Neutron/Proton emission in mass-asymmetric intermediate energy heavy-ion collisions

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Introduction

One of the fundamental questions in the nuclear physics is to understand the highly complex nucleonic interactions, reaction dynamics related to stable and neutron rich nuclei and the equation of state as well as its isospin dependence. The nuclear equation of state, which is most commonly discussed in reference to its density dependence is often expanded in terms of the asymmetry dependence as [1, 2]:

$$E(\rho, \delta) = E(\rho) + E_{symm}(\rho)\delta^2 \qquad (1)$$

Multifragmentation (emission of nucleons from the highly dense matter) is still a crucial tool to study the reaction dynamics and isospin dependence of the equation of state. However, dynamics associated with the asymmetric colliding nuclei is highly different from the dynamics associated with the symmetric colliding pairs [3]. Fragmentation in heavy-ion collisions is highly affected by the mass-asymmetry of the colliding pairs [4]. Neutron to proton ratio and double neutron to proton ratio is an important observable to extract the role of symmetry energy in the low density region [5]. It is worth mentioning that some indications about the soft density dependence of symmetry energy is available in literature. However, no exact information of high density behavior of symmetry energy is available. Obviously, it could be of interest to introspect the impact of density dependence of symmetry energy on the neutron to proton yield obtained from different mass-asymmetric intermediate energy heavy-ion collisions. The present analysis is performed for the soft (S) equation of state.

The Model

Our calculations are carried out within the framework of isospin dependent quantum molecular dynamics (IQMD) model [6]. It contains the correlation effects and explicitly represents the many body states of the system. In IQMD model, the centroid of each nucleon propagates using Hamilton equations of motion:

$$\frac{d\vec{r_i}}{dt} = \frac{\partial H}{\partial \vec{p_i}} \; ; \; \frac{d\vec{p_i}}{dt} = -\frac{\partial H}{\partial \vec{r_i}} \; . \qquad (2)$$

One of the component of baryon-baryon potential is symmetry energy. The variation of symmetry energy with respect to density can be parameterized as [7]:

$$E_{symm}(\rho) = E_{symm}(\rho_o)(\rho/\rho_o)^{\gamma} \qquad (3)$$

Preliminary Results

The present analysis is based on the theoretical study of the reactions $^{80}Kr+^{80}Kr$ ($\tau = 0$), $^{72}Zn+^{88}Zr$ ($\tau = 0.1$), $^{54}Fe+^{106}Cd$ ($\tau = 0.3$), $^{40}Ca+^{120}Te$ ($\tau = 0.5$), $^{24}Al+^{136}La$ ($\tau = 0.7$), where $\tau \left(= \frac{A_T - A_P}{A_T + A_P}\right)$ is the mass-asymmetry factor. Simulations for the above said reactions have been carried out at the incident energy of 50 MeV/nucleon. The impact parameter of the reaction b = 0.3 b_{max}, where $b_{max} = 1.12(A_P + A_T)^{1/3}$, and A_P, A_T represent the mass of projectile and target respectively. The Coulomb interaction induces

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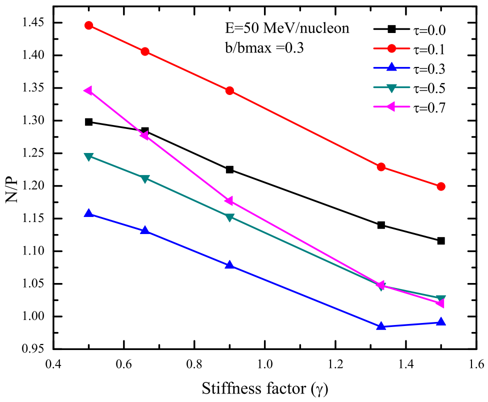

FIG. 1: Neutron to proton ratio (N/P) as a function of the stiffness factor γ for different colliding pair combinations τ with fixed system mass.

repulsion between the protons. At the same time, the symmetry energy tends to induce the repulsion between the neutrons. It could be of the interest to quantify the neutron/proton emission in the reactions subjected to different symmetry energy forms. The analysis is performed for the different mass-asymmetric reactions when subjected to different parameterizations of density dependence of symmetry energy (γ values).

In Fig.1, we display the neutron to proton ratio (N/P) ratio for the reactions having different τ values. The different gamma values justify the magnitude of symmetry energy in the low density region which can affect the fragment production (neutron/proton production). Also, the large asymmetric reactions leads to lesser average density/temperature reached during the overlapping phase [3]. Our results, show that for all the reactions (having different τ values) the neutron to proton ratio tends to decrease with an increase in the stiffness of symmetry energy. Interestingly, for the very stiff form of symmetry energy ($\gamma = 1.5$), the N/Z ratio $\approx$ 1.0 for $\tau = 0.3$. It is concluded that the N/Z emission can be used to probe the symmetry energy strength in the symmetric as well as asymmetric heavy-ion reactions.

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