Effect of isospin dependence of cross section on symmetric and neutron rich systems

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Introduction

The existing and upcoming radioactive ion beam (RIB) facilities lead a way in exploring the role of isospin degree of freedom in both nuclear physics and astrophysics. The ultimate goal of such studies is to extract information on the isospin dependence of in-medium nuclear effective interactions as well as equation of state (EOS) of isospin asymmetric nuclear matter. The later quantity especially the symmetry energy term is important for both nuclear physics and astrophysics community. Heavy-ion collisions induced by neutron rich beams provide unique opportunities to investigate the isospin-dependent properties of asymmetric nuclear matter, particularly the density dependence of symmetry energy [1]. Experimentally symmetry energy is not a directly measurable quantity and has to be extracted from observables related to symmetry energy. It has also been shown in ref [2, 3] that the collective transverse in-plane flow and its disappearance is sensitive to the various isospin effect like Coulomb repulsion, symmetry energy, isospin dependence of cross section and there is a complex interplay among above mentioned reaction mechanisms. In refs. [2, 3], it was also shown that the Coulomb repulsion dominates over the symmetry energy in isospin effects on collective flow. Sood [4] studied the disappearance of flow i.e. balance energy E_{bal} for isotopic series of Ca with N/Z varying from 1 to 2 i.e. $^{40}Ca +^{40} Ca$ to $^{60}Ca +^{60} Ca$ and found that N/Z dependence of E_{bal} is sensitive not only to symmetry energy but its density dependence as well. Here we aim to explore the effect of isospin dependence of cross section on symmetric and neutron rich system. We also aim to explore whether the analysis is affacted if one discusses in terms of "E_{bal} as a function of N/Z or N/A" of the system.

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Results and Discussion

Using IQMD model [5] we have simulated several thousand events at incident energies around balance energy in small steps of 10 MeV/nucleon for each isotopic system of Ca+Ca having N/Z (N/A) varying from 1.0 to 2.0 (0.5-0.67) for the semicentral colliding geometry range of 0.2 - 0.4. For the transverse flow, we use the quantity "*directed transverse momentum* $\langle p_x^{dir}\rangle$" which is defined as [4]

$$\langle p_x^{dir}\rangle = \frac{1}{A}\sum_{i=1}^{A} sign\{y(i)\}p_x(i), \qquad (1)$$

where $y(i)$ is the rapidity and p_x(i) is the momentum of i^{th} particle. The rapidity is defined as

$$Y(i) = \frac{1}{2}\ln\frac{\mathbf{E}(i) + \mathbf{p}_z(i)}{\mathbf{E}(i) - \mathbf{p}_z(i)}, \qquad (2)$$

where $\mathbf{E}(i)$ and $\mathbf{p}_z(i)$ are, respectively, the energy and longitudinal momentum of i^{th} particle. In fig. 1(a) we display the E_{bal} as a function of N/Z of the system. Solid green circles represent the calculated E_{bal}. Lines are the linear fit to E_{bal}. We see that E_{bal} follows a linear behavior $\propto$ m∗N/Z. As the N/Z of the system increases, the mass of the system increases due to addition of neutron content. In addition, the effect of symmetry energy also increases with increase in N/Z. To check the relative contribution of increase in mass with N/Z and symmetry energy towards the N/Z dependence of E_{bal}, we make the strength of symmetry energy zero and calculate E_{bal}. The results are displayed by open circles in fig. 1(a). E_{bal} again follows a linear behavior $\propto$ m∗N/Z. However, E_{bal} decreases very slightly with increase in N/Z, whereas when we include the symmetry energy also in our calculations then the $\mid m \mid$ increases by 3 times which shows that N/Z dependence of E_{bal} is highly sensitive to the symmetry energy. To explore the effect of isospin dependence of cross section (i.e. $\sigma_{nP} = 3\sigma_{nn} = 3\sigma_{pP}$), we switch off the symmetry energy and also make the cross section isospin independent (i.e. $\sigma_{np} = \sigma_{nn}$ and calculate E_{bal} for two extreme N/Z. The results are displayed in fig. 1(a) by open squares. Again E_{bal} follows a linear behavior. We see that the E_{bal} for both ^{40}Ca + ^{40}Ca and ^{60}Ca + ^{60}Ca increases as expected. However, the increase in E_{bal} for system with N/Z = 1 is more as compared to the system with N/Z = 2. This is because with increase in N/Z the neutron number increases due to which neutron-neutron and neutron-proton collisions pairs increase. However, the increase in number of neutron-neutron collision pairs is much larger as compared to neutron-proton collision pairs. Therefore, the possibility of neutron-proton collision is much less in system with N/Z = 2. Therefore the effect of isospin dependence of cross section decreases with increase in N/Z.

In fig. 1(b), we display the E_{bal} as a function of N/A of the system. Symbols have same meaning as in fig. 1(a). Again E_{bal} follows a linear behaviour with m = -191 and -68, respectively, for F_1 (u) and F_4 where F_1 (u) represents symmetry energy $\propto \frac{\rho}{\rho_0}$ and F_4 represent calculations without symmetry energy. However, the percentage difference ΔE_{bal} % (where $\Delta E_{bal} \% = \frac{E_{bal}^{F_1(u)} - E_{bal}^{F_4}}{E_{bal}^{F_1(u)}}$) is same (about 65%) in both the figs. 1(a) and 1(b) which shows that the effect of symmetry energy is on N/Z dependence of E_{bal} is same whether we discuss in terms of N/Z or N/A.

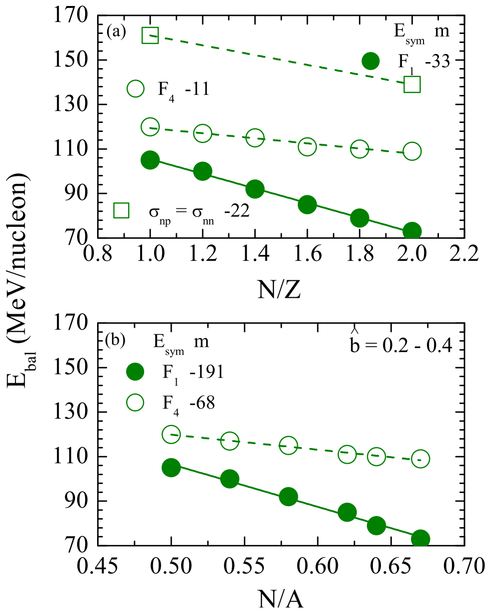

FIG. 1: E_{bal} as a function of N/Z (upper panel) and N/A (lower panel) of system for $E_{sym} \propto F_1(u)$ and F_4. Lines are linear fit proportional to m. Various symbols are explained in the text.

Acknowledgments

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