Influence of symmetry energy on the multifragmentation of asymmetric heavy-ion collisions

Arun Sharma[1],[*] Sakshi Gautam[2], Arun Bharti[1], and Rajeev K. Puri[2]
[1]*Department of Physics, University of Jammu, Jammu -180006. and*
[2]*Department of Physics, Panjab University, Chandigarh -160014.*

Introduction

With the rapid advances of high-intensity radioactive beams facilities, one can have excellent opportunity to investigate symmetry potential by studying collision dynamics. A large number of studies are available in the literature where authors have studied the influence of symmetry energy on various phenomenon [1]. Observables such as fragment yield, isospin diffusion, the double n-p ratio have been used to extract behavior of symmetry energy below saturation density. On the other extreme, high density behavior of symmetry energy being investigated using pion ratio, kaon ratio and the relative n-p differential collective flow etc. The extensive efforts of the community have led to constrained behavior of symmetry energy in subsaturation density region which on contrary, is still unconstrained at supra-saturation density region. In this regard, in the present study, we investigate the influence of symmetry energy towards fragmentation of asymmetric reactions within semiclassical model namely, isospin-dependent quantum molecular dynamics (IQMD). The isospin-dependent quantum molecular dynamics model is a modified version of quantum molecular dynamics (QMD) model [2]. For details, one can consult the Ref. [3]. The nuclear symmetry energy at a particular density reads as:

$$E_{Sym}(\rho) = E_{Sym}(\rho_0)\Big(\frac{\rho}{\rho_0}\Big)^{\gamma}, \qquad (1)$$

where $E_{Sym}(\rho_0)$ is the symmetry energy at normal nuclear matter density and γ is the stiffness factor specifying the strength of symmetry energy at densities away from the normal nuclear matter density.

*Electronic address: arungaur.ju@gmail.com

Results and discussions

In order to study the role of different density dependencies of symmetry energy on fragmentation pattern, we simulated thousands of events for the asymmetric collisions of ^{40}Ar + ^{64}Cu,^{108}Ag, ^{197}Au using soft equation of state supplemented by energy-dependent nucleon-nucleon cross-section reduced by 20%, i.e, σ^{nn} = 0.8 σ^{nn}_{free} for three different values of γ = 0.5, 1 and 2. The choice of colliding geometry and incident energies is guided from the experimental measurements [4]. As these reactions cover wide range of asymmetry (η = 0.2-0.6) and experimental measurements are also available, so we simulate these reactions to study the effect of different density dependencies of symmetry energy.

In Fig. 1, we display the (unfiltered) size of heaviest fragment (A^{max}) and yield of light charged particles (LCPs) for various (soft and stiff) density dependencies of symmetry energy. We notice that role of symmetry energy is clearly visible in highly asymmetric reactions (such as ^{40}Ar+^{108}Ag and ^{40}Ar+^{197}Au) compared to less asymmetric reaction of ^{40}Ar+^{64}Cu and moreover, stiff symmetry energy (solid triangles) leads to bigger A^{max} when compared to that with others (open triangles and circles). This happens because of greater repulsion provided by stiff symmetry energy ($\propto \rho^2$) and thus the number of binary collisions get reduced (by 10-15 %) and one observes a bigger A^{max} when compared to that obtained with other calculations corresponding to γ= 0.5 and 1. Similar trends were also observed in Ref. [5] for transverse flow. We also compare our present cal-

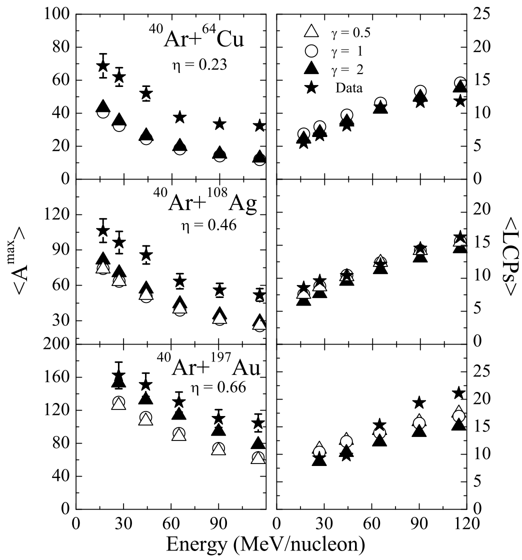

FIG. 1: Average mass of heaviest fragment (left panels) and multiplicities of light charged particles (right panels) as a function of incident energy for the central collisions of ^{40}Ar+^{64}Cu,^{108}Ag,^{197}Au. Experimental data is taken from Ref. [4] .

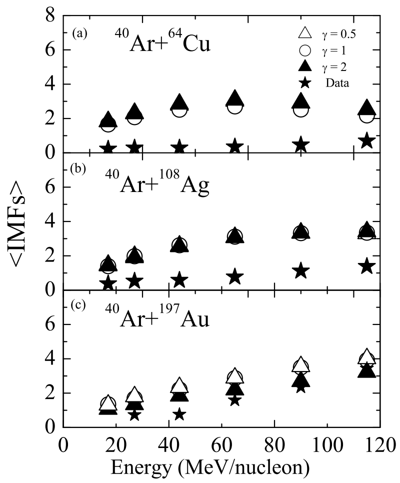

FIG. 2: Same as Fig. 1, but for IMFs.

culations with the experimental data of Ref. [4] and it has been found that stiffer symmetry energy is close to experimental data compared to softer one for highly asymmetric colliding nuclei. Note that the conclusion is in accordance with various other studies [6] where stiffer form of symmetry energy has been proposed at supra-saturation density region. The (unfiltered) yield of IMFs is plotted in Fig. 2 for the same mentioned reactions and one finds that for various forms of symmetry energy, yield changes differently. Interestingly, for less asymmetric reactions, one gets higher yield with stiff symmetry energy compared to softer one which gets reversed in case of highly asymmetric reactions of ^{40}Ar+^{197}Au (compare circles and solid triangles). This results because of significant compression in less asymmetric reaction of ^{40}Ar+^{64}Cu which, in turn, dissemble the system into various small/medium sized fragments. On the other hand, due to the less compression in highly asymmetric reactions, one observes a higher yield with soft symmetry energy (less repulsive) compared to stiffer one as now the soft symmetry energy will break the colliding systems into various fragments. Similar conclusions were also reported in Ref. [7]. Again comparison with data leads to stiffer symmetry energy for highly asymmetric colliding systems (see Fig. 2).

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