On the system size dependence of the emission of intermediate mass fragments in neutron-rich reactions

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Introduction

The nuclear multifragmentation, wherein several small (Z = 1 or 2) and intermediate size fragments (IMFs) ($Z\geq3$) are emitted, gives an opportunity to study the nuclear matter at the extreme conditions of temperature and density. The multiplicity of IMFs is found to show a rise and fall with beam energy in the center-of-mass frame [1-3]. Sisan *et al.* [2] observed that $E_{c.m.}^{max}$ (energy at which maximum production of IMFs occurs) increases linearly with the system mass whereas a power law ($\propto A^{\tau}$) dependence was reported for $\langle N_{IMF}\rangle^{max}$ ($\tau \approx 0.7$). All these studies were limited to systems lie close to the stability line. The established and upcoming secondary radioactive ion beam (RIB) facilities around the world gave a new direction to the present day nuclear physics research. Recently, it has been shown that the universal "rise and fall" of fragment production remain preserved for the neutron-rich/neutron-poor colliding pairs [4]. In the present work, we shall make a systematic study to see the effect of system mass on the behavior of $E_{c.m.}^{max}$ and $\langle N_{IMF}\rangle^{max}$ for neutron-rich/neutron-poor systems.

The Model

The present study is carried out within the framework of the isospin-dependent quantum molecular dynamics (IQMD) model [5]. In IQMD model, propagation of each nucleon is governed by the classical equations of motion:

$$\frac{d\vec{r}_i}{dt} = \frac{d\langle H\rangle}{d\vec{p}_i}, \qquad \frac{d\vec{p}_i}{dt} = -\frac{d\langle H\rangle}{d\vec{r}_i} \qquad (1)$$

where H stands for the Hamiltonian which is given by:

$$H = \sum_i \frac{p_i^2}{2m_i} + \sum_i V_i^{Sky} + V_i^{Yuk} + V_i^{Coul} + V_i^{mdi} + V_i^{sym} \qquad (2)$$

The V_i^{Sky}, V_i^{Yuk}, V_i^{Coul}, and V_i^{sym} are, respectively, the Skyrme, Yukawa, Coulomb, and symmetry potentials. The phase space generated with IQMD model is stored at different time steps. The minimum spanning tree (MST) method is used most frequently to clusterize the phase-space of nucleons [3].

Results and Discussion

Firstly, we simulate the reactions for those systems for which experimental data is available. In particular, we simulate the reactions of ^{40}Ar+^{45}Sc (E_{lab} = 35-115 AMeV), ^{58}Ni+^{58}Ni (E_{lab} = 35-105 AMeV), ^{86}Kr+^{93}Nb (E_{lab} = 35-95 AMeV), and ^{84}Kr+^{197}Au (E_{lab}= 35-400 AMeV) for b = 0.0 fm. We used a soft equation of state along with standard isospin- and energy-dependent cross section. The reactions are followed till 300 fm/c and clusters are formed with MST method using a clusterization radius of 2.8 fm.

In Fig. 1, we display the peak multiplicity of IMFs $\langle N_{IMF}\rangle^{max}$ (upper panel) and peak center-of-mass energy $E_{c.m.}^{max}$ (lower) as a function of the combined mass of the system. Solid stars represent the experimental data whereas solid circles correspond to our theoretical calculations. Open triangles represent percolation model calculations [2]. $\langle N_{IMF}\rangle^{max}$ and corresponding $E_{c.m.}^{max}$ are obtained by making a quadratic fit to the theoretical calculations for $\langle N_{IMF}\rangle$ as a function of $E_{c.m.}$. We find that $E_{c.m.}^{max}$ increases linearly with the system mass ($\propto A$) whereas $\langle N_{IMF}\rangle^{max}$ follows a power law behavior ($\propto A^{\tau}$) with $\tau = 0.8$. From the Figure, we see that our calculations are in good agreement with experimental data. The good agreement of our calculations with experimental results motivated us to study the system size effects for the above mentioned quantities. For this study, we simulate several thousands of events of Ne+Ne, Al+Al, Cl+Cl, Ca+Ca, Mn+Mn, Ni+Ni, Zn+Zn, Zr+Zr, Sn+Sn, Pd+Pd, and Xe+Xe reactions for different values of N/Z

