Theoretical study of cluster emission and fission dynamics using Binary Fragmentation Approach

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Introduction

Extensive studies for the comprehensive understanding of nuclear dynamics are being done on experimental as well as theoretical front. The consolidated outcomes of this experimental and theoretical nuclear research provide an insight to view and portray the nuclear decay dynamics with an improved perception. The present work presents a comprehensive theoretical analysis of various ground state and excited state decay mechanisms in terms of α-radioactivity, cluster decay, heavy-particle emission, spontaneous fission and heavy-ion induced fission, etc. To have a clear picture of the binary fragmentation, the identification of the mass fragments emitted in different spontaneous and induced decay processes play very important role and the same is investigated in the present study. The fundamental methodology implemented in this work is the Quantum Mechanical Fragmentation Theory (QMFT) [1], which is extensively exercised to streamline various aspects related to formation and decay paths of heavy-ion induced reactions (HIRs). Within the QMFT formalism, Preformed Cluster Model (PCM) [2] is implemented here to analyze various spontaneous decay processes whereas to exercise the excited state decays, Dynamical Cluster Model (DCM) [3], the extended version of PCM, is used.

Calculations and Results

As a first application, the addressal of α-cluster emission in the ground state as well as excited state decays of some trans-Sn nuclei lying near N=Z line is accomplished within the collective clusterization approach of PCM. Firstly, the triple α-decay chain $^{114}\mathrm{Ba}\xrightarrow{\alpha}{}^{110}\mathrm{Xe}\xrightarrow{\alpha}{}^{106}\mathrm{Te}\xrightarrow{\alpha}{}^{102}\mathrm{Sn}$ is investigated, within the methodology of DCM. It is observed that $^{106}\mathrm{Te}\rightarrow{}^{102}\mathrm{Sn}+\alpha$ is the most probable decay channel among the three parent nuclei in the successive α-decay chain due to the magicity of its daughter fragment. Furthermore, while comparing the preformation profile of ^{114}Ba at T=0 and T$\neq$ 0, it has been observed that the most probable fragment in lower mass region changes from ^{4}He to ^{6}Li as one moves from ground state to excited state decays possibly because of the dissipation of shell effects at higher temperature. Next, the α-decay half-lives of some parent nuclei lying in the trans-Sn region are calculated using different nuclear proximity potentials. ^{4}He is found to compete with ^{1}H for all the ground state nuclei considered in the present study. The reported α half-lives for nuclei from ^{105}Te to ^{112}Xe find nice agreement using Prox00, whereas Prox Ngo80 seems to provide a favorable option for the decay of nuclei above ^{112}Xe.

After exploring α-decay within the framework of PCM, cluster emission in view of Sn-radioactivity is explored. Here, the effect of deformations and orientations is investigated in reference to the ground-state clusterization of $^{108-116}$Xe, $^{112-120,146}$Ba, $^{116-124,152}$Ce, $^{120-130,156}$Nd, $^{124-130,160,162}$Sm and $^{128-136,166}$Gd nuclei using the PCM. It is found that cluster half lives reduce significantly after the inclusion of deformation effects. Hence, it is observed that the consideration of deformed choice seems to provide a favorable option to deal with the decays leading to ^{100}Sn and ^{132}Sn daughter nuclei. The neutron-deficient parents have been observed to emit $\alpha-$like, A_2=4n clusters, whereas the

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neutron-rich radioactive nuclei decay via emission of A_2=4n+2 clusters independent of the choice of fragmentation. In addition to this, it is also concluded that the decays forming ^{100}Sn as daughter product are more probable as compared to the decays leading to ^{132}Sn daughter fragment in view of cluster radioactivity phenomenon. In order to extract the further description on the structural behavior involved, the contribution of shell effects is examined via preformation profile which reveals that the shell effects (δU) are one of the vital factor that decides the decay dynamics of cluster emission process.

After analyzing cluster radioactivity of the ground state parent nuclei, the structural aspects and barrier characteristics of parent and daughter nuclei are probed in context of spontaneous fission phenomenon. Here, spontaneous fission of 45 ground state parent nuclei, varying from ^{232}U to ^{264}Hs is studied using PCM for spherical choice of fragmentation. The PCM reported SF half-lives for all the considered systems find good agreement with experimental data. The most probable decay fragments have been identified and the fragments in the mass range A_2 = 98-130 seem to be the prominent contributors towards SF half-lives for all the chosen cases. Furthermore, the decay path of even mass nuclei $^{232-238}$U is investigated, in terms of α-emission and most probable cluster decay(s).

Besides the PCM applications in ground state α-, cluster and spontaneous fission, next the heavy-ion induced fission of heavy nuclei ^{181}Re* and ^{244}Pu* is worked out within the methodology of DCM [3]. The results related to decay of these systems are divided into two parts: (i) Firstly, the fission dynamics of ^{181}Re* nucleus formed in ^{12}C+^{169}Tm reaction is addressed. The mass distribution of ^{181}Re* nucleus is analyzed and then, compared with the experimental cross-sectional yield. It is observed that the spherical approach gives nice comparison with the experimental data and the fission fragments identified within DCM are in good agreement with the ones explored in experiment. The fission emission times τ_f have been predicted at optimized neck-length parameter whose values lie in the range of 10^{-21} to 10^{-17} seconds which is in line with the previous results. Finally, the dynamics of ^{181}Re nucleus is examined on the basis of structural analysis of decaying fragments in order to analyze the comparative behavior of spontaneous and induced fission processes. Almost similar fission mass distribution is obtained at T=0 and T$\neq$0. (ii) Secondly, the dynamics of heavy-ion induced fission for the decay of excited ^{244}Pu* compound nucleus is studied. Here, the fission cross-sections have been calculated over a wide range of incident energies and are found to exhibit good comparison with the available data. The contribution of light-particles cross section σ_{LPs} is also estimated, which comes out to be negligibly small ($\sim 10^{-5}$ barns) at all energies. Beside this, SF is also investigated so as to compare the induced and spontaneous fission processes. The most probable fission fragments emitted in the ground state decays of even mass $^{236-244}$Pu parents are also identified; which are not detected experimentally yet. By comparing the spontaneous versus induced fission, it is observed that both SF and induced-fission show similar shell structure effects; the SF requires a larger barrier modification as compared to one for heavy-ion induced fission.

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