N/Z dependence of balance energy throughout the colliding geometries

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Introduction

Heavy-ion reactions are unique means to produce in terrestrial laboratories hot neutron-rich matter similar to those existing in many astrophysical situations. The rapid advances in technologies to accelerate radioactive beams provide a great opportunity to explore the properties and equation of state (EOS) of such asymmetric neutron-rich matter. As a result of such advancements, studies on the role of isospin degree of freedom have recently attracted much attention. These detailed studies of isospin degree of freedom in nuclear reactions provide valuable probes of the different formulation of nuclear EOS and specially its isospin-dependent part. Therefore, the new challenge is to determine the EOS of asymmetric nuclear matter and in particular the symmetry energy. In recent past a large number of variables have been proposed which show sensitivity to symmetry energy [1]. For example, in the low density region, i.e. at density below the saturation density, isospin diffusion, isoscaling parameter, neutron to proton ratio, neutron skin thickness have been found to be sensitive to symmetry energy. On the other extreme, in high density region, at densities above the saturation density, π^+/π^- ratio, neutron-proton differential flow show sensitivity to symmetry energy. In our recent study [2], we show the sensitivity of collective transverse in-plane flow to the symmetry energy in the Fermi energy region and its insensitivity in high energy region. Motivated by this result, in the present work, we study the N/Z dependence of balance energy for various systems throughout the colliding geometry range, i.e from central to peripheral one. The study is carried out within the framework of isospin-dependent quantum molecular dynamics (IQMD) model. For the details of the model, the reader is referred to Ref [3].

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Results and discussion

We simulate the reactions of Ca+Ca, Ni+Ni, Zr+Zr, Sn+Sn, and Xe+Xe with N/Z varying from 1.0 to 2.0 in small steps of 0.2. In particular we simulate the reactions of ^{40}Ca+^{40}Ca, ^{44}Ca+^{44}Ca, ^{48}Ca+^{48}Ca, ^{52}Ca+^{52}Ca, ^{56}Ca+^{56}Ca, and ^{60}Ca+^{60}Ca; ^{56}Ni+^{56}Ni, ^{62}Ni+^{62}Ni, ^{68}Ni+^{68}Ni, ^{72}Ni+^{72}Ni, and ^{78}Ni+^{78}Ni; ^{81}Zr+^{81}Zr, ^{88}Zr+^{88}Zr, ^{96}Zr+^{96}Zr, ^{104}Zr+^{104}Zr, and ^{110}Zr+^{110}Zr; ^{100}Sn+^{100}Sn, ^{112}Sn+^{112}Sn, ^{120}Sn+^{120}Sn, ^{129}Sn+^{129}Sn, and ^{140}Sn+^{140}Sn; and ^{110}Xe+^{110}Xe, ^{120}Xe+^{120}Xe, ^{129}Xe+^{129}Xe, ^{140}Xe+^{140}Xe, and ^{151}Xe+^{151}Xe at b/b$_{max}$ = 0.2 - 0.4, 0.4 - 0.6 and 0.6 - 0.8. We also use a soft equation of state along with the standard isospin- and energy-dependent cross section reduced by 20%, i.e. $\sigma = 0.8\ \sigma_{nn}^{free}$.

The reactions are followed till the transverse in-plane saturates. In the present study we use the quantity "*directed transverse momentum* $\langle p_x^{dir}\rangle$" which is defined as

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

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

$$Y(i) = \frac{1}{2}\ln\frac{\vec{E}(i)+\vec{p_z}(i)}{\vec{E}(i)-\vec{p_z}(i)}, \qquad (2)$$

where $\vec{E}(i)$ and $\vec{p_z}(i)$ are, respectively, the energy and longitudinal momentum of the i^{th}

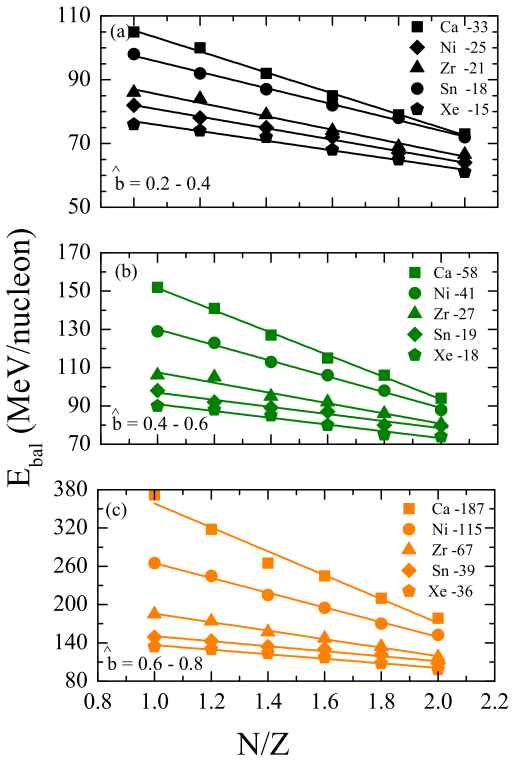

FIG. 1: N/Z dependence of E_{bal} for various systems. Lines are linear fit. Top, middle and bottom panels represent the results for b/b_{max} = 0.2 - 0.4, 0.4 - 0.6 and 0.6 - 0.8, respectively.

particle. In figure 1 we display the N/Z dependence of E_{bal} for b/b_{max} = 0.2-0.4 (top panel), 0.4-0.6 (middle panel) and 0.6 -0.8 (bottom panel). From figure, we find that at all the colliding geometries E_{bal} follows a linear behaviour with N/Z. The slopes are 33, 25, 21, 18, and 15 (at b/b_{max} = 0.2-0.4), 58, 41, 27, 19, and 18 (at b/b_{max} = 0.4-0.6) and 187, 115, 67, 39, and 36 (at b/b_{max} = 0.6-0.8) for the series of Ca, Ni, Zr, Xe and Sn, respectively. From figure, we find that
(i) the N/Z dependence of E_{bal} is steeper for the lighter systems as compared to the heavier systems at all the colliding geometries,
(ii) for a particular isotopic series, the N/Z dependence of E_{bal} is more at peripheral colliding geometry.
(iii) and the change in slope is more for lighter systems as compared to the heavier systems when we move from central to peripheral colliding geometries. From figure, we see that for Ca series, slope increases by almost 400% when we move from central to peripheral collisions, whereas for Xe series increase in slope is almost 150%.

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References

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