Statistical and dynamical model studies of nuclear multifragmentation reactions at intermediate energies

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Nuclear multifragmentation is an important phenomenon, the study of which can throw light on reaction mechanism of heavy ion collisions at intermediate and high energies [1]. Based on statistical and dynamical model studies, this work is concentrated mainly on, the following three aspects of nuclear multifragmentation reactions namely (i) production of exotic nuclei which are normally not available in the laboratory (ii) nuclear symmetry energy from heavy ion collisions at intermediate energies and (iii) Nuclear liquid-gas phase transition. In addition to these equivalence of statistical ensembles under different conditions is also studied in the framework of multifragmentation.

Projectile fragmentation is very useful for producing radioactive ion beams. A model for projectile fragmentation is developed [2] which involves the traditional concepts of heavy-ion reaction (abrasion) plus the well known statistical model of multifragmentation (Canonical thermodynamical Model (CTM) [3]) and evaporation model based on Weisskopf theory. This model is in general applicable and implementable in the limiting fragmentation region (for beam energies of 100 MeV/nucleon or higher). A very simple impact parameter dependence of freeze-out temperature profile is introduced for understanding the reaction mechanism in the limiting fragmentation region. The projectile fragmentation model is successfully applied to calculate the production cross-sections for a wide range of exotic as well as stable nuclei of different projectile fragmentation reactions at different energies. Different important observables of projectile fragmentation like intermediate mass fragments, largest cluster size, differential charge distribution etc. are also calculated from this model.

While the projectile fragmentation model results have reasonable agreement with the various data considered here, it is desirable to push the model for further improvements. A microscopic static model and dynamical model based on Boltzmann-Uehling-Uhlenbeck (BUU) equation is developed for determining the initial conditions (mass and excitation) of projectile fragmentation reactions [4]. It is observed that the projectile like fragment masses at different impact parameters calculated from transport model are comparable to that obtained from geometric abrasion calculation. Nice agreement between the deduced temperature profile and earlier used parameterized temperature profile is obtained for different projectile fragmentation reactions at different energies.

In addition to the projectile fragmentation model, a hybrid model is also developed separately for explaining the multifragmentation reaction around Fermi energy domain [5]. In the hybrid model, initially the excitation of the colliding system is calculated by using the dynamical BUU approach with proper consideration of pre-equilibrium emission. Then the fragmentation of this excited system is studied by the CTM and finally the decay of the excited fragments, which are produced in multifragmentation stage, is calculated by the evaporation model. This model is used to calculate the freeze-out temperature of the central collision multifragmentation reactions. In order to check the accuracy of the model, different observables of nuclear multifragmentation like charge distribution, largest cluster probability distribution, average size

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of largest cluster are calculated theoretically for ^{129}Xe on ^{119}Sn reaction at beam energies of 32, 39, 45 and 50 MeV/nucleon and compared with the experimental data.

The underlying physical assumption behind the canonical and the grand canonical ensembles is fundamentally different, and in principle they agree only in the thermodynamical limit when the number of particles become infinite. In any statistical physics problem it is easier to compute any observable using grand canonical ensemble where total number of particles can fluctuate. For finite nuclei in intermediate energy heavy ion reactions there is no particle fluctuation, therefore canonical or micro canonical ensembles are better suited for this purpose. For the nuclear multifragmentation of finite nuclei the total charge distribution is calculated in the framework of both canonical and grand canonical ensembles. It is observed that when the fragmentation is more, i.e. the production of larger fragment is less, the particle fluctuation in grand canonical model is less and the results from canonical and grand canonical model are found to converge [6]. This condition can be achieved by increasing the temperature or freeze-out volume or the source size or by decreasing the asymmetry of the source. When the results calculated from the two models are different, an analytical formula is derived which enables one to extract canonical results from a grand canonical calculation and vice versa [7]. The conditions under which the equivalence holds are amenable to present day experiments.

Study of nuclear symmetry energy in intermediate energy heavy ion reactions is an important area of research for determining the nuclear equation of state [8]. In this part of work, symmetry energy coefficient is determined using different methods (isoscaling source method, isoscaling fragment method, fluctuation method and isobaric yield ratio method) in the framework of canonical and grand canonical models [9]. It is observed that the best possible way to deduce the value of the symmetry energy is to use the fragment yield at the breakup stage of the reaction (not the cold fragments) as the secondary decay from higher energy states disturbs the equilibrium scenario [10].

Another important area in the study of intermediate energy heavy ion collisions is the phenomenon of nuclear liquid gas phase transition [11]. The standard methods of theoretical studies are based on statistical model calculations. This part of work focuses on whether results of transport model calculations (BUU) at intermediate energy can point to signatures of phase transition. To do that, a simplified yet accurate method of transport model is developed which allows calculation of fluctuations in systems much larger than what was considered feasible in a well-known and already existing model. The distribution of clusters is remarkably similar to that obtained in equilibrium statistical model and provides evidence of phase transition [12].

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