Influence of charge asymmetry in heavy ion collisions at intermediate energies

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Introduction

The heavy-ion reactions in intermediate energy regime are best suited to carry out investigations for the nuclear equation of state (NEOS) (i.e. the behavior of nuclear matter under the extreme conditions) as well as its isospin dependence. Lots of efforts have been made to understand the properties of stable nuclei (N ≈ Z). Then physics divert in recent times to understand the dynamics for nuclei away from the drip line, in which we have collision of nuclei with large neutron/proton content. Many factors such as isospin asymmetry, momentum dependent interactions and nucleon-nucleon cross-section affect the nuclear equation of state. In order to amplify the effect of asymmetry term in heavy-ion collision dynamics, large neutron to proton asymmetries are best keys.

In the present work, we have studied the isospin effects on the various observables of heavy-ion collision namely multifragmentation, nuclear stopping and collective flow particulary in regard to Coulomb interactions (by taking isobaric nuclei), density dependence of symmetry energy and isospin dependence of nucleon-nucleon cross-section. The Coulomb interactions in intermediate energy heavy-ion collisions is expected to play a dominant role in the above mentioned phenomenon due to its repulsive nature. These effects are supposed to be more pronounced in the presence of isospin effects. Moreover, the magnitude of symmetry energy effects are absent for the symmetric nuclei which increase its importance to study the systems with large N/Z asymmetries. Furthermore, since the symmetry potential is repulsive for neutrons and attractive for protons, the observables of heavy-ion collisions mentioned above are sensitive to the symmetry energy. In addition, the isospin dependence of nucleon-nucleon cross-section also plays a significant role in reaction dynamics. We have studied the effect of Coulomb potential, symmetry energy and isospin dependent nucleon-nucleon cross section on multifragmentation, elliptical flow as well as on the nuclear stopping by taking different isobaric systems. Moreover, we have also elaborated the correlation between directed transverse flow and nuclear stopping in relation to isospin asymmetry. The present work is performed within the framework of Isospin dependent Quantum Molecular Dynamics Model [1].

Results and discussion

The burning topic of the present day nuclear physics is to study the behavior of symmetry energy at sub saturation and supra saturation density both theoretically as well as experimentally. Therefore, as a first step, we have studied the influence of density dependence of symmetry energy, charge asymmetry of colliding nuclei as well as the isospin dependence of nucleon-nucleon cross-section on the multiplicity of fragments. Comparison of theoretical calculations for the mean multiplicity of IMFs will also be made with the experimental findings of ALADiN collaboration. Our study reveals that isospin dependence of nucleon-nucleon cross-section shows its influence on fragmentation in the collision of neutron-rich nuclei and there is a constant difference in the production of FN's and LMF's with σ_{iso} ($\sigma_{np} = 3\sigma_{pp} = 3\sigma_{nn}$) and σ_{noiso} ($\sigma_{np} = \sigma_{pp} = \sigma_{nn}$) for charge asymmetric nuclei [2].

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In order to get the first hand information for estimating the energy and particle densities of the compressed nuclear matter at early stage of the participant fireball, one of the essential observable in heavy-ion collision is the degree of nuclear stopping. Therefore, as a next step, we have studied the N/Z dependence of participant-spectator matter, anisotropic ratio $\langle R_a \rangle$, relative momentum $\langle K_R \rangle$. We have also discussed the isospin dependence of nucleon-nucleon cross-section on nuclear stopping as well as on the multiplicity of FN's and LMF's for charge asymmetric nuclei. Our study reveals that, for charge asymmetric nuclear collisions participant (spectator) matter decreases (increases) with increase in N/Z of the system whatever be the definition of the participant matter. The variation of slope of $\langle participant \rangle_{norm}$ with energy give an indication about the global equilibrium of the system and the variation of slope of $\langle spectator \rangle_{norm}$ with energy give indication about the local equilibrium of the system. Participant-spectator matter, anisotropy ratio, relative momentum as well as production of LMFs are found to depend strongly on the isospin dependence of nucleon-nucleon cross-section. Moreover, theoretical results on the anisotropy ratio $\langle R \rangle$ follow the same trend as recorded by INDRA collaboration [3].
Further we elaborate our study by exploring the influene of above said observables on directed and elliptical flow. We conclude that the directed flow of both neutrons and protons is affected by the momentum dependence of nuclear equation of state and the isospin dependence of nucleon-nucleon cross-section. A soft momentum dependent (SM) equation of state is found to be more compatible with the experimental data [4]. Phase space analysis shows that the nucleon which suffer maximum number of collisions contribute in elliptical flow [5]. The distribution of nucleons and fragments is not symmetric around the beam axis [6]. We also shows that, the elliptical flow depends strongly on the isospin dependence of nucleon-nucleon cross-section. However, transition energy shows a significant variation with the system mass because the Coulomb potential and symmetry energy play significant role in reaction dynamics [7].
Isospin effects have been found to be due to the interplay between Coulomb potential, symmetry energy, nucleon-nucleon cross-section and surface properties of colliding nuclei. To shed light on the relative importance of above mentioned observables, we studied the effect of isospin degree of freedom on nuclear stopping throughout the mass range between 50 and 350 for two sets of isotopic systems as well as isobaric systems. Analysis is carried out at an incident energy below, at, and above the energy of vanishing flow (EVF). Our findings reveal that nuclear stopping does not show any particular behavior at EVF. Moreover, system size effects dominate the isospin effects throughout the range of colliding geometry. The Coulomb effects becomes important at higher colliding geometry. The comparative study of counterbalancing of Coulomb and mean field by removing the nucleon-nucleon collisions clearly indicates the dominance of nucleon-nucleon cross-section over the repulsive Coulomb potential.

References

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