Study of isospin effects in the disappearance of flow

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Introduction

The upcoming and existing radioactive ion beam (RIB) facilities around the world have simulated a lot of interest in studying the role of isospin degree of freedom in reaction dynamics. Such reactions involving neutron- or proton-rich nuclei help to explore the isospin dependence of in-medium nuclear effective interactions through both nuclear equation of state (EOS) and nucleon-nucleon (nn) cross section. The knowledge about nuclear EOS of isospin asymmetric nuclear matter is of great interest to solve key questions like structure of radioactive isotopes, dynamics of heavy-ion reactions involving RIBs, mechanism of supernova explosions and properties of neutron stars.

In the present work, we have studied role of isospin degree of freedom in flow, its disappearance and other related phenomena using many-body isospin-dependent quantum molecular dynamics model [1]. The IQMD model treats different charge states of nucleons, deltas, and pions explicitly, as inherited from the Vlasov-Uehling-Uhlenbeck (VUU) model. The isospin degree of freedom enters into the calculations via symmetry potential, cross sections, and Coulomb interaction. The nucleons of the target and projectile interact by two- and three-body Skyrme forces, Yukawa potential and Coulomb interactions. A symmetry potential between protons and neutrons corresponding to the Bethe-Weizsäcker mass formula has also been included.

Results and discussion

As a first part of the problem, we have studied isospin effects in the disappearance of flow (at energy of vanishing flow EVF) for reactions of ^{58}Ni+^{58}Ni and ^{58}Fe+^{58}Fe for which the first experimental study was carried out [2]. Our study has revealed that neutron-rich colliding pair of ^{58}Fe+^{58}Fe has higher EVF throughout the range of colliding geometry in agreement with experimental observation [3]. This has been attributed to isospin dependence of nn cross section as neutron-proton cross section is three times compared to neutron-neutron or proton-proton cross section. Moreover, we, for the first time, could reproduce all the measured EVFs for ^{58}Ni+^{58}Ni and ^{58}Fe+^{58}Fe which were not reproduced in earlier attempts. We also investigated reasons for earlier failures and in this direction we have found that interaction range of nucleons has a major role to play. Motivated by good agreement of our theoretical calculations with experimental EVFs, as a next step, we have studied role of isospin degree of freedom throughout the mass from A = 48 to 270 range for isobaric pairs having N/Z = 1.0 and 1.4. Isospin effects have been found to be due to interplay between Coulomb potential, symmetry energy, nn cross section and surface properties of colliding nuclei. We also shed light on the relative importance of above mechanisms and have found that Coulomb potential is dominant in isospin effects through EVF for isobaric pairs. Our results have also demonstrated that role of the symmetry energy is unform throughout the mass range and impact parameter range. We have also found that isospin effects are more pronounced at peripheral collisions due to dominance of Coulomb potential [4].

The nuclear symmetry energy is a very hot topic these days and presently lots of theoretical and experimental efforts are going on to study the behavior of the symmetry energy at sub saturation and supra saturation densities. To study its behavior, various probes

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have been proposed in past decade throughout the density region. So, as a next part of our work, we have also studied sensitivity of the EVF of isotopic colliding pairs (throughout the mass range from Ca+Ca to Xe+Xe) with neutron content of the colliding pair to the symmetry energy and its density dependence. Since in isotopic pairs, the Coulomb potential will be same, so isospin effects would be either due to symmetry energy or isospin dependence of nn cross section. Our calculations have shown that N/Z dependence of the EVF (for isotopic pairs) is sensitive to the symmetry energy as well as its density dependence, whereas, it is insensitive to isospin dependence of nn cross section. This study thus has provided us a new probe to study and constrain the density dependence of the nuclear symmetry energy at supra saturation density region.

Motivated by above mentioned studies, we have studied the sensitivity of directed transverse in-plane flow to the nuclear symmetry energy for neutron-rich ^{60,48}Ca+^{60,48}Ca reactions. Our study has revealed that directed flow is sensitive to the symmetry energy and its density dependence in Fermi energy region whereas shows insensitivity at higher incident energies [5]. This is due to dominance of repulsive nn scattering at higher energies. We have also found that transverse flow of low density particles during the initial stages are different for various choices of the symmetry energy ($\propto \rho, \rho^{0.4}$, and ρ^2). In fact, the acceleration time of low density particles to central dense zone varies with the symmetry energy, being smaller for stiffer density dependence and this, in turn, determines the final value of transverse flow.

Finally we have studied nuclear dynamics of neutron-rich colliding pairs at fixed incident energy as well as at the EVF. In particular, we have studied density, temperature, participant and spectator matter, and thermalization achieved in reactions. We have found that density decreases with increasing neutron content of colliding pairs [6]. This has been attributed to the enhanced role of the repulsive symmetry energy which throws the matter away from central dense zone. Similar behavior is followed by temperature. The mass dependence of these quantities have also been studied. Our calculations have shown that density achieved during a reaction is almost independent of the system size as observed for stable colliding pairs. We have also studied participant and spectator matter and found that participant matter also decreases slightly with increasing neutron content [7]. A nearly mass independent behavior of participant and spectator matter is also observed at the EVF. We have also studied the role of momentum-dependent interactions (MDI) and the symmetry energy on participant and spectator matter at fixed incident energies of 50 and 250 MeV/nucleon. Our results have shown that participant matter decreases with inclusion of the MDI and symmetry energy because of their repulsive nature. We have also studied thermalization achieved in reactions of neutron-rich colliding pairs using anisotropy ratio and relative momentum. The calculations have shown that anisotropy ratio saturates after high dense phase is over whereas relative momentum decreases as reaction proceeds and finally approaches zero. An insignificant influence of system size on anisotropy ratio has also indicated towards equilibration of the systems [7].

References

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