Energy of vanishing flow: mass-isospin dependence

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Introduction

The investigation of the system size effects in various phenomena of heavy-ion collisions has attracted a lot of attention. The collective transverse in-plane flow which reflects the competition between attractive and repulsive interactions has been found to depend strongly on the combined mass of the system [1]. The energy dependence of the collective transverse in-plane flow has led us its disappearance at the balance energy (E_{bal}) [2]. A power law mass dependence ($\propto A^{\tau}$) of E_{bal} also has been reported [3]. Earlier power law parameter τ was supposed to be close to -1/3 [3], whereas recent studies showed a deviation from the above-mentioned power law [4] where τ was close to -0.45. With the availability of high intensity radioactive beams at many facilities, the effects of isospin degree of freedom in nuclear reactions can be studied in more details over a wide range of masses at different incident energies and colliding geometries. In the present work, we aim to study the effect of isospin degree of freedom on the E_{bal} throughout the mass range. As reported in the literature, the isospin dependence of collective flow has been explained as the competition among various reaction mechanisms, such as nucleon-nucleon (nn) collisions, symmetry energy, surface property of the colliding nuclei, and Coulomb force. The relative importance among these mechanisms is not yet clear. In the present study, we aim to shed light on the relative importance among the above-mentioned reaction mechanisms.

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The model

In the IQMD model [5],the propagation is governed by the classical equations of motion:

$$\dot{\mathbf{r}}_i = \frac{\partial H}{\partial \mathbf{p}_i}; \; \dot{\mathbf{p}}_i = -\frac{\partial H}{\partial \mathbf{r}_i}, \qquad (1)$$

where H stands for the Hamiltonian which is given by:

$$H = \sum_i^A \frac{\mathbf{p}_i^2}{2m_i} + \sum_i^A (V_i^{Sk} + V_i^{Yu} + V_i^{Cou} + V_i^{mdi} + V_i^{sym}). \qquad (2)$$

The V_i^{Sk}, V_i^{Yu}, V_i^{Cou}, V_i^{mdi}, and V_i^{sym} are, respectively, the Skyrme, Yukawa, Coulomb, momentum dependent interactions (MDI), and symmetry potentials. The final form of the potential reads as [6]

$$U^{mdi} \approx t_4 ln^2[t_5(\mathbf{p_1}-\mathbf{p_2})^2+1]\delta(\mathbf{r_1}-\mathbf{r_2}). \qquad (3)$$

Here $t_4 = 1.57$ MeV and $t_5 = 5\times10^{-4} MeV^{-2}$. A parameterized form of the local plus MDI potential is given by

$$U = \alpha(\frac{\rho}{\rho_0}) + \beta(\frac{\rho}{\rho_0})^{\gamma} + \delta ln^2[\epsilon(\rho/\rho_0)^{2/3}+1]\rho/\rho_0. \qquad (4)$$

The parameters α, β, γ, δ, and ϵ are listed in Ref. [6].

Results and discussion

We have simulated the reactions ^{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

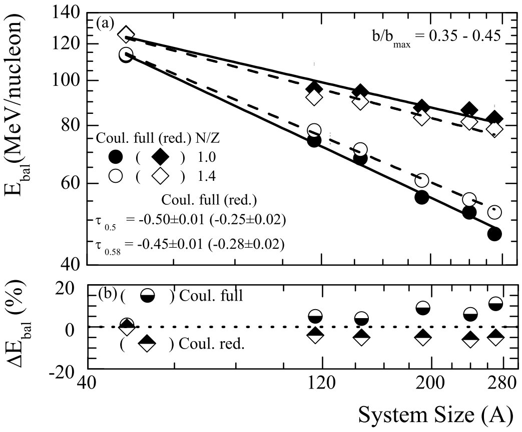

FIG. 1: (a) E_{bal} as a function of combined mass of system. (b) The percentage difference $\Delta E_{bal}(\%)$ as a function of combined mass of system. Solid (open) symbols are for N/Z = 1.0 (1.4).

N/Z = 1.4, respectively at semicentral impact parameter range 0.35 - 0.45. A soft equation of state along with anisotropic standard isospin and energy dependent nucleon-nucleon cross section $\sigma = 0.8\ \sigma_{NN}{}^{free}$ [7] is being used. In Fig. 1(a), we display the E_{bal} as a function of combined mass of the system for the two sets of isobars. The solid and open circles represent the E_{bal} for systems with less and more neutron content, respectively. The calculated E_{bal} fall on the line that is a fit of power law nature ($\propto A^{\tau}$), where τ = -0.45 $\pm$ 0.01 and -0.50 $\pm$ 0.01 for N/Z = 1.4 and 1.0, respectively. The different values of τ for two curves can be attributed to the larger role of Coulomb force in the case of systems with more proton content. Our value of $\tau_{1.4}$ is equal/close to the value -0.45/-0.42 in Ref. [**?**] both of which show deviation from the standard value $\simeq$ -1/3 where analysis was done for lighter mass nuclei only ($\leq$ 200). However, for heavier systems, τ increased to -0.45 [**?**], suggesting the increasing importance of Coulomb repulsion. This indicates that the difference in the E_{bal} for a given pair of isobaric systems may be dominantly due to the Coulomb potential. To demonstrate the role of Coulomb, we have calculated the E_{bal} with Coulomb being reduced by a factor of 100. The results are displayed in Fig. 1(a) with solid and open diamonds representing systems with less and more neutron content, respectively. One can clearly see the dominance of Coulomb repulsion in both the mass dependence as well as in isospin effects. The value of $\tau_{1.4}$ and $\tau_{1.0}$ are now, respectively, -0.28 $\pm$ 0.02 and -0.25 $\pm$ 0.02. Now with reduced Coulomb, the systems with more neutron content have less E_{bal}. This is because of the fact that the reduced Coulomb repulsion leads to higher E_{bal}. So the density achieved during the course of the reaction will be more due to which the impact of the repulsive symmetry energy will be more in neutron-rich systems, which in turn leads to less E_{bal} for neutron-rich systems and hence to the opposite trend for $\tau_{1.4}$ and $\tau_{1.0}$ for two different cases. In Fig. 1(b), we display the percentage difference $\triangle E_{bal}(\%)$ between the systems of isobaric pairs as a function of combined mass of system where $\triangle E_{bal}(\%) = \frac{E_{bal}^{1.4} - E_{bal}^{1.0}}{E_{bal}^{1.0}} \times 100$. From figure, we see that the percentage difference between the two masses of a given pair is larger for heavier masses as compared to the lighter ones. However, this trend is not visible when we reduce the Coulomb (diamonds).

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