Comparison of the density-dependent and constant reduction of the cross-section on the nuclear dynamics at intermediate energies

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Introduction

The ultimate goal of nuclear physics community at intermediate energies is to understand the nuclear equation of state (EoS) as well as in-medium nucleon nucleon (nn) cross-section. A considerable progress has been made in determining the EoS of nuclear matter, however strength of in-medium nn cross-section has still been a topic of debate [1–4]. In the literature a variety of cross-section have been used by various authors according to the need of the their studies. At the same time comparisons of different types of cross-sections has also been made. Kumar *et. al.* [1] carried out the analysis of constant, energy-dependent Cugnon and G-matrix cross-section by taking collective flow as a probe. Also in an another study, they found effect of different nn cross-section on the muntiplicity of IMF's over the whole range of energy and colliding geometry [2]. Zhang and Li [3] showed the sensitivity of elliptical flow towards the different density-dependent reductions of the cross-section and also expressed the need of 40 % density dependent reduction to reproduce experimental elliptical flow excitation function. Recently Jain *et. al.* [4] showed the strong sensitivity of isospin-dependence of cross-section on the elliptic flow and nuclear stopping using IQMD model. In this context the energy of vanishing flow (EVF) is found to be good probe to gather the information about nn cross-section, as it is more sensitive to the cross-section compared to different nuclear equation of states. In this direction theoretical studies with different transport models using different EoS along with a variety of cross-sections are being made to explain the experimental data. The experimental mass dependence of balance energy was reproduced by Westfall *et al.* [5] and Magestro *et al.* [6] by using soft EoS along with 20% density-dependent reduction of the cross-section. Recently, we reproduced the mass dependence of balance energy for more wider range using 20% constant reduction of the cross-section with SMD EoS [7]. Nowhere in the literature, the discussion of constant reduction of the cross-section and density-dependent reduction of the cross-section has been done simultaneously. Here we aim to compare the role of density-dependent reduction of the cross-section as well as constant reduction of the cross-section on the mass dependence of the balance energy throughout the mass range between 48-270 using IQMD model [4].

Results and discussion

For the present study, we simulated several thousands of events of each reaction at incident energies around E_{bal} in small steps of 10 MeV/nucleon. In particular, we simulated the reactions ^{24}Mg + ^{24}Mg, ^{58}Cu + ^{58}Cu, ^{72}Kr + ^{72}Kr, ^{96}Cd + ^{96}Cd, ^{120}Nd + ^{120}Nd and ^{135}Ho + ^{135}Ho, having N/Z = 1.0. We used soft equation of state (with and without momentum dependence) along with $\sigma = 0.8\sigma_{free}$ as well as with 20% density-dependent reduction of cross-section given by

$$\sigma = (1 - \alpha\rho/\rho_0)\sigma_{free}. \quad (1)$$

The reactions were followed till the transverse

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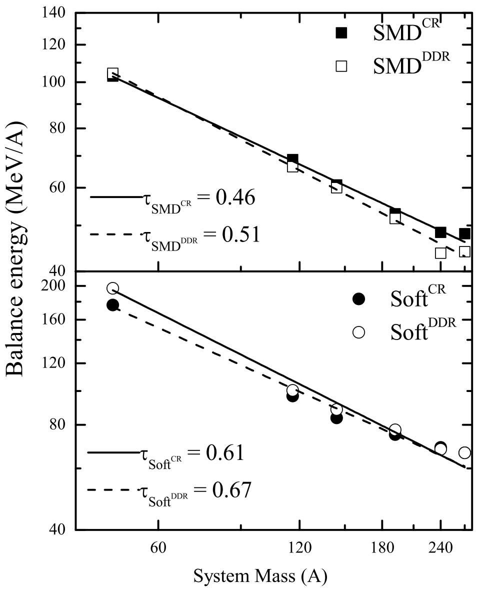

FIG. 1: Mass-dependence of EVF using SMD (upper panel) and soft (lower panel) equation of state. Different lines corresponds to different options of the cross-section.

in-plane flow saturates. The saturation time varies between 150 fm/c (for lighter colliding nuclei such as ^{24}Mg + ^{24}Mg) and 300 fm/c (for heavier colliding nuclei such as ^{135}Ba + ^{135}Ba) depending upon the mass of colliding pair. A straight line interpolation is used to calculate the energy of vanishing flow.

In Fig. 1(a), we display the mass dependence of the balance energy, calculated using SMD EoS state along with both options of the cross-section (constant 20% reduction as well as with density-dependent 20% reduction). From the figure, we see that both the options with SMD EoS results in same EVF in case of lighter colliding pairs, whereas the difference in the energies of vanishing flow starts appearing as we move towards the heavier side. We also see that density-dependent reduced cross section results in the lower EVF as compared to constant reduced cross-section. This is because of the reason that density achieved in the heavier system is less than one (as lower incident energies and MDI are involved), which in turn result in less reduction of cross-section. We also know that increase in cross-section results in more transverse flow and hence leads to lower EVF. In Fig 1(b), we did the same analysis but with soft EoS. We see that balance energies calculated using different cross-section are different for lighter cases, whereas difference disappears as we move to heavier side (contradictory to that observed in Fig. 1). This is due to the absence of momentum-dependent interactions (repulsive in nature) in these calculations. In Fig 1(a), momentum dependence of mean field especially in, lighter systems does not let the density achieved to be greater than one, whereas in the present case, absence of MDI leads to achievement of higher density (i.e. $\rho/\rho_0 > 1$) and leads to the greater reduction of cross-section compared to 20% which in turn will increase the energy of vanishing flow. On the other hand, in the heavier systems, density achieved in the reaction is almost equals to that of normal nuclear matter density, hence leads to only 20% reduction of cross-section that's why we did not see any difference in the EVF calculated using constant reduced cross-section and as well as with density-dependent reduced cross-section.

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