Influence of nucleon-nucleon collisions on multi-fragmentation and nuclear flow

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Introduction

The present thesis deals with the theoretical study of multi-fragmentation and its related phenomena's like directed transverse flow, rapidity distribution, elliptical flow and nuclear stopping in intermediate energy heavy-ion collisions for asymmetric colliding nuclei. We aim to discuss the role of Coulomb interactions, nuclear equations of state (NEOS) and various rapidity bins by taking mass asymmetry into account. An attempt has also been made to understand the disappearance of directed transverse flow and elliptical flow and hence balance energy and transition energy, respectively. Moreover, it also presents the comparison of theoretical simulations with data produced by various experimental collaborations. The theoretical investigations are carried out using microscopic *isospin-dependent quantum molecular* (IQMD) model [1].

In the first part of the thesis, we present a complete systematic theoretical study of multi-fragmentation [2] for free nucleons and various fragments by simulating different asymmetric reactions at incident beam energies between 50 and 600 MeV/nucl. at semi-central impact parameter using soft and hard NEOS. While the total mass of the system stays constant, mass asymmetry varies between 0.2 and 0.7. We find that in the case of nearly symmetric reaction, spectator parts will come from both projectile and target, whereas in the case of highly asymmetric reaction, no spectator part will come from projectile i.e. only target will contribute to the spectators. Although nearly symmetric nuclei depict a well-known trend of rising and falling for intermediate mass fragment (IMF's) production with peak around E= 100 MeV/nucl., this trend, however, is completely missing for large asymmetric colliding nuclei. The measured distributions are also given as a function of the total charge of all projectile fragments, Z_{bound}. The highly asymmetric system produces largest Z_{bound}, while, maximum number of intermediate mass fragments (IMF's) are produced at $Z_{bound} = 20$. This observation may throw light on the formation mechanisms behind multi-fragmentation. Moreover, the brief study of the directed transverse flow shows that balance energy is affected by the Coulomb interactions as well as different NEOS. This balance energy is further parametrized in terms of mass power law.

We have also examined a new investigation of the interplay between the participant and spectator regions in terms of rapidity distributions [3]. The maxima and minima in the incident energy dependence of elliptical flow are produced by different contributions of the passing time of the spectator and the expansion time of the participant. The shadowing of the spectator matter plays an important role up to later times due to the comparable magnitude of the passing and expansion times up to energies of 400 MeV/nucl. However, at high energies the shadowing effect is dominant only at earlier times due to the fact that the passing time is shorter than the expansion time. The transition from in-plane to out-of-plane emission is observed only when the mid-rapidity region is included into the rapidity bin. Otherwise, no transition is observed. The transition energy is found to be strongly dependent on the size of the rapidity bin, while only depends weakly on the type of the rapidity distributions. The transition energy is parameterized

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by a straight-line interpolation. A comparison with experimental bins reveals that a competition is observed between the rapidity bins of $|Y^{red}| \leq 0.1$ and $|Y^{red}| \leq 0.3$.
Based on the detailed analysis of elliptical flow using various rapidity bins, we present the systematic theoretical results on elliptical flow by analyzing nearly symmetric and asymmetric reactions at different incident energies [4]. In the case of nearly symmetric reactions, general features of the elliptical flow are investigated with the help of theoretical simulations, particularly, the transverse momentum, impact parameter, system size and incident energy dependence. Special emphasis is put on the energy dependence of the elliptical flow. We also compare our theoretical calculations with 4π Array data. This comparison, performed for the reaction of $_{18}Ar^{40} +_{21} Sc^{45}$ shows that the hard NEOS explains the data nicely. In general, a reasonable agreement is obtained between the data and calculations. We also predict that elliptical flow for different kind of fragments follows power law dependence α C$(A_{tot})^{\tau}$. Moreover, in the case of asymmetric reactions, elliptical flow is analyzed by varying the mass asymmetry of colliding nuclei while total mass is kept fixed. The mass asymmetry dependence of elliptical flow (in terms of transverse momentum dependence) for free nucleons and LMF's shows a weaker squeeze-out flow as compared to larger asymmetric reactions. Moreover, the elliptical flow is found to show a transition from in-plane to out-of-plane in the mid rapidity region with incident energy, while no such transition is observed when integrated over the entire rapidity region. The transition energy, at which elliptical flow $< V_2 >$ changes sign from positive to negative values, is different for different mass asymmetries, and is found to increase with the mass asymmetry for lighter fragments. The comparison with experimental data of INDRA@(GSI+GANIL) and MSU collaborations supports our findings.
In the last part of the thesis, we study the nuclear stopping in asymmetric colliding channels by keeping total mass fixed [5]. The calculations are carried out by varying the mass asymmetry of the colliding pairs with different neutron-proton ratios at incident beam energy 250 MeV/nucl. The contribution of the neutrons and protons is checked in terms of anisotropy ratio $< R >$ and quadrupole moment $< Q_{zz} >$. The maximum stopping is obtained for nearly symmetric systems. Also a reasonable agreement is observed between theoretical results of anisotropy ratio $< R >$ and energy dependent anisotropy ratio $< R_E >$ with the experimental data of INDRA collaboration.
In summary, an attempt has been made to pin down the role of mass asymmetry on fragmentation, collective flow and nuclear stopping. The study presented in this thesis is of great importance for experimentalists. Experimental groups can plan the experiments for such studies.

References

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