Transverse flow and its disappearance for superheavy mass reactions

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Introduction

The collective transverse flow of nuclear matter and it's disappearance at the energy of vanishing flow (EVF) observed in heavy-ion collisions have been studied systematically as a function of beam energy, system mass, colliding geometry as well as isospin and mass asymmetry of reacting/colliding partners. Among them, system size effects have drawn a significant interest of the community and have been proved to be useful to pin down the behavior of nuclear equation of state (EOS) and in-medium nucleon-nucleon (nn) scattering cross-section. Recent past has witnessed lot of efforts in this direction of investigating the mass dependence of EVF on both experimental [1, 2] as well as theoretical fronts. [3–5]. Though all studies reported power law ($\propto A^{-\tau}$) behavior of the energy of vanishing flow with combined reacting mass (A); yet they gave different power law factors (τ). For e.g., earlier studies pointed toward $A^{-1/3}$ dependence resulting from the interplay between attractive mean field and repulsive nn scattering [1]. Such studies were limited to lighter masses only. Later on, deviation from this -1/3 dependence was reported when studies were extended to the reactions involving heavier masses [2, 4]. Recently, one of the authors and collaborators reported the dependence $\propto \frac{1}{\sqrt{A}}$, when heavier systems like ^{238}U + ^{238}U were included [4]. Their investigations pointed toward the dominance of Coulomb interactions and also predicted the EVF for the reaction of ^{238}U + ^{238}U (for the first time) to be around 37-39 MeV/nucleon.

At the same time rapid advances in nuclear beam technology have led to a rapid growth of nuclear chart in superheavy mass region. Several experimental facilities at Berkeley, GSI, Riken and JNR Dubna have been actively involved in exploring this predicted island of superheavy nuclei since last 30 years. This possible existence of superheavy nuclei was proposed long ago due to the appearance of shell closures of protons and neutrons. The synthesis of proton-rich or neutron-rich isotopes of superheavy nuclei through cold/hot reactions has emerged as an exciting field and proved to be quite useful in gaining information about the island of stability beyond Z=82, N=126. The extreme efforts to search for superheavy long lived nuclei in laboratories have resulted in expanding the nuclear chart till Z=118 [6]. These artificial nuclei have life times varying from 10^7 years to few seconds and usually decay via spontaneous alpha-decay or spontaneous fission. But the possibility of having these nuclei in the form of projectile beams in near future can't be ruled out. Till now the theoretical calculations of the behavior of transverse flow and its disappearance have been carried out till ^{238}U + ^{238}U as reported earlier. Since recent past has witnessed tremendous success in synthesizing superheavy nuclei, therefore, the reaction dynamics of these superheavy nuclei would be of great interest. It would be worth investigating that whether these superheavy nuclei follow the known dependence of EVF ($\propto A^{-\tau}$ with $\tau \sim 0.4$) or behave differently. With this in mind, in the present analysis we aim to study the mass dependence of EVF for the reactions involving superheavy nuclei. For the present study we employed isospin-dependent

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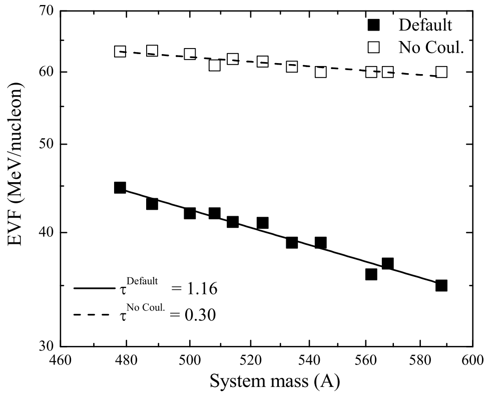

FIG. 1: The EVF as a function of total mass of the system for reactions involving superheavy nuclei only. Lines represent the power law fit $\propto A^{-\tau}$. Different symbols are explained in text.

quantum molecular dynamics (IQMD) model to perform the calculations [5].

Results and discussion

We simulate the reactions (involving superheavy nuclei) of ^{239}Np + ^{239}Np, ^{244}Pu + ^{244}Pu, ^{250}Cm + ^{250}Cm, ^{254}Cf + ^{254}Cf, ^{257}Fm + ^{257}Fm, ^{262}Lr + ^{262}Lr, ^{267}Rf + ^{267}Rf, ^{272}Bh + ^{272}Bh, ^{281}Ds + ^{281}Ds, ^{284}113 + ^{284}113 and ^{294}118 + ^{294}118 at semi-central colliding geometry of b/b_{max} = 0.25 using soft momentum-dependent (SMD) equation of state along with 20% reduction in nn cross-section (labeled as Default). The choice of equation of state is motivated by our previous study [5] where the above set nicely reproduced the measured energies of vanishing flow of various reactions through out the mass range. In Fig. 1, we display the mass dependence of EVF of the reactions involving superheavy nuclei only between the mass range of 478 and 588 units. Solid (open) squares represent the energies of vanishing flow with (without) Coulomb potential. From the figure we find that EVF of superheavy nuclei do obey observed power law behavior with the combined reacting mass, but with convincingly steeper dependence having $\tau \sim 1.2$. Thus EVF of reactions involving superheavy nuclei decreases almost linearly with combined reacting mass. It is worth mentioning that Coulomb interaction also increases almost linearly with system mass. The EVF for reactions of superheavy nuclei without Coulomb potential are displayed by open squares. From figure, we notice that now the EVF becomes almost the same for all superheavy nuclei having A between 478-588 units, reducing the power law factor to 0.3. Therefore, this sharp dependence of EVF on the system mass for superheavy nuclei in contrast to that of normally observed mass dependence of EVF (with τ =0.4) points towards the dominant role of Coulomb potential in the reaction dynamics of heavy masses.

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