# Isospin dependence of the peak fragment production in heavy-ion collision

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## Introduction

With the advent of secondary radioactive ion beam (RIB) facilities around the world, there has been an increasing interest in the characteristics of multifragmentation as a function of the isospin ratios of the colliding pairs. Neutron content of the colliding pairs is found to affect the fragment production [1]. Neutron-rich system are found to emit more intermediate mass fragments (IMFs) as a function of charged particles at low incident energies while at the highest energy difference is found to be disappeared [2]. The $E_{c.m.}^{max}$ (energy at which maximum number of IMFs are produced) and $<N_{IMF}>^{max}$ (peak multiplicity of IMFs) are found to scale with system mass [3, 4]. It would be interesting to see how these quantities behave with isospin asymmetry of colliding pairs. Therefore, in the present work, we made a systematic study to see the effect of isospin degree of freedom on the behavior of $E_{c.m.}^{max}$ and $<N_{IMF}>^{max}$ for neutron-rich/neutron-poor systems. The present study is made within the framework of the isospin-dependent quantum molecular dynamics (IQMD) model [5]. The fragments are constructed with minimum spanning tree method [4] using a clusterization range 2.8 fm.

## Results and Discussion

The systems having large isospin asymmetry could be best suited to study the isospin effects on $E_{c.m.}^{max}$ and $<N_{IMF}>^{max}$. For present 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 ratios at different incident beam energies (30-150 MeV/nucleon in small steps of 10 MeV/ nucleon). In particular, we simulate $^{20\text{-}34}$Ne + $^{20\text{-}34}$Ne, $^{34}$Al + $^{34}$Al, $^{34}$Cl + $^{34}$Cl, $^{40\text{-}60}$Ca + $^{40\text{-}60}$Ca, $^{60}$Mn + $^{60}$Mn, $^{56\text{-}84}$Ni + $^{56\text{-}84}$Ni, $^{60}$Zn + $^{60}$Zn, $^{80\text{-}120}$Zr + $^{80\text{-}120}$Zr, $^{120}$Pd + $^{120}$Pd, $^{100\text{-}150}$Sn + $^{100\text{-}150}$Sn, and $^{110\text{-}162}$Xe + $^{110\text{-}162}$Xe, which cover N/Z ratios from 1.0 to 2.4, at $b/b_{max}$= 0.2 - 0.4.

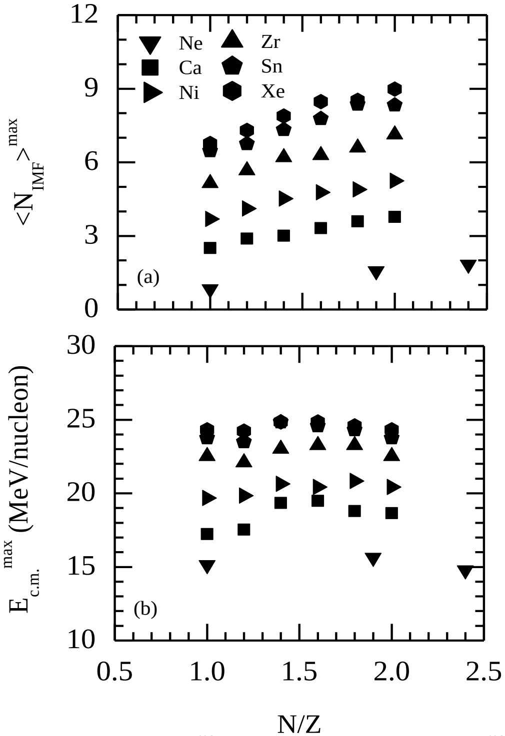

**Fig. 1** The $<N_{IMF}>^{max}$ (upper panel) and $E_{c.m.}^{max}$ (lower panel) as a function of N/Z ratio of the composite system.

