Influence of in-medium effects via nucleon-nucleon scattering cross-section on transverse flow and nuclear stopping

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Introduction

Various observables at intermediate energies such as collective transverse flow (and its disappearance), fragmentation, nuclear stopping etc. have been proved to be the promising ones in determining the nuclear compressibility and scattering cross-section which is one of the goals of present day nuclear physics. Out of the above mentioned observables, the energy of vanishing flow (incident energy where transverse in-plane flow vanishes) and nuclear stopping are the most sensitive ones to the scattering cross-section and therefore major studies have been done on these to investigate the nucleon-nucleon (NN) cross-section. In the literature, a variety of cross-sections have been used by various authors. For example, in Ref. [1] the transverse flow was studied by taking constant cross-section. But it is well known that free NN cross-section changes rapidly with energy [2]. So, with the time, energy-dependent NN cross-section was implemented in theoretical tools. Later on, it was also proposed to take in-medium effects in the cross-section. These in-medium effects are incorporated by imposing reduction factor to the cross-section. This reduction factor is supposed to be around 20% when various theoretical results are compared with experimental data [3]. It is also argued that this reduction factor should also depend on the density of the nuclear medium as cross-section should enhance in low density nuclear matter [4]. Still no consensus has been obtained that whether one should take density-dependent reduced cross-section or constant reduced one to incorporate in-medium effects. So, here we aim to see the influence of in-medium effects on transverse flow and nuclear stopping by incorporating the same through constant reduction and density-dependent reduction in the NN cross-section. The present study is carried out using isospin-dependent quantum molecular dynamics (IQMD) model, the details of which can be found in Ref. [5].

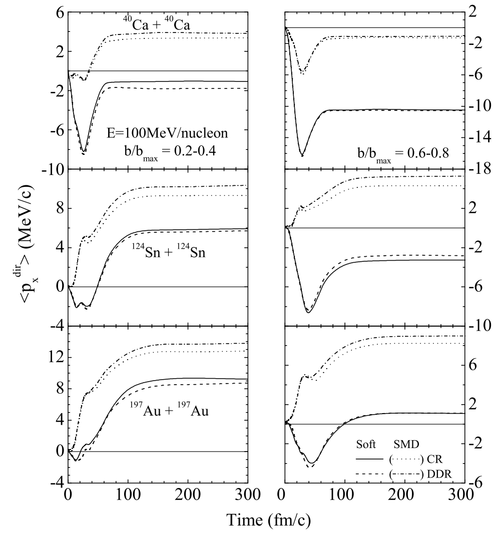

FIG. 1: The time evolution of directed transverse flow $\langle p_x{}^{dir}\rangle$ with soft and SMD EOS for CR and DDR cross-sections at central (left panels) and peripheral (right panels) collisions of ^{40}Ca+^{40}Ca, ^{124}Sn+^{124}Sn and ^{197}Au+^{197}Au (preliminary results).

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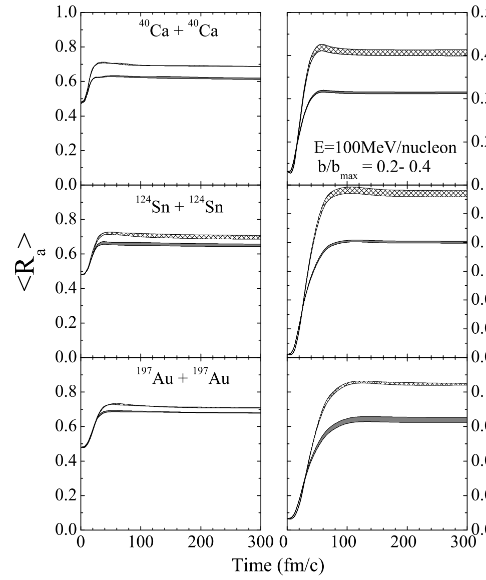

FIG. 2: The time evolution of anisotropy ratio $\langle R_a \rangle$ (left panels) and quadrupole moment $\langle 1/Q_{ZZ} \rangle$ (right panels) with soft and SMD EOS for CR and DDR cross-sections for central collisions of $^{40}Ca+^{40}Ca$, $^{124}Sn+^{124}Sn$ and $^{197}Au+^{197}Au$ (preliminary results).

Results and discussion

We simulated the reactions of $^{40}Ca+^{40}Ca$, $^{124}Sn+^{124}Sn$ and $^{197}Au+^{197}Au$ at an incident energy of 100 MeV/nucleon with b/b_{max}=0.2-0.4 and 0.6-0.8. We used a soft equation of state with and without momentum-dependent interactions labeled as SMD and Soft, respectively. The parameterized form of the density-dependent reduced cross-section is:

$$\sigma = \sigma_{free}(1 - \alpha\frac{\rho}{\rho_0}), \qquad (1)$$

where α is the reduction factor and σ_{free} is free NN cross-section. We have used two choices of reduced cross-section; constant reduction ($0.8\sigma_{free}$, labeled as CR) and density-dependent reduction (α=0.2, labeled as DDR).

In Fig. 1, we display the time evolution of transverse flow $\langle p_x{}^{dir} \rangle$ for central (left panels) and peripheral (right) collisions. The solid (dotted) and dashed (dash-dotted) lines represent the calculations using soft (SMD) EOS with CR and DDR cross-sections, respectively. We find that with soft EOS, $\langle p_x{}^{dir} \rangle$ for CR is higher compared to that with DDR cross-section. This is due to the reduced magnitude of DDR cross-section compared to CR as higher densities (ρ/ρ_0>1) are achieved in central collisions and effective reduction increases in DDR cross-section. However, opposite behavior is observed with SMD EOS (where $\langle p_x{}^{dir} \rangle$ is higher with DDR cross-section). This happens because of repulsive nature of the momentum-dependent interactions and lower densities (ρ/ρ_0<1) are achieved with SMD EOS which makes effective DDR cross-section more than CR cross-section and leads to enhancement in flow.

In Fig. 2, we display the time evolution of nuclear stopping described in terms of anisotropy ratio $\langle R_a \rangle$ and quadrupole moment $\langle 1/Q_{ZZ} \rangle$. The crossed and full areas represent the calculations using soft and SMD EOS, respectively. From the figure, we notice that better equilibrium is achieved with static EOS compared to that involving momentum-dependent interactions. Moreover, the difference between soft and SMD EOS is more visible at peripheral collisions where momentum-dependent interactions play a significant role. We also notice an insignificant effect of CR and DDR cross-sections on thermalization.

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