Probing isospin effects via symmetry energy and cross section in asymmetric heavy-ion collisions

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Introduction

Heavy-ion collisions at intermediate energies offer the possibility to investigate various microscopic and macroscopic features of complex nuclei at high densities and excitation energies. At high excitation energies and temperature, the colliding nuclei may break up into many fragments, known as multifragmentation. In recent times, a lot of research is going on for the study of collision of mass asymmetric nuclei at intermediate energy range.

The growing study of radioactive beam facilities at many laboratories over the world and the use of radioactive beams with large neutron or proton excess have offered an excellent tool to probe the isospin effects in terms of symmetry energy and in–medium nucleon-nucleon (NN) cross section. The nuclear symmetry energy, which is defined as the difference in the energy per nucleon between the pure neutron matter and symmetric nuclear matter, is an important quantity that determines not only the properties of atomic nucleus [1] but also governs many important issues in astrophysics [2].

The isospin effects in the NN cross sections arise from the fact that NN cross sections for neutron-neutron (or proton-proton) and neutron-proton collisions are different. As the little information is known about in-medium NN cross section and how its isospin dependence effects the mass asymmetric reactions, it thus becomes desirable to do theoretical study to gain knowledge about isospin effects in mass asymmetric reactions in heavy-ion collisions. It is worth mentioning that multifragmentation in mass asymmetric reactions have been studied before [3], but the investigations about the role of isospin effects in such reactions are still missing.

The Model

The present study is carried out within the framework of Isospin-dependent Quantum Molecular Dynamics (IQMD) [4] model, which is a modified version of Quantum Molecular Dynamics (QMD) [5] model. The IQMD model is a semi-classical model which describes the heavy-ion collisions on an event by event basis. For more details, the reader is referred to Ref. [4]. In IQMD model, the centroid of each nucleon propagates under the classical equations of motion

$$\frac{dr_i}{dt} = \frac{d\langle H\rangle}{dp_i}, \frac{dp_i}{dt} = -\frac{d\langle H\rangle}{dr_i}, \qquad (1)$$

where H refers to the Hamiltonian and reads as:

$$\sum_i \frac{P_i^2}{2m_i} + V_{Yukawa}^{ij} + V_{Coul}^{ij} + V_{Skyrme}^{ij} + V_{symm}^{ij}, \qquad (2)$$

and it contains contributions from Yukawa, Coulomb, Skyrme and symmetry potential. During the propagation, two nucleons are supposed to suffer binary collision if the distance between their centroids satisfy the below equation,

$$d \le d_0 = \sqrt{\frac{\sigma_{tot}}{\pi}}, \quad \sigma_{tot} = \sigma(\sqrt{s}, \text{type}), \qquad (3)$$

where σ_{tot} refers to total NN cross section.

Results and Discussions

For the present analysis, simulations are carried out for several thousand events at four different incident energies, i.e, at 50, 75 150 200 MeV/A for the reaction of $^{16}O + ^{92}Br$ having η =

0.7. Here η is asymmetry parameter and is defined as $\eta = (A_T - A_P)/ (A_T + A_P)$, where A_T and A_p are the masses of the target and projectile, respectively.

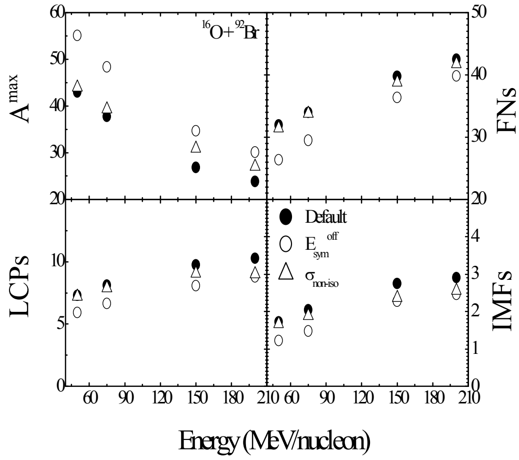

Fig. 1 The heaviest fragment (A^{max}), multiplicity of free nucleons (FNs), light charged particles (LCPs), and intermediate mass fragments (IMFs) as a function of incident energy. Various symbols are explained in the text (preliminary results).

The displayed reaction is simulated using soft equation of state for central collisions. To study the isospin effects via symmetry energy and cross section on multifragmentation, we display in Fig.1 the size of heaviest fragment (A^{max}), multiplicity of free nucleons, light charged particles and intermediate mass fragments at various incident energies. From the figure, we see that the size of heaviest fragment decreases with the corresponding increase in the multiplicities of free nucleons, LCPs and IMFs with increase in incident energy (see solid circles). This happens because of the violent nature of the collisions when we go towards higher incident energies. Similar results are also reported for mass symmetric reactions [6]. To see the role of isospin degree of freedom via symmetry energy, we performed the calculations without symmetry energy and results are displayed by open circles in the same Fig.1. We notice that now the size of heaviest fragment increases. This is because of repulsive nature of symmetry energy and therefore, with less repulsion (due to the absence of symmetry energy), A^{max} gets bigger. On the other hand, the multiplicities of free nucleons, LCPs and IMFs get decreased. We also notice that the role of symmetry energy is much more dominant at lower energies and it decreases as we move towards higher energy range. This is because of the importance of mean field at lower energies. Next, to see the role of isospin via NN cross section, we perform the calculations by keeping isospin independent cross section (i.e., the cross section for neutron-proton collisions is same as that for neutron-neutron collisions). The results are displayed by open triangles (and labeled by $\sigma_{non-iso}$). From the figure, we find that with isospin independent cross section also, the size of heaviest fragment (A^{max}) increases (compare solid circles and triangles). This happens because now the net magnitude of the NN cross section decreases (compared to that with isospin-dependent cross section). This leads to much less breaking of the colliding matter and therefore a bigger A^{max} is formed. We also see that the role of isospin dependence of NN cross section is enhanced at higher incident energies, as expected, whereas at lower energy of 50 MeV/nucleon, the results are insensitive to isospin dependence of cross section. As this is a theoretical study, experiments are required to verify these predictions.

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