Decay of heavy and superheavy nuclei formed in a variety of nuclear reactions

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Introduction

Nuclear physics provides a doorway to numerous research domains including nuclear engineering, nuclear medicines, radioactive dating and so on but the foremost and significant area is nuclear reactions. The novelty of using a variety of projectiles is in the fact that it leads to the formation of a variety of compound nuclei (CN) covering a broader region of the periodic table and provides an opportunity to explore their dynamical behavior. The significance of analyzing the kinematics of n, p, α and heavy-ion induced reactions arises from the fact that these reactions form incoming channels having different asymmetries and consequently, it may be of interest to explore the effect of excitations on the fragmentation structure and underlying nuclear properties.

The calculations are pursued within the frame-work of the Dynamical Cluster-decay Model (DCM)[1, 2] which finds its origin from the Quantum Mechanical Fragmentation Theory(QMFT)[3]. The methodology proceeds through the transference of the beam energy E_{beam} to center of mass energy $E_{c.m.}$ (which is controlled by the asymmetry of the incoming channel) and hence to the excitation energy $E_{CN}{}^*$ of the exit channel. It works in two-steps: the first step involves the estimation of probability with which the decaying fragments are pre-born within the parent nucleus, called the preformation probability P_0 and the second step involves the estimation of probability of the pre-born fragments tunnelling through the potential barrier, called the tunnelling probability P. The collective clusterization approach urges on the choice of one exit channel at the expense of another channels. It adequately incorporates the effects of the potentials used, the moment of inertia expressions, the radius terms and the level density parameter etc.

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Calculations and discussions

First of all, the fission decay analysis of compound nucleus ^{240}Np* formed in n-induced reactions over incident beam energy of E_n=0.62-18.75 MeV is carried out. The decay structure of ^{240}Np* is analyzed by including quadrupole deformations and it is observed that the decay profile becomes more asymmetric with inclusion of deformations, however, the fragments contributing towards the decay cross-sections remain same (A_2=100-112). The enhancement in cross-sections at the three energies is attributed to the orientations of the decaying fragments as change in structure is observed when hot (equatorial) orientations are replaced with cold (polar) configuration. The significance of moment of inertia in the decay of ^{240}Np* is also investigated from the corresponding structural variations that come in to picture. Also, the comparative analysis of decay profiles of ^{240}Np* and ^{238}U* shows similar fragmentation structures with small variations in magnitude for both the decaying nuclei.

After this, the effect of the mass of the decaying compound nucleus is analyzed and the decay of a lighter compound nucleus ^{61}Ni* formed in n-induced reaction over an incident beam energy range of E_n=1-100MeV is carried out that chooses to decay via particle evaporation. The experimental data reveals the presence of α-emission at low energies and $2p2n$-emission at high energies and this has been addressed nicely using the non-sticking moment of inertia I_{NS}. The transmutation of α-emission at lower energies and $2p2n$-emission at higher energies is explained on the basis of temperature dependence of the binding energies used in DCM. Also, the effect of mass (and charge) of the compound nucleus on α and $2p2n$-multinucleon emission is analyzed by studying the decay of various compound nuclei having mass ranging from light to intermediate mass region.

Furthermore, the decay analysis of compound systems- ^{77}As*, ^{83}Br* and ^{86}Sr* formed in p-induced reactions is also carried out at common beam energy E_{beam}=1-5 MeV. The chosen compound systems decay via n-evaporation and the calculations are done using spherical fragmentation approach. The DCM calculated cross-sections are analyzed for their dependence on the nuclear level density parameter by varying the value of LDP from 6-10 and by including mass-dependence in it. The results conclude that the DCM calculated cross-sections for n-evaporation are insensitive to the choice of level density up to those ℓ-values up to which the n-evaporation dominates in decay channel, and as soon as the ℓ-values are increased further, due to competing heavier fragments, a variation in the cross-sections can be observed.

After this, the decay analysis of the compound systems ^{117}Sb*, ^{145}Pm* and ^{191}Ir* formed in α-induced reactions is carried out over an incident beam energy range $E_\alpha \sim$ 10 to 15 MeV. The role of mass of the CN on the fragmentation structure is analyzed along with the role of deformations of the decaying fragments. The significance of these emerges from the structural variations that come in to picture. Additionally, the neutron to proton asymmetry effects are investigated and for this purpose asymmetry dependence is included in bulk constant α (used in LDM term) and the radius expression and the corresponding effect on fragmentation structure is investigated. It is observed that by including asymmetry in Bulk constant α, the overall fragmentation structure remains same however the magnitude of fragmentation potential changes at individual fragment level. For the use of asymmetry dependent radius, a decrement in preformation probability P_0 and an enhancement in barrier tunnelling probability P is observed while the decay cross-sections follow the trend of P_0 leading to a net decrement in their magnitude.

Lastly, this work highlights the role of different proximity interactions for the decay of ^{297,298}118* superheavy compound systems formed in the ^{48}Ca+^{249,250}Cf reactions within the framework of dynamical cluster decay model. By including the quadrupole (β_{2i}) deformations, together with the "optimum" orientations, the DCM calculated $2n$ and $3n$ evaporation residue (ER) cross-sections, using both Prox-1977 and Prox-2000, find a nice comparison with experimental data for ^{48}Ca+^{249}Cf reaction at two incident energies. The variation of decay barrier height, potential energy surfaces, and barrier-lowering effects etc. are analyzed to extract a better picture of the dynamics involved. A possible contribution for the, not yet observed, fusion-fission component constituting both heavy mass and asymmetric mass fragments is predicted. The α-decay half-lives of ^{294}118, and its subsequent ^{290}116 and ^{286}114 parents occurring in the α-decay chain, are addressed via preformed cluster model (PCM) for ground state analysis T=0 and T$\neq$0 considerations. The competition of α-decay with other possible heavy cluster emissions from all the parents in the α-decay chain is also probed here.

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