Isospin effects in the disappearance of flow as a function of colliding geometry

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Introduction

With the availability of radioactive ion beam (RIB) facilities, one has possibility to study the properties of nuclear matter under the extreme conditions of isospin asymmetry. Heavy-ion collisions induced by the neutron rich matter provide a unique opportunity to explore the isospin dependence of in-medium nuclear interactions, since isospin degree of freedom plays an important role in heavy-ion collisions through both nuclear matter equation of state (EOS) and in-medium nucleon-nucleon (nn) cross-section. After about three decades of intensive efforts in both nuclear experiments and theoretical calculations, the equation of state of isospin symmetric matter is now relatively well determined. The effect of isospin degree of freedom on the collective transverse in-plane flow as well as on its disappearance [1] (there exists a particular incident energy called *balance energy* (E_{bal}) or *energy of vanishing flow* (EVF) at which transverse in-plane flow disappears) has been reported in the literature [2, 3], where it was found that neutron-rich systems have higher E_{bal} compared to neutron-deficient systems at all colliding geometries varying from central to peripheral ones. The effect of isospin degree of freedom on E_{bal} was found to be much more pronounced at peripheral colliding geometries compared to central ones. Since colliding geometry has a significant role in the isospin effects so here we aim to understand the isospin effects in E_{bal} as well as on its mass dependence over full range of colliding geometry varying from central to peripheral ones. The present study is carried out within the framework of isospin-dependent quantum molecular dynamics (IQMD) model [4].

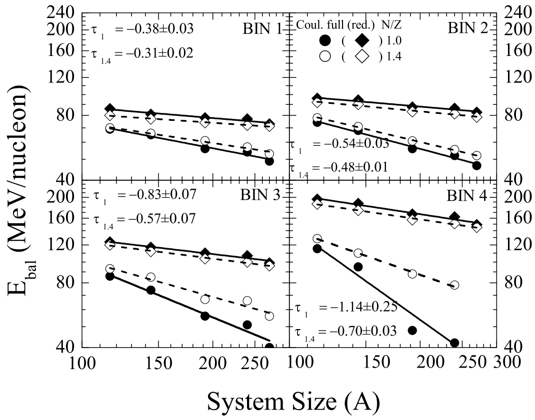

FIG. 1: E_{bal} as a function of combined mass at different impact parameter bins.

Results and discussion

We have simulated the reactions of $^{24}Mg+^{24}Mg$, $^{58}Cu+^{58}Cu$, $^{72}Kr+^{72}Kr$, $^{96}Cd+^{96}Cd$, $^{120}Nd+^{120}Nd$, $^{135}Ho+^{135}Ho$, having N/Z = 1.0 and reactions $^{24}Ne+^{24}Ne$, $^{58}Cr+^{58}Cr$, $^{72}Zn+^{72}Zn$, $^{96}Zr+^{96}Zr$, $^{120}Sn+^{120}Sn$, and $^{135}Ba+^{135}Ba$, having N/Z = 1.4, respectively. The colliding geometry is divided into four impact parameter bins of $0.15 < \hat{b} < 0.25$ (BIN 1), $0.35 < \hat{b} < 0.45$ (BIN 2), $0.55 < \hat{b} < 0.65$ (BIN 3), and $0.75 < \hat{b} < 0.85$ (BIN 4), where $\hat{b} = b/b_{max}$. Figure 1 displays the mass dependence of E_{bal} for these impact parameter bins. The solid (open) circles indicate E_{bal} for systems with lower

