Cluster decay of various Gd isotopes from the trans-tin region

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Introduction

Apart from the usual α, β and γ emission, the study of the exotic radioactive decay mode, in-between α-decay and spontaneous fission, is known as cluster radioactivity. It was theoretically predicted in 1980 and confirmed experimentally in 1984. Since then, a whole family of such phenomenon is observed from ^{221}Fr to ^{242}Cm parent nuclei, emitting different isotopes of C, N, O, F, Ne, Mg and Si clusters in the company of closed shell daughters such as ^{208}Pb or its neighboring nuclei. Besides the above mentioned cluster emissions in the trans-lead region, another island for cluster emission is also expected [1] in the decays of neutron-deficient nuclei giving ^{100}Sn (Z=N=50) daughter or a neighboring nucleus.

Knowing the importance of shell structure of daughter nucleus, Gupta *et al.* [1] studied ground state decay paths of proton-rich $^{128\text{-}132}$Gd and other neighboring nuclei $^{108\text{-}116}$Xe, $^{112\text{-}120}$Ba, $^{116\text{-}124}$Ce, $^{120\text{-}124}$Nd, and $^{124\text{-}128}$Sm on the basis of preformed cluster model (PCM) [2] to explore the region of Sn radioactivity. It is important to note here that, in addition to shell effects the deformations and orientations of nuclei are also anticipated to play an important role in cluster decay process [3]. In order to extend the above study [1], we apply the same methodology to analyze the influence of nuclear deformations and orientations on the fragmentation path of $^{128\text{-}136}$Gd isotopes.

The PCM finds its basis in the well known Quantum Mechanical Fragmentation Theory (QMFT), where the stationary Schrödinger equation for the dynamical flow of mass and charge is solved to evaluate the preformation factor, which in turn, provides necessary structure information in the decay process of a nuclear system. It is important to note that, not only the shapes of parent, daughter and cluster nuclei are important in PCM, but also the shapes and masses of all other possible fragments play an important role in collective clusterization adopted in the present study. The deformation effects are included up to quadrupole (β_2) within the optimum orientation approach [4]. We have confined our present study to $^{128\text{-}136}$Gd isotopes in order to investigate the role of spherical as well as β_2 deformed clusters exhibited in the form of fragmentation profile of Gd isotopes.

The Model

The preformed cluster model (PCM) uses the collective coordinates of mass and charge asymmetries ($\eta = \frac{A_1 - A_2}{A_1 + A_2}$ and $\eta_Z = \frac{Z_1 - Z_2}{Z_1 + Z_2}$), the relative separation R, and the multipole deformations $\beta_{\lambda i}$ and orientations θ_i (i=1,2) of daughter and cluster nuclei which allows to define the decay half-life $T_{1/2}$, or the decay constant λ, as

$$\lambda = \frac{\ln 2}{T_{1/2}} = P_0 \nu_0 P$$

Here ν_0 is the assault frequency, P_0 corresponds to cluster preformation probability and P the barrier penetrability. The structure information of the decaying nucleus is contained in P_0 via the fragmentation potential defined as:

$$V_R(\eta) = -\sum_{i=1}^{2} [B_i(A_i, Z_i)] + V_C + V_P$$

where V_C and V_P are, respectively, the Coulomb and nuclear proximity potentials for deformed and oriented nuclei.

Calculations and Results

First of all, we look at the fragmentation potentials V(η), illustrated in Fig. 1 for the $^{128\text{-}136}$Gd parents calculated for the fragments taken with quadrupole deformations β_{2i} alone and optimum orientations θ_i^{opt} of cold compact configuration [4]. Note that we have made our calculations at touching configuration for the radioactivity. It is observed that there is no significant change in PES as we increase the mass of

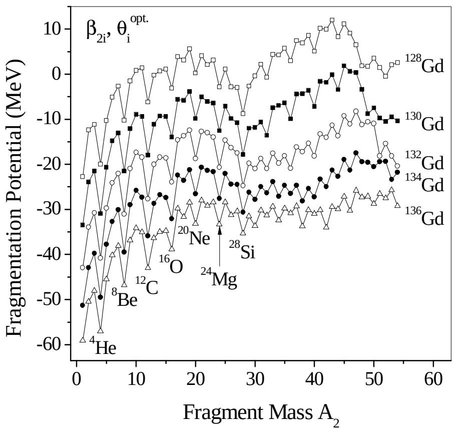

Fig. 1: Fragmentation potentials for $^{128\text{-}136}$Gd parents using β_{2i} alone with optimum cold orientations for all possible fragments.

Gd isotopes, which are potential candidates for the cluster emission in this mass region. Apparently, the potential energy minima (inclusive of deformation and orientation effects) show a clear preference for A_2=4n α-nuclei, like ^{8}Be, ^{12}C, ^{16}O, ^{20}Ne, etc., emitted from N=Z parents and hence suggest the probable occurrence of possible cluster emission. However, as the neutron-proton ratio N/Z of the parent nuclei increases, the contribution of A_2=4n+2 fragments starts appearing in the decay profile. Notice that the present study is confined to only A_2=28 (^{28}Si) cluster having Sn-daughter product.

The relevant results of PCM calculated preformation probability along with decay half-lives are shown in Fig. 2 as a function of parent nuclei mass. In order to address the effect of deformation, the decay pattern is also addressed using spherical approach. One can clearly see that the inclusion of deformation and orientation effects of the decay fragments changes the relative preformation probability P_0, quite significantly which in turn affects the decay constant and half-life time accordingly. The preformation probability P_0 is found to be larger for the case of deformed approach as compared to that for spherical fragmentation. One may notice from Fig. 2(b), that $\log_{10}T_{1/2}$ (s) for ^{28}Si clusters follow a systematic of P_0 for all the decaying Gd parent nuclei. The calculated decay half-lives show a clear preference for ^{28}Si emiss-

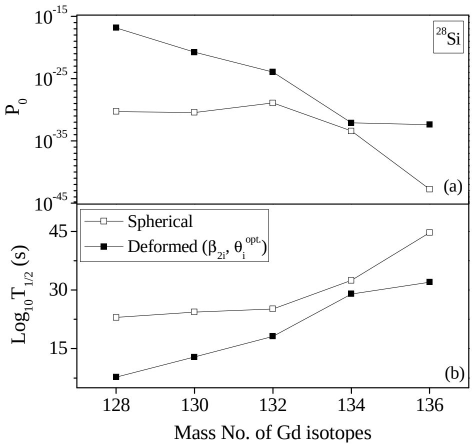

Fig. 2: Comparison of the PCM calculated preformation probability P_0 and decay half-lives for the ^{28}Si cluster emitted from various Gd isotopes with Sn as the daughter product for spherical and deformed choices of nuclei.

ion from ^{128}Gd parent and hence the same is predicted to be the most probable case for future measurements. In other words, the lowest $T_{1/2}$ value for the ^{28}Si cluster emitted from ^{128}Gd indicates the role of doubly magic ^{100}Sn daughter in the cluster decay process.

Summarizing, we conclude that, just like for trans-lead region, deformations and orientations are found to play a vital role in cluster decay of various Gd isotopes in the trans-tin region. Thus, proper understanding of nuclear shapes along with the relative orientations is essential to make an explicit prediction of cluster dynamics of trans-Sn region.

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