Study of participant-spectator matter and thermalization in isospin asymmetric systems

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Introduction

Besides the many radioactive ion beam facilities that already exist in the world, a number of next-generation radioactive beam facilities are being constructed or planned. At these facilities, nuclear reactions involving nuclei with large neutron or proton excess can be studied, thus providing a great opportunity to study both the structure of rare isotopes and the properties of isospin asymmetric nuclear matter. The ultimate goal of these studies is to determine the isospin dependence of the in-medium nuclear effective interactions and the equation of state of isospin asymmetric nuclear matter. Role of isospin degree of freedom has been investigated in disappearance of flow (at balance energy (E_{bal})) for the past decade. The first study predicting the isospin effects in E_{bal} was done by Pak *et al* [1]. Later on Liewen *et al.* [2] also demonstrated isospin effects using IQMD in disappearance of flow. The study revealed that the isospin effects in flow is due to the competition between nucleon-nucleon collisions, symmetry energy, surface properties and Coulomb force. But relative importance among these mechanisms was not clear. One of the authors and collaborators demonstrated the dominance of Coulomb potential in isospin effects (for isobaric pairs) [3]. Motivated by the dominance of Coulomb potential in isobaric pairs, authors and collaborators studied flow in isotopic pairs and revealed its sensitivity to symmetry energy in Fermi energy region [4]. Hence many studies exist in literature which have been carried out showing isospin effects in balance energy of neutron-rich colliding pairs, but none of the study deals with other heavy-ion phenomena at balance energy. Since at balance energy the attractive mean field potential is balanced by repulsive nucleon-nucleon interactions, so this counterbalancing is reflected in quantities like participant-spectator matter etc. In the present work, we study participant-spectator matter, thermalization reached in the reactions of neutron-rich colliding pairs at the energy equal to the the balance energy. The study is carried out within the framework of IQMD model [5].

Results and discussion

We simulate the reactions of Ca+Ca, Ni+Ni, Zr+Zr, Sn+Sn, and Xe+Xe series having N/Z = 1.0, 1.6 and 2.0. In particular, we simulate the reactions of ^{40}Ca+^{40}Ca (105), ^{52}Ca+^{52}Ca (85), ^{60}Ca+^{60}Ca (73); ^{58}Ni+^{58}Ni (98), ^{72}Ni+^{72}Ni (82), ^{84}Ni+^{84}Ni (72); ^{81}Zr+^{81}Zr (86), ^{104}Zr+^{104}Zr (74), ^{120}Zr+^{120}Zr (67); ^{100}Sn+^{100}Sn (82), ^{129}Sn+^{129}Sn (72), ^{150}Sn+^{150}Sn (64) and ^{110}Xe+^{110}Xe (76), ^{140}Xe+^{140}Xe (68) and ^{162}Xe+^{162}Xe (61) at an impact parameter of $b/b_{\max}$ = 0.2-0.4 at the incident energies equal to balance energy. The values in the brackets represent the balance energies for the systems.

We define the participant-spectator matter in terms of nucleonic concept, i.e, all those nucleons which suffer at least one collision is called participant matter and the remaining nucleons are termed as spectator matter. In fig. 1, we display the system size dependence of the participant and spectator matter. Open (solid) symbols represent participant (spectator) matter. Upper, middle and lower panels represent the results for N/Z = 1.0, 1.6 and 2.0, respectively. We see that participant-spectator matter follows a power law behaviour ($\propto A^{\tau}$) with the system mass. The power

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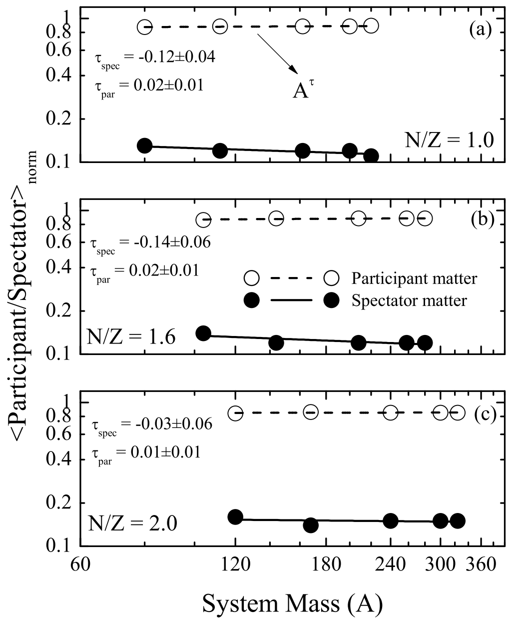

FIG. 1: The system size dependence of participant-spectator matter for different N/Z ratios.

law factor is -0.12± 0.04 (0.02± 0.01), -0.14± 0.06 (0.02± 0.01), and -0.03± 0.06 (0.01± 0.01) for spectator (participant) matter having N/Z = 1.0, 1.6 and 2.0, respectively. Thus, a nearly mass independent behavior is obeyed by the participant and spectator matter for all the N/Z ratios.

An anisotropy ratio is an indicator of the global equilibrium of the system. This represents the equilibrium of the whole system and does not depend on the local positions. The full global equilibrium averaged over large number of events will correspond to $< R_a >$ = 1. The $< R_a >$ is defined as

$$< R_a >= \frac{\sqrt{p_x^2} + \sqrt{p_y^2}}{2\sqrt{p_z^2}}. \qquad (1)$$

From figure 2, we see that anisotropy ratio increases as the reaction proceeds and finally saturates after the high density phase is over. We also see that the influence of system size

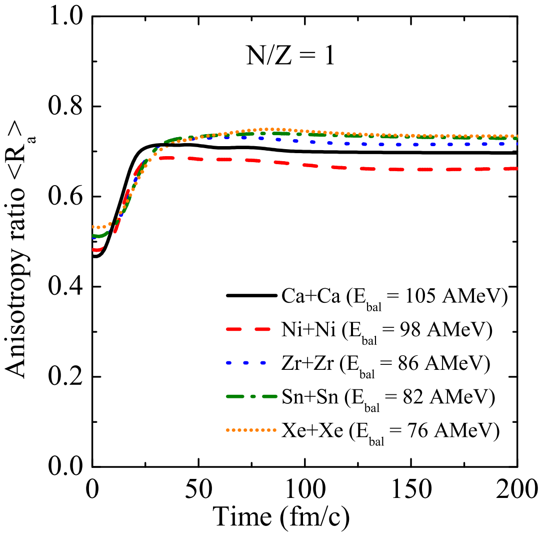

FIG. 2: The time evolution of anisotropy ratio for various systems having N/Z = 1.0.

is very less on anisotropy ratio and hence indicates towards the equilibrium of the system. Also, the saturation of $<R_a>$ ratio after the high density phase signifies that the nucleon-nucleon collisions happening after high density phase do not change the momentum space significantly.

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