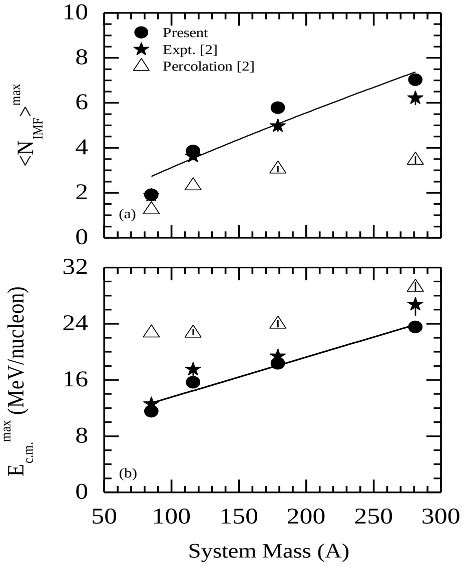

Fig. 1 The $\langle N_{IMF}\rangle^{max}$ (upper panel) and $E_{c.m.}^{max}$ (lower) as a function of composite mass of the system (A). Comparison of model calculations is made with experimental data [2] (solid stars).

ratios at different incident beam energies between 30 and 150 MeV/ nucleon. In particular, we simulate $^{20-34}$Ne + $^{20-34}$Ne, ^{34}Al + ^{34}Al, ^{34}Cl + ^{34}Cl, $^{40-60}$Ca + $^{40-60}$Ca, ^{60}Mn + ^{60}Mn, $^{56-84}$Ni + $^{56-84}$Ni, ^{60}Zn + ^{60}Zn, $^{80-120}$Zr + $^{80-120}$Zr, ^{120}Pd + ^{120}Pd, $^{100-150}$Sn + $^{100-150}$Sn and $^{110-162}$Xe + $^{110-162}$Xe, which cover N/Z ratios from 1.0 to 2.4, at b/b_{max}= 0.2 - 0.4.

In Fig. 2, we display the system size dependence of $\langle N_{IMF}\rangle^{max}$ (left panels) and $E_{c.m.}^{max}$ (right) for isospin ratios equal to 1.0 (upper panels), 1.6 (middle) and 2.0 (lower). Here, in each window, the results are displayed for a particular value of N/Z ratio, i.e., the isospin asymmetry is kept fixed and system mass is increased. In order to obtain $\langle N_{IMF}\rangle^{max}$ and corresponding $E_{c.m.}^{max}$, second order polynomials are fit to theoretical calculations. Lines in the left (right) panels represent linear $\propto A$ (power law $\propto A^{\tau}$) fit. From Fig. We see that the $E_{c.m.}^{max}$ increases linearly with composite mass of the system for different N/Z ratios and $\langle N_{IMF}\rangle^{max}$ shows a power law dependence with power factor (τ) = 1.03, 0.91, and 0.87 for N/Z = 1.0, 1.6 and 2.0, respectively. This type of behavior of $E_{c.m.}^{max}$ and $\langle N_{IMF}\rangle^{max}$ is also true for other values of N/Z ratios. This is supported by Ref [3] where Puri and co-workers studied the similar type of system size dependence for stable systems.

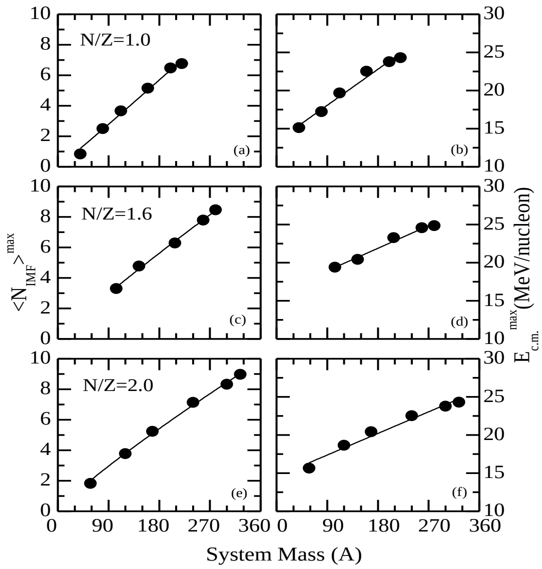

Fig. 2 The $\langle N_{IMF}\rangle^{max}$ (left panels) and $E_{c.m.}^{max}$ (right panels) as a function of composite mass of the system (A) for different N/Z ratios.

Acknowledgments

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