Influence of isospin dependent nuclear charge radius in heavy ion collisions at intermediate energies

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Introduction

Study of neutron-rich/deficient nuclei (termed as isospin asymmetry nuclear matter) have attained much interest and attention due to the development of radioactive beam facilities around the world. This has keyed up new interest on the subfield emerging from the nuclear physics research, called isospin degree of freedom. The key point to elucidate the isospin asymmetric nuclear matter is to obtain the isospin dependence of NEOS. The present work deals in the theoretical investigation of isospin degree of freedom in the nuclear reaction dynamics and related phenomena via isospin dependent nuclear charge radii parameterizations at intermediate energies. The study is carried out using Isospin dependent Quantum Molecular Dynamics (IQMD) model [1] which is based on many body molecular dynamics approach. The isospin physics is included in this models via symmetry potential, Coulomb potential and isospin dependent nucleon-nucleon scattering cross section to achieve the corrected information on distribution as well as interaction among the neutrons and protons. With regards to various parameterizations of nuclear charge radii proposed in literature, four of these have been used to fulfil the current aim. Because of growing interest in the study of isospin degree of freedom, one of the chosen parameterizations is the liquid drop model (LDM) proposed i.e. R_{LDM}, which is isospin-independent and the other three are isospin-dependent i.e. R_{NGO}, R_{PP} and R_{RR} to account for **isospin effects**. One can refer to Ref. [2] for the detail of these radii parameterizations.These radii parameterizations have been considered such that the radius of a particular nucleus follows the pattern: $R_{LDM} < R_{NGO} < R_{PP} < R_{RR}$ to study the influence of increase in radius on the various phenomena occurring at intermediate energies in a systematic way i.e. to optimize the **structural effects**.

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Results and discussion

As a first step of study, the influence of isospin dependent nuclear charge radii on fragmentation in HICs has been studied for a wide range of atomic mass and neutron-to-proton ratio [3, 4]. It has been concluded that, heavier colliding nuclei are good probe to study the influence of isospin dependent nuclear charge radii on multi-fragmentation in heavy ion collisions at E = 50 MeV/nucleon. Moreover, the multiplicity of fragments has been found to depend up on N/Z ratio colliding nuclei by including isospin dependent nuclear charge radius which was observed to be insensitive in earlier studies by R_{LDM}. The isospin dependent radii R_{RR} reduces the gap between the theoretical calculations and the experimental findings of ALADIN collaboration.

Next, a systematic study of the influence of nuclear charge radii parameterizations on the excitation function of reduced flow and elliptical flow as well as on the balance and transition energies for the whole mass range and initial neutron-to-proton ratio has been presented [5]. The study concludes that the pressure gradient developed in mid-rapidity region reduces with increase in nuclear charge radius of colliding nuclei and repulsive nucleon-nucleon collisions gets suppressed. With increase in nuclear charge radius the magnitude of reduced flow decreases and of elliptical flow increases. Moreover, the role of change in radius on collective flow is more for the neutron-deficient reactions compared to neutron-rich reactions. Both transition energy of elliptical flow (E_{trans}) and balance energy of reduced flow (E_{bal}) increases with increase in nuclear radius and follows a power law behavior. From both types of collective flow, the elliptical flow has been found to be more sensitive towards different nuclear charge radii parameterizations compared to reduced flow. The theoretical calculations with different radii parameterizations are appropriate with experimental data points of ALADIN, INDRA and FOPI collaborations.

The nuclear stopping is another crucial phenomenon of HICs as it gives estimation of energy lost during the collisions and nucleonic density of compressed nuclear matter. Therefore, different aspects of nuclear stopping with different nuclear charge radii parameterizations have been studied [6]. The study concludes that the increase in available phase space at initial state enhances the longitudinal as well as transverse momentum which increases the production of fragments. However, the longitudinal momentum dominates the transverse momentum which in turn reduces the nuclear stopping. The study also shows that an average of those nucleons which have experienced at least five collisions are close to complete equilibrium [7]. The radii parametrization affects the excitation function of nuclear stopping at relatively high energies and influence of momentum dependent interactions (MDI) more is prominent at relatively lower energies [8]. Hence, the nuclear stopping calculations via isospin dependent nuclear charge radius parametrization R_{RR} along with MDI are more closer to the experimental findings of INDRA and ALADIN collaborations.

As a last step, a comparative study upon the correlation of temperature and multi-fragmentation with nuclear stopping for mass symmetric as well asymmetric nuclear reactions has been performed [9, 10]. Our results reveal that the role of nuclear charge radii on thermal equilibrium decreases with increase in impact parameter for mass symmetric reactions; however, remain almost the same for asymmetric reactions. In addition to that, the nuclear charge radii parameterizations affect the correlation curve of multi-fragmentation and nuclear stopping more for symmetric reaction as compared to asymmetric reaction (having same total mass). In an asymmetric reaction, the smaller projectile experiences more influence through nuclear charge radii compared to heavier target. For mass asymmetric nuclear reactions, the contribution of smaller projectile in nuclear stopping is more but the collective contribution of projectile and target nuclei becomes less than as that of mass symmetric reaction.

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