Role of equation of state in multifragmentation of asymmetric heavy-ion collisions

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Introduction

The breaking of colliding nuclei into various mass fragments and free nucleons is known as multifragmentation. The detailed experimental and theoretical studies reveal that fragmentaion is a complex process which depends crucially on reaction inputs as well as on colliding geometry of the reaction. Also, incident energy of the projectile beam, masses of colliding nuclei and their asymmetry η (where η = [(A_T-A_P)/(A_T+A_P)]; $A_{P/T}$ = mass of projectile/target nucleus) are the major factors governing the dynamics of a reaction. Multifragmentation has also been considered as a gateway to nuclear equation of state [1]. The knowledge about compressibility of nuclear matter (or in general about the nuclear equation of state [EOS]) isn't only relevant for nuclear physics but is of equal importance for understanding many astrophysical problems such as stability of neutron stars or dynamics of supernova explosions etc. Several experimental and theoretical attempts were made in the past to pin down the form of equation of state. Apart from the nature of the equation of state, its momentum dependence has also attracted lot of considerations as it is well known that the outcome of a reaction depends not only on the density but also on the momentum space [2]. With the help of theoretical tools, one is able to analyze the formation of fragments by employing variety of equations of state as well as its momentum dependence. The present study is focussed on the influence of different equations of state on the fragmentation of asymmetric collisions of ^{40}Ar (as projectile) on ^{64}Cu, ^{108}Ag and ^{197}Au (as targets) using isospin-dependent quantum molecular dynamics (IQMD) model.

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The Model

The isospin-dependent quantum molecular dynamics model [3] is a modified version of quantum molecular dynamics (QMD)[4] model. The IQMD model is a semi-classical model which describes heavy-ion collisions on an event by event basis. In IQMD model, the centroid of each nucleon propagates under the classical equations of motion,

$$\frac{d\vec{r_i}}{dt} = \frac{d\langle H\rangle}{d\vec{p_i}}; \quad \frac{d\vec{p_i}}{dt} = -\frac{d\langle H\rangle}{d\vec{r_i}}, \tag{1}$$

where H refers to the Hamiltonian and reads as

$$H = \sum_{i}^{A} \frac{p_i^2}{2m_i} + \sum_{ij}^{A}(V_{ij}^{Sky} + V_{ij}^{Yuk} + V_{ij}^{Coul} + V_{ij}^{mdi} + V_{ij}^{sym}), \tag{2}$$

where V_{ij}^{Sky}, V_{ij}^{Yuk}, V_{ij}^{Coul}, V_{ij}^{mdi}, and V_i^{sym} are, respectively, the Skyrme, Yukawa, Coulomb, momentum-dependent interactions (MDI), and symmetry potential. The details of the model are presented in Ref. [3].

Results and discussions

To address the influence of different equations of state in fragmentation pattern, we simulated thousands of events for the asymmetric collisions of ^{40}Ar + ^{64}Cu,^{108}Ag, ^{197}Au using static (Soft and Hard) as well as momentum-dependent (soft momentum-dependent [SMD] and hard momentum-dependent [HMD]) equations of state. The choice of colliding geometry and incident energies are guided from the experimental measurements [5]. As these reactions cover wide

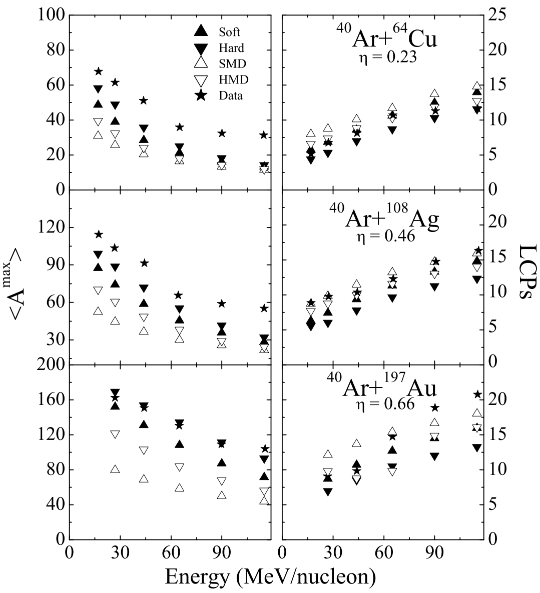

FIG. 1: Average mass of heaviest fragment (left panels) and multiplicities of light charged particles (right panels) as a function of incident energy for the central collisions of ^{40}Ar+^{64}Cu,^{108}Ag,^{197}Au. Experimental data is taken from Ref. [5] (preliminary results).

range of asymmetry (η = 0.2-0.6) and experimental measurements are also available so we simulate these reactions to study the role of equations of state. In Fig. 1, we display the calculated results using Soft, Hard, SMD and HMD equations of state for the average heaviest remanent ($<A^{max}>$)(left panels) and multiplicity of light charged particles ($2 \leq A \leq 4$) (right panels) along with the experimental data. We find that size of heaviest fragment decreases with beam energy with the corresponding increase in multiplicity of light charged particles indicating violence of collisions at higher energies. It is worth mentioning that $<A^{max}>$ is generated from spectator matter and hard equation of state being more repulsive yields a bigger $<A^{max}>$ compared to the one obtained using soft equation of state. From the figure, it is also clear that inclusion of momentum-dependent interactions (open symbols) lead to smaller $<A^{max}>$ and correspondingly higher multiplicity of light charged particles is observed for all reactions at different incident energies. This is because of the fact that static equations of state (soft and hard) don't destroy initial nucleon-nucleon correlations and therefore yield heavier $<A^{max}>$ compared to that obtained with the momentum-dependent (SMD and HMD) equations of state. As momentum-dependent interactions shatter the matter and thus, results in enhanced emission of free nucleons and light mass fragments. We also find a nice agreement with static equations of state throughout the energy range for all asymmetric reactions. A complete systematic study for various asymmetric reactions is still under process.

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