Investigation of nuclear stopping with system size at intermediate energies

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Introduction

The nuclear stopping provides a deep insight of the estimation of the nucleon densities and energies of the compressed nuclear matter at an early stage of the nuclear reaction and therefore is one of influential observable in heavy ion collisions. On the other hand, nuclear stopping controls the interplay between various phenomenons such as deep inelastic reactions, neck emission, and fusion reaction, the amount of dissipated energy and the amplitude of large collective motion[1]. It is an important tool to determine the consequence of the nuclear reaction and also helpful in determining the information on nucleon-nucleon (N-N)cross section, the Equation Of State (EOS) and the degree of equilibrium achieved in the heavy ion reactions[1, 2].
Nuclear stopping can be studied using various parameters like rapidity distribution[3], anisotropy ratio[4] and Quadrupole moment[4]. Out of these, the anisotropy parameter has been used to carry out the present work. The anisotropy ratio (R)[4] is defined as:

$$\langle R\rangle = \frac{2}{\pi}\frac{(\sum_i P_\perp(i))}{(\sum_i P_\parallel(i))}, \quad (1)$$

where, $P_\perp(i) = \sqrt{P_x^2(i)+P_y^2(i)}$ and $P_\parallel(i) = P_z(i)$. For a complete stopping, the value of R is expected to be unity.

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In the present work, we attempt to study the energy dependance of nuclear stopping by using the parameter anisotropic ratio for fragment phase space of variable mass reactions. Isospin-dependent quantum molecular dynamics (IQMD)model has been used to meet the objective of the study.

Methodology

In IQMD model[5], the isospin degree of freedom enters into the calculations via Symmetry potential, cross-sections and Coulomb interactions. The nucleons of target and projectile interact via two and three-body Skyrme forces, Yukawa potential and Coulomb interactions. In addition to the use of explicit charge states of all baryons and mesons, a symmetry potential between protons and neutrons corresponding to the Bethe-Weizsacker mass formula has been included.
In IQMD model, baryons are represented by wave packet

$$f_i(\vec{r},\vec{p},t) = \frac{1}{\pi^2\hbar^2}\cdot e^{-(\vec{r}-\vec{r_i}(t))^2\frac{1}{2L}}\cdot e^{-(\vec{p}-\vec{p_i}(t))^2\frac{2L}{\hbar^2}}. \quad (2)$$

The centeroids of these wave packets propagate using classical Hamilton equations of motion:

$$\frac{d\vec{r_i}}{dt} = \frac{\partial\langle H\rangle}{\partial p_i} \; ; \; \frac{d\vec{p_i}}{dt} = -\frac{\partial\langle H\rangle}{\partial r_i} \quad (3)$$

with

$$\begin{aligned}\langle H\rangle &= \langle T\rangle + \langle V\rangle \\ &= \sum_i \frac{p_i^2}{2m_i} + \sum_i\sum_{j>i}\int f_i(\vec{r},\vec{p},t)V^{ij}(\vec{r}',\vec{r}) \\ &\quad \times f_j(\vec{r}',\vec{p}',t)d\vec{r}d\vec{r}'d\vec{p}d\vec{p}'. \quad (4)\end{aligned}$$

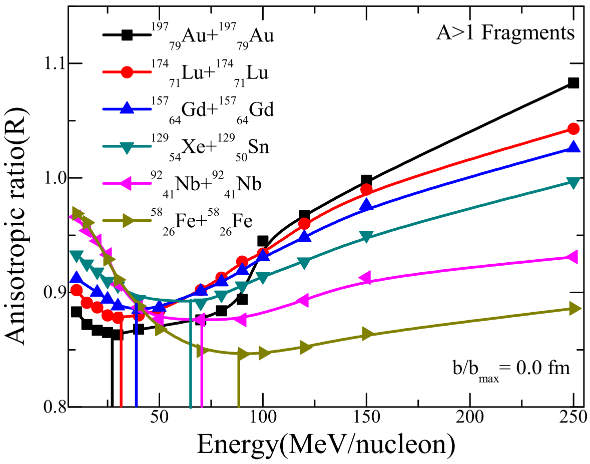

FIG. 1: Energy dependance of nuclear stopping for $A > 1$ fragments for different reactions at central collision for $-0.1 < Y_{c.m.}/Y_{beam} < 0.1$ mid rapidity range.

Results and Discussions

We have simulated the reactions of $^{197}_{79}Au + ^{197}_{79}Au$, $^{174}_{71}Lu + ^{174}_{71}Lu$, $^{157}_{64}Gd + ^{157}_{64}Gd$, $^{129}_{54}Xe + ^{129}_{50}Sn$, $^{92}_{41}Nb + ^{92}_{41}Nb$ and $^{58}_{26}Fe + ^{58}_{26}Fe$ at incident energy between 10 and 250 MeV/nucleon for central collisions (b/b_{max}=0.0 with $b_{max} = 1.12(A_P^{1/3} + A_T^{1/3})$, where A_P and A_T are the masses of projectile and target respectively) using soft equation of state.

In figure 1, the anisotropy ratio has been calculated for the fragment phase space of the above said systems. The same analysis has also been performed for nucleonic phase space (not shown here). It has been observed from this figure that the anisotropy ratio behaves differently at fermi energy and away from fermi energy range. The value of anisotropy ratio is decreased at the fermi energy and this fall in value of (R) has been observed at different points on the incident energy scale depending on the system size. However this energy dip is basically due to the reason that the longitudinal rapidity distribution of fragment phase space is broadened in comparison to the transverse rapidity distribution and the entrance channel effects are preserved which reduces the nuclear stopping. Also, at the Fermi energy, the lesser value of nuclear mean field is insufficient in stopping the two colliding nuclei[6].

The energy dip is also influenced by the system mass, more the mass of colliding nuclei lesser is the value of energy dip. This inverse behaviour is also dominated by the Pauli blocking and the heavier fragments having mass comparable to mass of parent nuclei are emitted, which are difficult to stop. However, lighter nuclei achieves higher value of energy dip due to their size. At higher energies, the size of the system and the nucleon mean free path govern the N-N collisions. Larger the colliding system, the more will be the N-N collisions and therefore the larger is the value of stopping power as confirmed by the observation at E=250 MeV/nucleon[7].

The detailed work in this direction is in progress.

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