Dynamics of heavy ion collisions at low and intermediate energies

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Introduction

Innovations in the field of heavy-ion (HI) reaction technology facilitate to probe the nucleus and to study its dynamical behavior by employing a variety of projectile and target combinations. In other words, it helps to explore the nuclear reaction dynamics in different mass regions as well as in different energy domains. Among different factors which influence the reaction dynamics, projectile energy is the principal one which governs the reaction dynamics. The low energy HI reactions ($\sim$ E $\leq$ 10 AMeV) serve to explore nuclear structure, different reaction mechanisms, clustering in nuclei, behavior of nuclei under different conditions of temperature, angular momentum, entrance channel mass asymmetry (η_{in}) etc.

The nuclear reaction dynamics can be explored via study of decay products of composite systems (CS) formed in low energy HI reactions. For light mass CS, the standard rotating liquid drop model predicts strong inhibition of fusion-fission (FF) as compared to deep inelastic orbiting (DIO) due to very high fission barrier. Quite interestingly, low energy reactions act as an indispensable tool to explore the cluster structure within the nucleus. Several attempts have been undertaken to study the role of cluster structure on the dynamics of reactions involving light mass α-cluster nuclei. It makes an interesting case to look into the reaction dynamics of these light mass systems, which has been explored along with clustering aspects in the present work within the Dynamical Cluster-decay Model (DCM) [1–3]. Also, the decay study of medium mass CS is carried out [4].

The availability of HI beam upto several hundred MeV has opened the new phase of nuclear reactions termed as intermediate energy reactions ($\sim$ 10 AMeV $<$ E $\leq$ 2 AGeV) in order to understand the properties of nuclear matter under extreme conditions of temperature and density. The different phenomena which emerge at these energies include multifragmentation, collective flow, etc. The interaction potential between colliding partners plays a key role in deciding the fate of a reaction. Moreover, the mass asymmetry of entrance channel play an important role in the reaction dynamics. In the present work, the role of different parts of nucleon-nucleon (NN) interaction potential in different mass asymmetric collisions is investigated on different phenomena using isospin-dependent quantum molecular (IQMD) model [5]. Besides, a comparative study of fragment production for same nuclear reactions at low and intermediate energies has been made [6].

Calculations and results

At first, the binary symmetric decay (BSD) of extremely light mass $^{20,21,22}Ne^*$ CS with both spherical and oriented nuclei consideration is studied using DCM. The results show the dominant BSD for $^{20}Ne^*$ in comparison to other CS. The study reveals the presence of FF and DIO processes which compete in the decay path. The comparison of results for both considerations present similar observations except that FF contribution is largest in the decay of $^{20}Ne^*$ for deformed nuclei case which is having more value of neck length parameter (ΔR) compared to spherical case. For both the considerations, the experimental data is nicely compared [2].

At next step, clustering effects in light-mass N = Z and N $\neq$ Z nuclear systems $^{20}Ne^*$, $^{28}Si^*$ and $^{21,22}Ne^*$ respectively, have

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been investigated in their intrinsic excited state at resonant-state energies given by the Ikeda diagram, by taking into account the proper temperature-dependent pairing-energy term in liquid drop energies. Also, the clustering features have been studied in N = Z, $^{40}Ca^*$ and N $\neq$ Z, $^{39}K^*$ composite systems in reference to experimentally available data. The results present that clustering scenario changes with increasing temperature due to decrease in pairing strength at high energies. Furthermore, the emission of different IMFs/clusters has been studied in reference to available Z-distribution data. The study shows the coexistence of competing reaction mechanisms (FF and DIO) in their decay. The DCM calculated cross-sections are in good comparison with experimental data [3].

Further, DCM based study of $^{179}Re^*$ and $^{189}Au^*$ CS formed in ^{20}Ne+^{159}Tb,^{169}Tm reactions reveals the presence of two fission windows, the symmetric fission and asymmetric fission in potential energy surface which gives the possibility of sub-structure of fission fragments. It is noted that in both the reaction the projectile lab energy and η_{in} are same leading to same ΔR value to fix ER and fission cross-section. The results show the presence of quasi fission, evaluated empirically [4].

Next, the decay of A = 80 compound systems - $^{80}Zr^*$, $^{80}Kr^*$ and $^{80}Sr^*$ formed in ^{40}Ca+^{40}Ca, ^{32}S+^{48}Ca and ^{16}O+^{64}Zn reactions having η_{in} = 0, 0.2, 0.6 respectively, have been studied to explore the role of η_{in} on the fragment production at low and intermediate energies, comparatively. The chosen projectile energies are such that all compound nuclei have same $E^*_{CN} \sim 47$ MeV at low energy while at intermediate energy the total energy brought in by the projectile is same (E = 2000 MeV). At low energy, the decay has been compared for the emissions of light particles (LPs), intermediate mass fragments (IMFs) and fission fragments in the total fusion cross-sections, within DCM. The results show that in the decay of $^{80}Zr^*$ ($\eta_{in} = 0$) fission process is dominant and with increase in η_{in}, the LPs and IMFs start competing [6]. At intermediate energy, in symmetric reactions (η_{in} = 0), the multiplicity of light and intermediate mass fragments is more and with increase in η_{in}, their multiplicity decreases while the mass of heavy fragments increases, within IQMD model. In addition, the role of different parts of NN potential on elliptic flow (v_2) of these reactions has been studied. The v_2 is found to decrease with participation of momentum dependent interaction (MDI) followed by symmetry potential.

Next, the comparative effect of soft and momentum dependent equation of state (EOS) on fragment production in mass asymmetric reactions with $A_{tot} = 152$ at intermediate energies has been investigated within IQMD model. With momentum dependent EOS, IMFs production increases while the mass of heaviest fragment (A_{max}) decreases in comparison to soft EOS [7]. Further, the role of different parts of NN potential has been studied for different mass asymmetric reactions with $A_{total} = 240$ within different rapidity domains. It is observed that MDI plays a dominant role and the symmetry potential has a minor influence on fragment production yet both together lead to an increase in multiplicity of fragments [8].

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