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(higher) neutron content. E_{bal} follows a power law behavior $\propto A^{\tau}$ for both N/Z = 1 and 1.4 at all colliding geometries. Isospin effects are clearly visible as neutron-rich system has higher E_{bal} throughout the mass range. The magnitude of isospin effects increases with increase in the impact parameter and mass of the system for a given impact parameter bin. One also sees that the difference between $\tau_{1.0}$ and $\tau_{1.4}$ increases with increase in the impact parameter. The solid (open) diamonds represent E_{bal} calculated with reduced Coulomb calculations for systems with lower (higher) neutron content. Lines are power law fit $\propto A^{\tau}$. The values of $\tau_{1.0}$ ($\tau_{1.4}$) are -0.17$\pm$ 0.02 (-0.14$\pm$ 0.01), -0.17$\pm$ 0.02 (-0.19$\pm$ 0.02), -0.24$\pm$ 0.03 (-0.26$\pm$ 0.01), and -0.31$\pm$ 0.03 (-0.29$\pm$ 0.02) for BIN 1, BIN 2, BIN 3, and BIN 4, respectively. Interestingly, we find that the magnitude of isospin effects is now nearly same throughout the mass range and also throughout the range of colliding geometry. We also see that the enhancement in the E_{bal} (by reducing Coulomb) is more at higher impact parameter compared to lower one for a given mass and also the enhancement in the E_{bal} is more in heavier systems as compared to lighter systems for a given bin. Moreover, throughout the mass range and range of colliding geometry, the neutron-rich systems have less E_{bal} as compared to neutron-deficient systems when we reduce the Coulomb [5]. This trend is quite the opposite to the one which we have when we have full Coulomb. This clearly shows that the enhancement in the isospin effects at peripheral colliding geometries is due to the Coulomb potential.

In figs. 2a, 2b, and 2c, we display E_{bal} as a function of $\hat{b}$ for masses 116, 192, and 240, respectively, for both full and reduced Coulomb. Symbols have the same meaning as in the fig. 1. Form the figure, we find that:(i) for a given mass (eg. A=116), the difference between E_{bal} for systems with different N/Z (in case of reduced Coulomb) remains almost constant throughout the range of colliding geometries which indicates that the effect of symmetry energy is uniform throughout the range of $\hat{b}$.

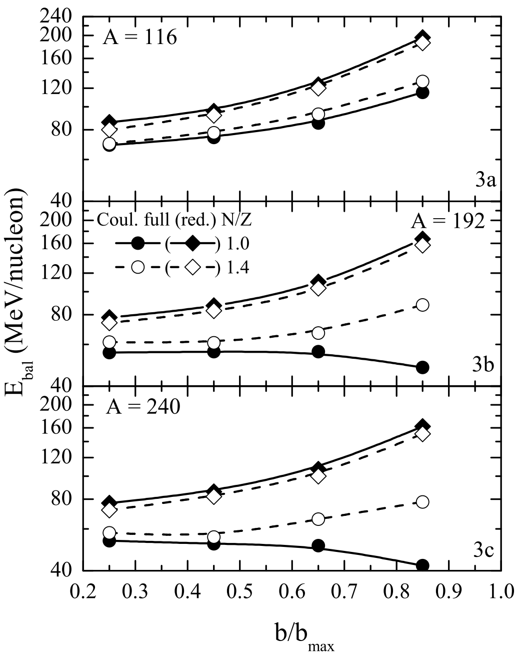

FIG. 2: E_{bal} as a function of impact parameter for different colliding masses.

(ii) Comparing figs. 2a, 2b, and 2c, one finds that for a given $\hat{b}$, the difference between E_{bal} for systems having different N/Z remains constant throughout the mass range also which indicates that the effect of symmetry energy is uniform throughout the mass range as well.

Acknowledgments

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References

[1] D. Krofcheck *et al.*, Phys. Rev. Lett. **63**, 2028 (1989).

[2] R. Pak *et al.*, Phys. Rev. Lett. **78**, 1026 (1997).

[3] S. Gautam *et al.*, J. Phys. G:Nucl. Part. Phys. **37**, 085102 (2010).

[4] C. Hartnack *et al.*, Eur. Phys. J. A **1**, 151 (1998).

[5] S. Gautam and A. D. Sood, Phys. Rev. C **82**, 014604 (2010).