Light cluster and entropy production in heavy-ion collisions

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Introduction

It is well known that fragments formed in heavy-ion collisions depend crucially on the bombarding energy, composite mass of the system and impact parameter of the reaction. Apart from various entrance channels, model ingredients (such as equation of state, nucleon nucleon (nn) cross-section, Gaussian width etc.) also affect the various phenomena ranging from low to high incident energies. The fragmentation pattern at peripheral geometries is significantly affected by nn cross section compared to that of at central geometries [1]. The width of the Gaussian is also found to affect the fragment formation [2]. In recent years, light cluster production is subject of keen interest. The composite clusters such as *d*, *t*, ^{3}He, and ^{4}He can be used to extract entropy produced during a collision which can shed light on the early phase of the reaction. Here we will make an attempt to see the role of various model ingredients on the composite particle yield ratios as well as entropy production.

The present study is made within the framework of isospin-dependent quantum molecular dynamics (IQMD) model [3]. The phase space generated with IQMD model is clusterized using minimum spanning tree (MST) method. For the detailed calculations of composite particle yield ratios and entropy, we refer the reader to Refs. [4].

Results and Discussion

We simulated the reactions of ^{20}Ne+^{20}Ne, ^{40}Ca+^{40}Ca, ^{93}Nb+^{93}Nb, ^{145}Nd+^{145}Nd, ^{197}Au+^{197}Au and ^{238}U+^{238}U at energies between 150 and 1050 MeV/nucleon for central collisions ($b/b_{max} = 0.0 - 0.2$). To check the role of the equation of state (EOS), we used soft, hard and soft momentum dependent (SMD) equations of state along with full and reduced (20%) energy and isospin dependent nn cross-sections. Here, apart from the standard mass dependent Gaussian width, we have also taken two fixed Gaussian widths i.e., $4L = 4.33 fm^2$ (Narrow) and $4L = 8.66 fm^2$ (Broader).

In fig. 1, we display the system size dependence of the composite particle yield ratios at incident energy of 150 MeV/nucleon. The solid circles, squares, diamonds, hexagons, half filled circles and solid triangles represent calculations using soft, hard, soft along with reduced cross-section (Soft^{Red}), SMD, soft with narrow (Soft^{Narrow}) and soft with

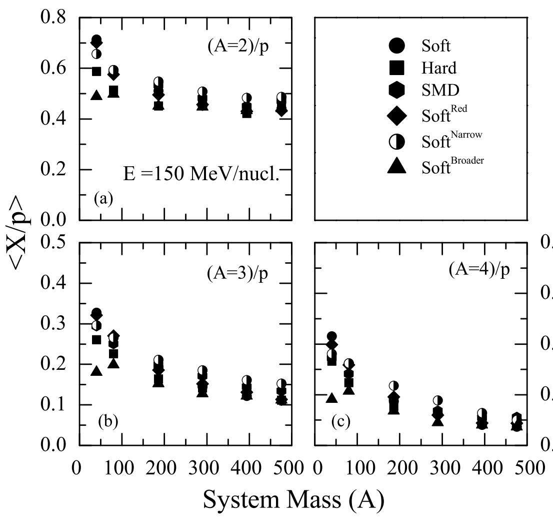

FIG. 1: The composite particle yield ratios as a function of composite system mass at incident energy of 150 MeV/nucleon. Various symbols are explained in the text.

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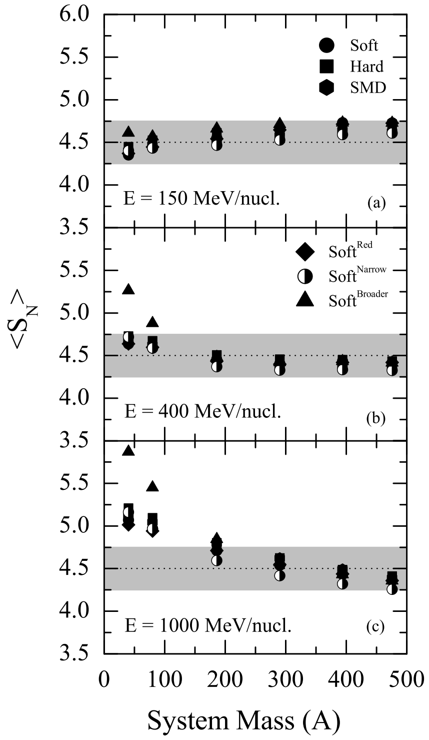

FIG. 2: The entropy $< S_N >$ per nucleon as a function of composite system mass for the central collisions at incident energies 150 (upper), 400 (middle) and 1000 (lower panels) MeV/nucleon. Symbols have the same meaning as in Fig. 1.

broader (Soft^{Broader}) Gaussian widths, respectively. It is clear from the figure that the composite particle yield ratios are very sensitive to the width of the Gaussian irrespective of the mass of the system. In lighter systems, some sensitivity towards equation of state can also be seen. Nearly no effect is visible for the medium and heavy masses towards different equations of state as well as its momentum dependence and reduced cross-section. The effect of different Gaussian widths, however, remains visible even for medium and heavy masses. Further as noted, broader width of the Gaussian causes decrease in the composite particle yield ratios. An extended wave packet has larger interaction range and it will connect large number of nucleons in a fragment that will generate more heavier fragments. Hence, the yield of the light fragments will eventually decrease with the width of the Gaussian.

In fig. 2, we display the system size dependence of the entropy production for various model ingredients at incident energies of 150 (upper), 400 (middle) and 1000 (lower panel) MeV/nucleon. Symbols have the same meaning as in fig. 1. From the figure, we see that the entropy is insensitive to the EOS, momentum dependent interactions and nn cross-section but it shows sensitivity towards the width of the Gaussian. The effect is more prominent at higher incident energies for lighter systems. As noted, entropy (S_N) is nearly independent of the system size at 150 MeV/nucleon whereas one sees significant dependence at 1000 MeV/nucleon. Since the fragments produced in the reaction of ^{20}Ne+^{20}Ne are close to d_{like} clusters, further increase in the incident energy breaks them into free-nucleons. This not only decreases the number of d_{like} clusters, but will also increase p_{like} clusters that leads to net fall in the ratio of the d_{like}/p_{like} clusters and hence rise in the entropy production. On the other hand, in the case of heavier nuclei, intermediate fragments break into free-nucleons and d_{like} clusters, therefore, keeping their ratio nearly unaffected.

Acknowledgments

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