Density and thermalization in heavy-ion reactions at the geometry of vanishing flow

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Introduction

The heavy-ion reactions at intermediate energies provide a unique possibility of hot and dense nuclear matter under the extreme conditions of temperature and density. Various observables like multifragmentation, collective transverse in-plane flow [1-3] and particle production have been proposed in this direction to study the properties of nuclear matter like nuclear equation of state and in medium nucleon-nucleon cross-section. Out of these observables, collective flow has been found to be one of the most sensitive towards the above mentioned properties as well as towards incident energies, impact parameter and colliding systems. Collective transverse in-plane flow increases with impact parameter, reaches maximum at semi-central collisions and then again starts decreasing at peripheral collisions. The value of impact parameter where collective flow vanishes (crosses zero) is called geometry of vanishing flow (GVF). The system size dependence of GVF has been found to be sensitive to in-medium nucleon-nucleon cross-section and is insensitive to equation of state and momentum-dependent interactions [4]. In present paper, we studied the density and thermalization at GVF. We use *isospin quantum molecular dynamics* (IQMD) model [5].

The Model

The IQMD model treats different charge states of nucleons, pions and deltas explicitly. The isospin degree of freedom enters into the calculations via symmetry potential, cross sections and Coulomb potential. The nucleons of target and projectile interact by two- and three-body Skyrme forces, Yukawa potential and Coulomb interactions. A symmetry potential between protons and neutrons corresponding to the Bethe-Weizsacker mass formula has also been included. The hadrons propagate using Hamilton's equations of motion. For the density dependence of nucleon optical potential, standard Skyrme-type parametrization is employed. We use soft equation of state along with standard isospin and energy-dependent nucleon-nucleon cross section.

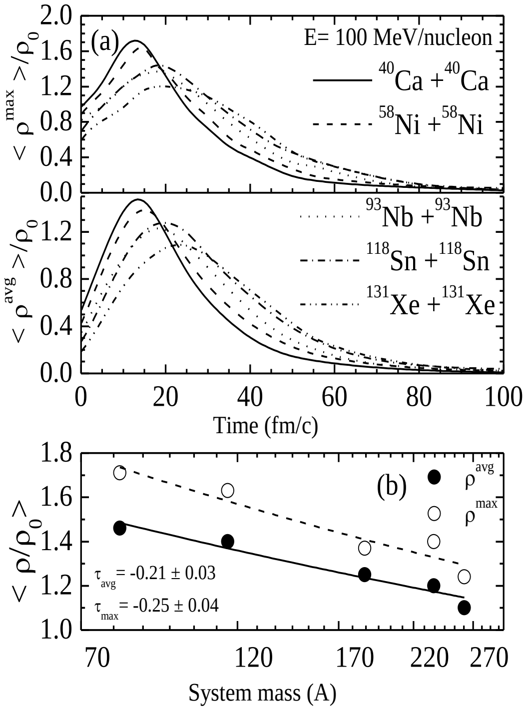

Fig. 1: (a) The evolution of the maximum density $<\rho^{max}>$ and average density $<\rho^{avg}>$ as a function of time and (b) shows its system size dependence.

Results and discussion

In fig. 1(a), we display the $<\rho^{max}>/\rho_0$ and $<\rho^{avg}>/\rho_0$ as a function of reaction time. The displayed reactions are for ^{40}Ca + ^{40}Ca (A=80), ^{58}Ni + ^{58}Ni (A=116), ^{93}Nb + ^{93}Nb (A=186), ^{118}Sn + ^{118}Sn (A=236) and ^{131}Xe + ^{131}Xe (262) spread-

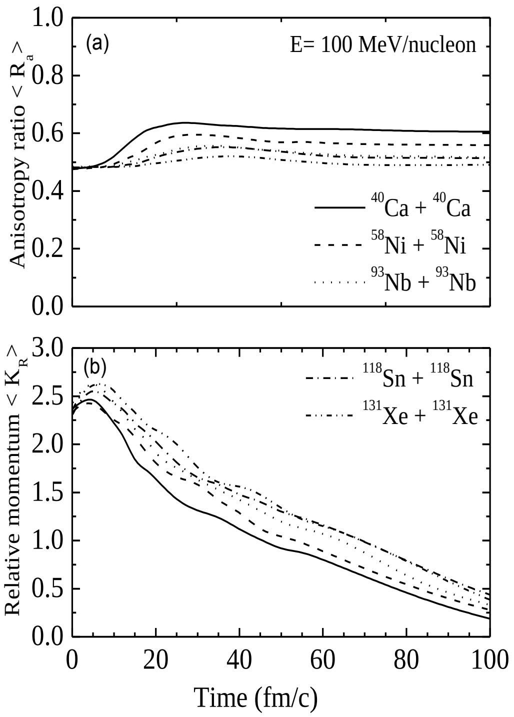

Fig. 2 The time evolution of the anisotropy ratio (upper panel) and relative momentum (lower panel).

ing over the whole mass range. It is evident that maximal ρ^{max} for lighter systems is slightly higher than for the heavier ones. A similar trend can be seen for the evolution of ρ^{avg}. Also, in lighter nuclei, reaction finishes much earlier compared to heavier ones (^{131}Xe + ^{131}Xe). Similarly, the peaks in (the ρ^{max} and ρ^{avg}) densities are also delayed in heavier nuclei compared to lighter ones. This is because of the fact that the value of GVF is more for heavier nuclei (0.8 for ^{131}Xe + ^{131}Xe) compared to lighter nuclei (0.5 for ^{40}Ca + ^{40}Ca). Due to large value of GVF the nucleon-nucleon collisions would be lesser and therefore less density are achieved in the reaction. Whereas in fig. (b), we display the maximal value of average and maximum density, labeled as $<\rho^{avg}>$ and $<\rho^{max}>$ respectively, versus composite mass of the system. Interestingly, the maximal value of $<\rho^{avg}>$ and $<\rho^{max}>$ follows a power law (αA^{τ}) with τ being -0.21 ± 0.03 for the average density $<\rho^{avg}>$ and -0.25 ± 0.04 for the maximum density $<\rho^{max}>$. In other words, a slight decrease in the density occurs with increasing size of the system, as explained earlier.

Also in fig. 2 (a) and (b), we display the time evolution of anisotropy ratio $<R_a>$ and relative momentum $<K_R>$. From figure, we see that anisotropy ratio increases as the reaction proceeds and finally saturates after the high density phase is over. Whereas the relative momentum decreases as the reaction proceeds and the smaller value of $<K_R>$ at the end of the reaction indicates toward the better thermalization of the matter. We also see from the figure that $<R_a>$ ratio saturates as soon as high density phase is over which signifies that the nucleon-nucleon collisions that happening after high density phase do not change the momentum space significantly. One also notices that in the absence of nucleon-nucleon collisions, almost no change is seen in $<R_a>$ from the start to the end of the reaction.

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