A study of competing decay channels of nuclear systems formed in low energy heavy-ion reactions

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Introduction

Horizon of human mind and of science has increased by solving puzzles posed by day to day experimentations. Thus, continuous efforts in experimental techniques and theoretical models have been carried out in order to expand our existing knowledge. In the present work, a theoretical attempt for the decay study has been done using the dynamical cluster-decay model (DCM) [1–4] has been employed to study the compound nucleus (CN) and non-compound nucleus (nCN) decay mechanisms observed in nuclei lying in different mass regions of the periodic table under extreme conditions of temperature and pressure. The DCM is based on well known quantum mechanical fragmentation theory (QMFT) [5] and gives descent estimate of various decay products formed in heavy ion reactions (HIRs). It is noteworthy that investigating the features of decay mechanisms observed through CN or nCN processes proves to be of immense help in growing our knowledge of nuclear structure, nuclear reaction and associated aspects. In framework of DCM, the decay in form of light particles (LPs) also called evaporation residue, intermediate mass fragments (IMFs), heavy mass fragments (HMFs) and symmetric or asymmetric fragments have been studied $^{278,286}112^*$, $^{213,215,217}Fr^*$, $^{201}Bi^*$,$^{150,158}Tb^*$,$^{96}Tc^*$,$^{66}As^*$,$^{40}Ca^*$ and $^{39}K^*$ nuclei [2–4]. The present study sheds light on the theoretical aspects and signatures of various processes such as quasi-fission(QF), deep inelastic collision (DIC) and incomplete fusion (ICF), in addition to the CN decay for the heavy, intermediate and light mass region.

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Calculations and Discussions

As a first application of DCM the decay of odd-mass $^{213,215,217}Fr^*$ isotopes is studied where the prime focus is to carry out complete study of decay cross-sections (both ER and ff) and fission fragment anisotropies. For $^{215}Fr^*$ nucleus, the evaporation residue (ER) cross-sections are predicted using DCM by assuming that neck-length parameter 'ΔR' for $^{215}Fr^*$ lies in between that for the $^{213}Fr^*$ and $^{217}Fr^*$ nuclei. Further, the fission and ER cross-sections of $^{213,217}Fr^*$ nuclei are predicted at higher incident energies. It is observed that for both $^{213,217}Fr^*$ isotopes, DCM based fission cross-sections σ_{fision} compare nicely with the experimental data and the predicted ER cross-sections σ_{ER} at the higher incident energies fit in to the systematics governed at relatively lower energies. The behavior of fission fragment anisotropy is also studied for $^{213,217}Fr^*$ isotopes. The DCM calculated anisotropies for use of I_{NS} limit of moment of inertia show a nice agreement with the data. The DCM is also applied to study the role of orientation degree of freedom in context to superheavy ^{278,286} 112 isotopes. For the use of hot (equatorial) compact orientation at above barrier energy, symmetric structure of fission fragments is observed whereas, at sub-barrier energy owing to the preferred cold (polar) elongated orientation the suppression in magnitude of symmetric fragments and dominance of asymmetric fragments is observed. Consequently, for the use of cold orientation, the DCM calculated fission cross-sections in subbarrier region are over-estimated in comparison to the experimental data and signify the presence of quasi-fission contribution, which is more for neutron deficient ^{278} 112 nucleus.

Besides this, the role of static and dynamic (temperature dependent) quadrupole deformations is studied in framework of DCM for the decay of intermediate mass ^{158}Tb * nucleus formed in ^{6}Li+^{152}Sm reaction. The barrier modification and angular momentum dependence is duly addressed for ^{158}Tb * nucleus. Also, the shell closure effect and the isospin dependence of decay fragments is studied for ^{150}Tb nucleus formed in ^{6}Li+^{144}Sm reaction, and comparative analysis is carried out with ^{158}Tb * nucleus. Furthermore, the orientation effect is investigated by considering hot (equatorial) compact as well as cold (polar) elongated orientational features. Finally, the ER cross-sections corresponding to ICF observed due to break up of loosely bound ^{6}Li projectile induced on the deformed target ^{152}Sm is worked out in the framework of DCM by applying relevant energy correction.

Further, the role of higher order deformation effects, upto hexadecapole (β_2-β_4) are studied for the decay of heavy mass ^{201}Bi* nucleus formed in ^{20}Ne+^{181}Ta reaction. Further, the decay cross-sections observed through ICF of ^{20}Ne projectile are also studied using DCM and results obtained are found to be consistent with Morgestern systematics. In addition to this, for the ER decay of light mass ^{96}Tc* system formed in ^{6}Li induced reaction, the effect of angular momentum in reference to the sticking (I_S) and non-sticking (I_{NS}) limit of moment of inertia is analyzed. It is observed that I_S approach is more favorable to address fusion excitation functions. Besides this, the role of angular momentum in disentangling the CF and ICF contribution observed due to break-up of loosely bound ^{6}Li projectile is exercised explicitly.

A systematic decay study of light mass $^{66}As^{*}$ nucleus formed through proton-halo ^{8}B induced reaction is carried out in framework of DCM in reference to the ER, IMF and fission decay fragments. The calculations suggest that the fusion excitation function of $^{66}As^{*}$ consists of LPs as the most dominant contributors, followed by IMFs and fission fragments. Further, decay of very light mass ^{40}Ca* and ^{39}K* nuclei formed in asymmetric channels ^{12}C+^{28}Si, ^{11}B+^{28}Si and ^{12}C+^{27}Al are investigated using spherical choice of fragmentation in framework of DCM. In reference to the experimentally measured charge particle cross sections, the fragment masses and their relative contribution towards the decay of ^{40}Ca* and ^{39}K* nuclei is identified. Also, the role of entrance channel is investigated by studying the decay of ^{39}K* nuclear system formed in two different reactions at same excitation energy. The behavior of fragmentation potential, preformation probability and penetrability is analyzed to figure out the favorable mass fragments, their relative emergence and the entrance channel effects etc. In addition to this, the cross sections for the LPs and heavier charge fragments are estimated for the CN decay. Besides this, one of the nCN process, DIC is also addressed in context to DCM approach. The cross sections obtained in framework of DCM for both CN and nCN processes are found to have nice agreement with the available experimental data.

Acknowledgments

I am thankful to Dr. Manoj K. Sharma for his guidance and all time help. The financial assistance from DST and then from University Grants Commission (UGC), New Delhi, is also gratefully acknowledged.

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