Transition energy of neutron-rich colliding pairs in intermediate energy heavy ion collisions

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Introduction

Elliptic flow can be descripted as the azimuthal momentum space anisotropy of the particles emitted from non-central collisions of heavy-ions in the reaction plane that is transverse to the direction of beam. It is defined as the second harmonic coefficient of the azimuthal Fourier decomposition of the momentum distribution [1]. Mathematically, it is equal to the average difference between the squared transverse momentum of the particles in the x and y directions, i.e., $v_2 = \langle cos(2\phi)\rangle = \langle \frac{p_x^2-p_y^2}{p_x^2+p_y^2}\rangle$. At low incident energies, the ϕ distribution is peaked at 0^o and $\pm180^o$ i.e. the elliptical flow is in-plane (*or* $v_2 > 0$), and with rise in the incident energy, the ϕ distribution is peaked at $\pm90^o$ i.e. the elliptical flow is out-of-plane (*or* $v_2 < 0$). The particular point of energy at which the transition from in-plane to out-of-plane occurs or the value of elliptical flow becomes zero is termed as transition energy (E_{trans}). The transition energy could also be interpreted as the energy at which the participant zone counter balances the spectator zone passing time in the mid-rapidity region ($|\frac{Y_{c.m.}}{Y_{beam}}| \leqslant 0.1$). In previous studies, the transition energy has been reported by many authors for stable nuclei as a function of system mass, centrality, fragment type, and scaled momentum and many useful conclusions have been extracted [1]. The influence of isospin degree of freedom in highly isospin asymmetric nuclei on the transition energy is still an untouch area. However, the N/Z dependence of the transition energy is documented earlier for the isobaric systems upto N/Z=2 and for isotopic pairs upto N/Z=1.3 only [2]. The availability of various accelerator facilities [3] for the nuclei away from the stability line has directed us to made a study for the transition of the elliptical flow for various neutron-rich colliding nuclei. In this paper, we calculate the transition energies for the colliding systems with N/Z upto 2 (neutron-rich) for free nucleons (FNs), light mass fragments (LMFs), and intermediate mass fragments (IMFs) and also calculate the percentage difference between the transition energies of neutron-rich and neutron-poor (N/Z=1) colliding pairs. The study is accomplished using isospin-dependent quantum molecular dynamics (IQMD) model, in which the isospin effects are taken into account through the Coulomb potential, symmetry potential and isospin-dependent cross-section. More details of the model are clearly documented in ref.[4].

Results and Discussions

The reactions of ${}^{A_1}_{28}Ni +{}^{A_1}_{28} Ni$; A_1=58, 72, 84, ${}^{A_2}_{40}Zr +{}^{A_2}_{40} Zr$; A_2=81, 104, 120 , ${}^{A_3}_{50}Sn+{}^{A_3}_{50}Sn$; A_3=100, 129, 150 and ${}^{A_4}_{54}Xe+{}^{A_4}_{54}Xe$; A_4=110, 140, 154 having N/Z=1.0, 1.6, and 2 are simulated for impact parameter of b/b_{max} = 0.3 with a soft equation of state and reduced isospin dependent cross-section ($\sigma = 0.9\sigma_{nn}^{free}$). The choice of these reactions is guided by ref. [5]. The phase space created using IQMD model is examined with minimum spanning tree method [6]. Figure 1 displays the transition energy as a function of isospin content of the colliding pair for the reactions of Ni+Ni, Zr+Zr, Sn+Sn, and Xe+Xe. With increase in N/Z value, mass of the system also increases i.e. number of neutrons (for isotopic series here) which are affected by the symmetry energy and isospin dependent cross-

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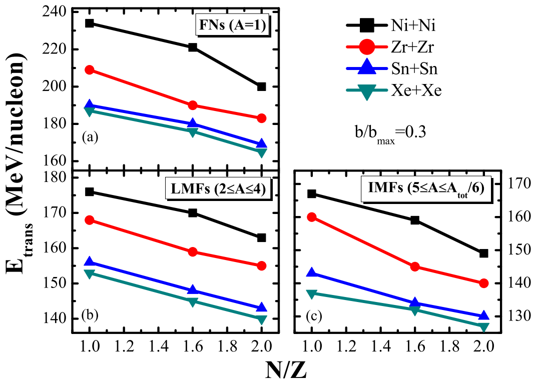

FIG. 1: Dependence of the transition energy on the isospin content of the colliding nuclei for (a) FNs (b) LMFs and (c) IMFs.

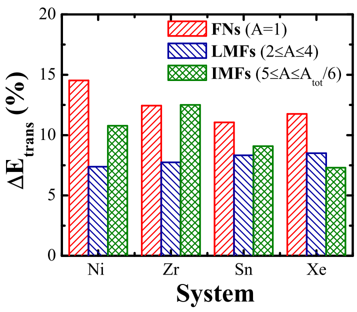

FIG. 2: The percentage difference $\triangle E_{trans}(\%)$ between neutron-poor and neutron-rich colliding nuclei.

section. The figure depicts that the transition energy is greater for the neutron-poor colliding partners and lower for those of neutron-rich ones. This could be attributed due to many reasons: Firstly, for a given series of isotopic systems (fixed Z), Coulomb potential plays an equally important role. So, here the dominant role is played by the symmetry energy and the isospin dependent cross-section. Secondly, for the isospin asymmetric systems, large neutron content will give rise to the significant contribution of repulsive symmetry energy. This repulsive nature of the symmetry energy gives extra push to the participant matter in out-of-plane direction. This helps in the earlier balancing of the participant and spectator matter passing time, thereby reducing the transition energy. And, the isospin dependent cross-section ($\sigma_{np} = 3\sigma_{nn}\ or\ 3\sigma_{pp}$) enhances the binary collisions and its contribution is maximum in the neutron-rich colliding nuclei thereby increasing the squeeze-out flow which in effect reduces the transition energy.

The nature of the transition energy with increase in the isospin asymmetry is consistent for all the fragments under study, but as proved earlier also , the transition energy is quite lower for the fragments with heavier mass [2]. The relative difference in the transition energy of the neutron-poor and neutron-rich colliding pairs is calculated as

$$\Delta E_{trans}(\%) = \left| \frac{[Etrans]^{(N/Z=1)} - [Etrans]^{(N/Z=2)}}{[Etrans]^{(N/Z=1)}} \right| * 100. \quad (1)$$

and is displayed in figure 2. For all the systems under study, this difference is considerable to be taken into account in order to report and compare the various aspects of the fragmentation structure at the transition energy for the neutron-poor and neutron-rich colliding partners.

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