Phase space analysis of nuclear stopping due to fragments

Mandeep Kaur,* Kamaldeep Kaur, and Suneel Kumar
School of Physics and Materials Science,
Thapar University, Patiala - 147001, Punjab (INDIA)

Introduction

The study of nuclear stopping in the past few years makes it a topic of considerable interest. Nuclear stopping governs most of the dissipated energy during the collision of heavy ions. Thus it can provide important information about the nuclear equation of state under the extreme conditions of temperature, pressure and density. Recently, nuclear stopping due to fragment phase space has been studied by Zhang et al. [1]. It was observed that the stopping due to fragments is responsible for the lesser nuclear stopping at low incident energies. Because at low energies, two-body collisions between nucleons is greatly suppressed due to Pauli blocking and mean field governs the Heavy-ion collision process, while at higher energy, two-body collision plays the dominant role and most of the nucleons suffer violent collisions and get excited to become free. In this case, the fragment phase space tends to get closer to the nucleon phase space. However, the reason for large value of nuclear stopping at low incident energies followed by a minima around the Fermi energy is yet to be fully explored. In the present study, nuclear stopping due to fragments is studied by analysing the phase space of fragments at different incident energies. The simulations are carried out by using the isospin-dependent quantum molecular dynamics (IQMD) model explained in the next section.

Methodology

In Isospin dependent quantum molecular dynamic model (IQMD)[2] neutrons and protons are treated separately and the charged states of nucleons, deltas and pions are treated explicitly. In IQMD model baryons are represented by Gaussian shaped density distributions as

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

The hadrons propagate using Hamiltonian equations of motion.

$$\frac{d\vec{r_i}}{dt} = \frac{d\langle\ H\ \rangle}{d\vec{p_i}} \ ; \ \frac{d\vec{p_i}}{dt} = -\frac{d\langle\ H\ \rangle}{d\vec{r_i}}, \quad (2)$$

where,

$$\begin{aligned}\langle\ H\ \rangle &= \langle\ T\ \rangle + \langle\ V\ \rangle \\ &= \sum_i \frac{p_i^2}{2m_i} + \sum_i\sum_{j>i}\int f_i(\vec{r},\vec{p},t)V^{ij}(\vec{r}\,',\vec{r}) \\ &\quad \times f_j(\vec{r}\,',\vec{p}\,',t)d\vec{r}d\vec{r}\,'d\vec{p}d\vec{p}\,'. \quad (3)\end{aligned}$$

$$V^{ij} = V^{ij}_{Skyrme} + V^{ij}_{Yukawa} + V^{ij}_{Coul} + V^{ij}_{mdi} + V^{ij}_{sym}$$

Two nucleons are supposed to suffer a binary collision if the distance between their centroids

$$|\vec{r_i} - \vec{r_j}| \le \sqrt{\sigma_{tot}/\pi} \quad (4)$$

$$\sigma_{tot} = \sigma(\sqrt{s}, type) \quad (5)$$

"type" denotes the ingoing collision partners(N-N,N-Δ,N-π etc.)

Results

For the present analysis, the phase space of single event is analysed for the central collision of the reaction $^{124}_{50}$Sn+$^{124}_{50}$Sn. Simulations were carried out for incident energies 30 MeV/nucleon, 50 MeV/nucleon, 80 MeV/nucleon and 400 MeV/nucleon. A soft equation of state has been employed. The phase space of nucleons is analysed by using

*Electronic address: mandeep062000@gmail.com

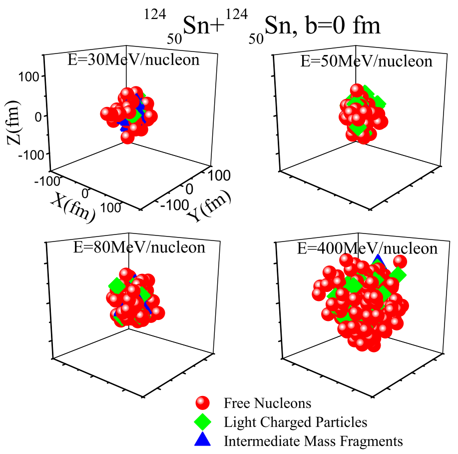

FIG. 1: Phase space of free nucleons (FN), light charge particles (LCP) and intermediate mass fragment (IMF) at different incident energies for central collision of the reaction $^{124}_{50}$Sn+$^{124}_{50}$Sn

MST method [3]. It is clear from the figure that the phase space of nucleons is confined at 30 MeV/nucleon and heavy mass fragments are produced in contrary to the production of free nucleons and light charge particles. With increase in incident energy, the intermediate mass fragments break into fragments of mass lesser than the mass of intermediate mass fragment. At low value of incident energy, the dominant behaviour of mean field block the nucleon-nucleon collisions. This result in large nuclear stopping at low incident energy. With increase in incident energy, the role of Pauli blocking becomes less important and the value nuclear stopping starts decreasing upto a certain value of incident energy. Above this energy, the the nuclear stopping again increases due to increase in binary nucleon-nucleon collisions. Due to violent nucleon-nucleon collisions at 400 MeV/nucleon, isotropic distribution of nucleons is observed in the phase space. This results in maximum value of nuclear stopping. Since, no specific conclusion can be drawn from the phase space of fragments, further investigation in this direction is in progress.

Acknowledgment

This work is supported by the grant from UGC, Govt. of India [Grant No. F1-17.1/2012-13/ MANF-2012-13-SIK-PUN-9214]

References

[1] G. Q. Zhang *et. al.*, Phys. Rev. C **84** 034612 (2011)

[2] C. Hartnack *et. al.*, Eur. Phys. J. **A 1**, 151 (1998); C. Hartnack *et. al.* Phys. Rep. **510**, 119 (2012).

[3] J Aichelin *Phys. Rep.* **202** 233 (1991)