Decay of nuclear systems with A≈110-260 and related stability aspects

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Introduction

Several theoretical and experimental groups are involved to gain a thorough understanding of nuclear dynamics. This leads to consolidated findings, which provide an insight to describe various aspects of nuclear dynamics with advanced perspectives. One such comprehensive analysis is done in the present work from theoretical viewpoint concerning various ground state (g.s.) and excited state decay mechanisms. For a better perception of the binary fragmentation, the identification of the decay products emitted in various g.s. and excited state decay processes play significant part and the same is investigated in the present study. The methodology used in this work is the Quantum Mechanical Fragmentation Theory (QMFT) [1], which is widely known to investigate various aspects related to formation and decay paths of variety of nuclear systems. Within the QMFT, Preformed Cluster-decay Model (PCM) [2] is applied here to analyze different g.s. decay processes whereas to analyze the excited state decays, Dynamical Cluster-decay Model (DCM) [3], the reformulated version of PCM, is used.

Calculations and Results

Firstly, the effect of shell correction and pairing energy on the fusion-evaporation cross sections and reaction dynamics of various hot and rotating compound systems such as ^{118}Xe*, ^{128}Ce*, ^{146}Sm*, ^{172}Yb*, and ^{196}Pt* are studied within the DCM corresponding to the available experimental data. It is observed that the magnitude of fragmentation potential alongwith preformation probability gets affected upon considering the shell correction and pairing energy. The overall decay pattern remains unaffected except that, few fragments minimized in energy correspond to different atomic (Z)-number compared to the case when these correction terms are ignored. The change of magnitude ultimately modifies the fusion-evaporation cross sections of the compound systems. The effect is more pronounced at the lower temperature or below barrier incident energies. The pairing energy has a relatively lesser influence on the considered observables as compared to the shell correction term. The order of sequence in which the shell and pairing energy is switched off leaves the decay structure unaltered, however the fusion-evaporation cross sections are influenced significantly if the charge of evaporation residue (ER) gets changed.
Next, the ER cross-sections are estimated considering ^{203,204}Pb* systems, formed via ^{6,7}Li+^{197}Au reactions, across a broad range of incident energies surrounding the Coulomb barrier, using DCM. A comparative analysis of different isotopes of Pb formed using stable beams is carried out in context of various effects namely excitation energy, angular momentum and deformation etc. The role of deformation is worked out by comparing the decay path in view of spherically symmetric as well as quadrupole (β_2) deformed fragmentations. Relative contribution of static and dynamic quadrupole deformations is analyzed in view of fragmentation potential. Further, the distributions of averaged total kinetic energy (TKE) among binary decay products of ^{203}Pb* is estimated. Role of different nuclear proximity interactions covering a wide spectrum of barrier characteristics is also explored for better understanding of the dynamics involved. For both the systems

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(^{203,204}Pb*), the computed ER cross sections obtain good agreement with the observed experimental data. Also, the contribution of fission decay mode for ^{203}Pb* system is predicted for several incident energies. The prediction on fission cross sections and average TKE call for the experimental confirmation.

Further, the cluster emission of radioactive nuclei with mass ^{221}Fr$\leq$A$\leq$^{252}Cf decaying to Lead and near Lead daughters are investigated considering four different sets of binding energies given by Möller *et al.* in 1995 (MN1995), Möller *et al.* in 2016 (MS2016), Wang *et al.* in 2010 (NW2010) with corresponding deformation parameters and experimentally measured data in 2017 (EX2017) with deformations of the MN1995, MS2016 and NW2010 formalisms by applying the PCM. With the incorporation of β_2-deformations along with optimum cold orientations, the fragmentation potential changes for different choices of binding energy data and hence the corresponding preformation probability of the clusters get accordingly modified. The computed half-lives concerning the cluster emissions find reasonable consent against the experimental numbers using MS2016 formalism. Applying MS2016, the prediction of half-lives of some competing clusters (not measured so far) from known parents is also made in the Lead and near Lead region, which could potentially suggest new edges for cluster emission measurements. Further, the role of axial deformations (β_2-β_4) from various tables along with cold elongated configurations of decay products is analyzed in view of cluster emission from considered radioactive nuclei. The fragmentation potential calculated using MN1995, MS2016 and NW2010 gets significantly influenced when β_2-deformations are replaced with β_2-β_4 deformations. In comparison to experimentally observed clusters, nearly 32% clusters are not found in the decay path using theoretical binding energies and deformation parameters of MN1995, which reduces to 16% for MS2016 and 7% for NW2010.

At last, theoretical prospects of the spontaneous emission of fission fragments (FFs) from $^{237-256}$Cf parents are explored by employing PCM. The fragmentation profile shows a transition from dominated asymmetric FFs to symmetric fragmentation upon increasing the isospin factor of mother nucleus. The estimated SF half-lives of Cf isotopes obtain good agreement with the experimental numbers. Within the PCM, the hydrodynamical mass transfer among the outgoing binary fragments occurs through a cylindrical vessel connecting them and is calculated using the two classical models viz. Model A and Model B. Notably, with change in the overlapping distance, the radius of the cylindrical vessel changes in Model A, whereas it remains fixed in Model B. In case of Model B, the effect of cylindrical radii parameter (α_c) is also analyzed for $^{237-256}$Cf parents at optimum neck-length (ΔR) in view of different observables such as most probable SF fragments, preformation probability, mass transfer, SF half-lives etc. and the results are compared with Model A calculations. The magnitude of mass transfer, preformation probability, and hence the SF half-lives gets significantly modified on switching from Model A to Model B. The SF half-lives are shown to depend remarkably on the choice of classical models as well as on α_c. The study infers the importance of classical models to spread further light in the quest of dynamical aspects concerning fragment production in the fission process.

Thus, the predictions made in this work may provide some relevant guidelines for the future experiments. It would be interesting to work on other g.s. decays like multi-proton and multi-neutron radioactivity using PCM.

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