0 being almost constant, $\sim 10^{21} \text{ s}^{-1}$), we notice in fig. 2 that the clusters referring to doubly magic daughter nucleus ${}^{100}\text{Sn}$ have the minimal decay half-lives. This is due to the fact that, both P_0 and P have larger magnitudes for each of the most probable (minimal $T_{1/2}$) cluster emission. Apparently, the shortest half-life time is obtained for, say, ${}^{12}\text{C}$ decay of ${}^{112}\text{Ba}$. In other words, the calculated decay half-lives indicate the possible decay of ${}^8\text{Be}$ from ${}^{108}\text{Xe}$, ${}^{12}\text{C}$ from ${}^{112}\text{Ba}$, ${}^{16}\text{O}$ from ${}^{116}\text{Ce}$, etc., giving rise to the doubly magic ${}^{100}\text{Sn}$ ($Z=N=50$) daughter, and hence are predicted to be most probable cases for measurements.

Summarizing, proper understanding of nuclear shapes along with the relative orientations is essential to make concrete and explicit predictions of cluster dynamics in trans-tin region. As an extension of this work, it will be of further interest to analyse the possible role of deformations in ${}^{132}\text{Sn}$ radioactivity predicted in the intermediate mass region of the periodic table.

Acknowledgments

Work supported by University Grants Commission (UGC), New Delhi under Dr. D. S. Kothari program.

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