In Figs. 1(a) and (b), we display the N/Z dependence of $<N_{IMF}>^{max}$ and $E_{c.m.}^{max}$, respectively for isotopic series of Ne (down triangles), Ca (squares), Ni (right triangles), Zr (up triangles), Sn (pentagons), and Xe (hexagons). We see from Fig. 1(a) that $<N_{IMF}>^{max}$ increases with increase in N/Z ratio and increase is sharp in case of heavier systems

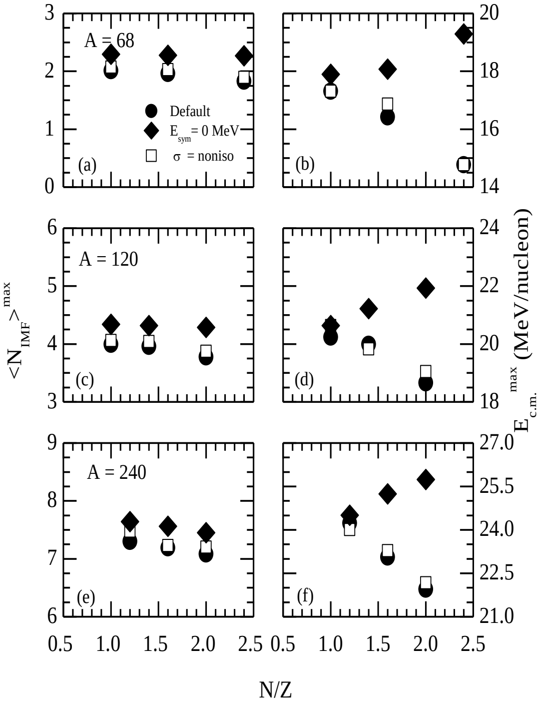

**Fig. 2** The $\langle N_{IMF}\rangle^{max}$ (left panels) and $E_{c.m.}^{max}$ (right panels) as a function of N/Z ratio of the composite system for system masses 68 (upper panels), 120 (middle), and 240 (lower) units.

as compared to lighter ones. Fig. 1(b) shows that in case of lighter systems $E_{c.m.}^{max}$ varies slightly with N/Z ratio, however, for heavier systems it does not change much.

In Fig. 1, both the total mass of the system and N/Z ratio of the system vary. This raises the question of how much of the dependence is due solely to the change in isospin asymmetry (N/Z ratio) of the composite system and how much is due to the mass of the system.

In order to pin down the exact cause of the isospin dependence, we performed same calculations for three sets with fixed total mass equals to 68, 120, and 240 units and results are shown in Fig. 2. Naturally, isospin effects can be due to either Coulomb potential, isospin-dependent cross section or symmetry potential. If Coulomb potential has been responsible, one expects delayed boil of in case of neutron-rich systems, $E_{c.m.}^{max}$ would be higher in the case of neutron-rich colliding pairs. By keeping total mass fixed, we convert proton to neutron to increase N/Z ratio. Due to decrease in the proton number, net coulomb repulsion will decrease leading to delay break up into IMFs. To see the effect of isospin dependence of the nucleon-nucleon cross section, we simulated the reactions using isospin-independent cross section by keeping $\sigma_{nn} = \sigma_{pp} = \sigma_{np}$ and calculated $E_{c.m.}^{max}$ and $\langle N_{IMF}\rangle^{max}$. The results are displayed by open squares. We find that both $E_{c.m.}^{max}$ and $\langle N_{IMF}\rangle^{max}$ are insensitive to the isospin dependence of nucleon-nucleon cross section. As a next step, to see the effect of symmetry energy on $E_{c.m.}^{max}$ and $\langle N_{IMF}\rangle^{max}$, we put the strength of the symmetry energy zero. The results are displayed by solid diamonds. Now, we find that neutron-rich systems see enhanced $E_{c.m.}^{max}$ compared to neutron-deficient systems. This means that if we have no symmetry potential in the hamiltonian, the results would be in accordance with Coulomb potential concept. This clearly demonstrates the dominant role of symmetry potential. The inclusion of symmetry energy makes neutron-rich systems to boil of faster compared to neutron-poor systems.

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