Study of nuclear fragmentation and associated phenomena with thermal binding energies

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Introduction

The heavy-ion collisions at intermediate energies provide the opportunity to produce nuclei at the limits of their stability in temperature and excitation energy. The understanding of the decay mechanism of these unstable nuclei into multiple fragments, termed as multifragmentation, has been one of the most provocative objectives of nuclear physics [1]. In the last couple of decade, a large number of accurate experiments have been performed to detect these fragments of all sizes. One is interested to look their associated properties such as how they are formed and evolve in time. Now, to obtain the knowledge of the mechanisms causing the fragment formation, one has to rely on various theoretical models. It was also observed in literature that various astrophysical phenomena such as formation of hot heavy nuclei in supernovae explosions can be investigated through nuclear multifragmentation reactions.

In the present work, we discuss various stability issues related to the bound-state of nucleons using various fragment identifiers. Here, we have simulated the different reactions for various entrance channel parameters using Quantum Molecular Dynamics (QMD) model [1, 2]. The QMD model is a n-body dynamical model based on Boltzmann-like approach for collision of two nuclei and uses classical distribution functions with relevant quantum effects. This model allows to preserve the correlations among the nucleons and thus, provides the complete description of the time evolution of all microscopic detail of the reaction dynamics. The multi-nucleonic information generated by QMD is comprehended to obtain the fragment information employing clusterization algorithms Minimum Spanning Tree (MST) method [1] and Simulated Annealing Clusterization Algorithm (SACA) [3]. Between these, the MST method is based on the spatial information of multi-nucleonic system, whereas, SACA is based on the metropolis procedure used in simulated annealing technique.

Results and discussion

In the first part of the thesis, we have discussed various stability issues related to the fragments identified using MST method [4]. We have discussed problems with the various previous modifications done over MST method to obtain realistic fragment structures [2]. We have shown that the inclusion of temperature in the fragmenting procedure plays a prominent role on the final fragment configurations. The temperature of the fragments have been taken care by modifying the MST method for additional temperature-dependent binding energy criteria. Our detailed calculations of ^{40}Ca+^{40}Ca and ^{197}Au+^{197}Au reactions for all colliding geometries and various incident energies showed the need for inclusion of temperature in identifying the realistic fragments. We have also discussed various observables comprising multiplicities and various dynamical properties of fragments such as rapidity, binding energy and transverse momenta of the fragments. Our study for the first time validated the use of MST method for identifying the fragments. We have also shown that the fragments obtained using MST method are realistic and, thus, deny the use of any de-excitation/statistical codes with dy-

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namical models.

In the next part of the thesis, we presented the details of various temperature-dependent binding energies documented in literature [5]. We included these binding energies in the MST method to check that our results, showing proper bound fragments using MST method, are independent of the form of binding energy formula used to put stability criteria [5]. We have also investigated various dynamical properties to ensure that these results are not accidental. Then, we have confronted our calculations with the experimental data for the reactions of ^{20}Ne+^{27}Al, ^{40}Ar+^{45}Sc, ^{84}Kr+^{93}Nb, ^{129}Xe+^{139}La and ^{197}Au+^{197}Au at various incident energies from 15 to 400 MeV/nucleon and over entire colliding geometry from central (b = 0 fm) to peripheral (b = b_{max} fm; $b_{max} = 1.142(A_P{}^{1/3}+A_T{}^{1/3})$; $A_{P/T}$ = mass of projectile/target) collisions or as guided by experimental setup. Our results are found to be in reasonable agreement with various experimental observables in certain entrance channel region. Our results show that MST method provides the relevant information about various observables at the later times of the reactions.

In the next part of the thesis, we have discussed the need and importance of developing clusterization algorithms based on energy minimization. We have confronted our calculations for the reactions of ^{40}Ca+^{40}Ca, ^{129}Xe+^{119}Sn, ^{155}Gd+^{238}U and ^{197}Au+^{197}Au using clusterizing technique SACA with the available experimental data [6, 7]. The experimental data comprises of the average observables such as multiplicities of the fragments and the charge distribution of the fragments as well as more complicated observables such as probability distribution of the six heavy fragments, multiplicity distribution of intermediate mass fragments and bound charge distribution per event etc. We for the first time have explained experimental observations spanning over various system masses, system mass asymmetries, colliding geometries and incident energies. These results have shown the capability of SACA to explain onset of fragmentation to multifragmentation and to the vaporization of the nuclear matter. For a comparative study, we have also compared our results with the calculations of one-body dynamical models and statistical models. We have also shown that SACA identifies the fragments much earlier in time compared to other models and provides the knowledge of the dynamics involved at the early phase of the reaction. Our results have pointed towards the dynamical origin of fragments denying the thermal origin.

As a last part of the thesis, we have discussed the stability of the fragments obtained using SACA [8]. This is achieved by employing various binding energy checks on the fragments identified by SACA. Our calculations have shown that the algorithms based on energy minimization like SACA gives stable fragments and, thus, no additional stability checks are required with these methods. These results also points towards the fact that fragments obtained using SACA are in their corresponding true ground states.

Acknowledgments

This work is done under the joint supervision of Prof. Rajeev K. Puri and Dr. Sakshi Gautam and funded by University Grants (UGC) Commission.

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