Fission studies using dynamical and statistical models

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The discovery of Hahn and Strassmann pointed out that a heavy nucleus irradiated with neutrons would split into two intermediate fragments, a process known as nuclear fission. Meitner and Frisch have given the first theoretical explanation to nuclear fission. Further, Bohr and Wheeler developed the concept of potential energy surface of a nucleus as a function of deformation parameters and found that the nucleus is highly unstable against nuclear fission at larger deformations. In addition, using the compound nucleus hypothesis, they have proposed the statistical concepts at the saddle point to calculate the fission widths. Fong, extended this idea of statistical theory at the scission point to explain the asymmetric fragment mass distributions. Further, Rajasekaran and Devanathan have introduced the Nilsson model single-particle energies (s.p.e) in the calculations of fission mass distribution.

After the advent of heavy-ion beams with various energy ranges, the fission dynamics of highly excited compound nuclei has considerable interest. The enhanced pre-scission particles and $\gamma-$ray multiplicities of hot nuclei compared with the statistical model emphasize the role of friction in the fission dynamics. Hence, a dissipative dynamical model based on Langevin equations has developed and applied to the fission dynamics of highly excited heavy nuclei.

This thesis employs the dynamical model to study binary fission observables such as fission lifetime, binary mass distributions and applies the statistical model to study the ternary fission mass/charge distributions. Within the Langevin dynamical model, the temperature and deformation dependent shell corrections are incorporated in the potential energy. Further, the pre-scission particles and the $\gamma-$ray evaporations within the statistical prescription is included. The shape of nucleus represented by the Funny-Hills shape parametrization. In addition, ternary fission shapes are obtained using the Funny-Hills parametrization without introducing any additional parameters. The statistical theory considers the thermodynamic equilibrium at the scission point to calculate the ternary charge and mass distributions. Further, the mass and charge distributions are calculated with two different approaches. In the first approach, the temperature-dependent relativistic mean-field theory is used and in the other approach, the finite range droplet model with the three cluster model potential is used.

Fission lifetime is the time required to scission from the ground state of the compound nucleus to scission configuration. A recent discrepancy arises in the fission lifetime calculations due to the nuclear and atomic measurements. To reconcile these two measurements, we have studied the fission lifetime of heavy and superheavy nuclei within the Langevin dynamical model [1]. First, the ^{224}Th compound system formed in the ^{16}O+^{208}Pb reaction at various excitation energies are considered for the study [1]. The fission lifetime can be calculated from Langevin dynamical fission time τ_f, the average pre-scission neutron time τ_n and the time when last pre-scission neutron evaporated τ_{nl}. The fission lifetime τ_f at low excitation energies is of the order of attosecond. However, at higher excitation energies, the fission lifetime τ_f is higher than $< \tau_{n,nl} >$ due to the long tail in fission time distributions. Hence, the pre-scission neutron times are inappropriate probes at lower excitation energies. The calculated n_{pre} values agree very well with the experimental data. Further, the effect of shell vanishing in the fission life-

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time calculations with the shell damping factor is emphasized in this work [1]. Finally, the fission lifetime of the superheavy ^{302}120 compound system with and without the effect of shell damping is studied [1]. The calculated average fission lifetime of ^{302}120 is more than $10^{-18}s$ which is in reasonable agreement with the atomic probe.

Further, the two dimensional Langevin dynamical model with the constant friction parameter is employed to study the fission mass distributions of ^{237}Bk compound nucleus which is formed in the ^{28}Si+^{209}Bi reaction at various excitation energies. The asymmetric and symmetric fragmentations have larger yield values at lower excitation energies. This scenario has changed at higher excitation energies. At these energies, the single-humped mass distributions represent the disappearance of shell effects. To understand the mass distributions, the trajectory density at larger deformations are studied. Further, the shell damping factor in the calculations has introduced to mimic the actual temperature-dependent shell model. In the new set of calculations, at the excitation energy $E^* \approx 65$ MeV, the triple humped mass distributions are obtained which indicate the presence of shell effects. This result is compatible with the actual temperature-dependent calculations.

To initiate the study of dynamical features in the ternary fission within the Langevin dynamical model, the shape evolution of the mono-nucleus compound system to the tri-nuclear compound system with two necks is obtained using the Funny-Hills shape parametrization [2]. The conditions for ternary shapes and the evolution of binary to ternary shape are discussed along with the deformation energies calculated for different shapes [2].

Ternary fission mass distributions of ^{252}Cf, ^{242}Pu and ^{236}U are studied using the level density approach of the statistical theory and TRMF formalism [3] for the fixed third fragments. One the most favourable fragments of theoretical and experimental reports is chosen as the fixed A_3. The possible fragmentations for the each parent nucleus is obtained from the charge to mass ratio [3, 4]. The results for ^{252}Cf gives $Sn + Ni + Ca$ as the most favourable combination at the temperatures $T = 2$ and 3 MeV. Similarly, for ^{242}Pu and ^{236}U, the fragmentation with closed shell nucleus is found to be the most favourable at $T = 2$ and 3 MeV.

Further, the ternary fission charge distributions of ^{252}Cf for all possible fragments are studied for the various excitation energies using charge bin procedure [5]. The collinear ternary fission with two different arrangements A_1+ A_2+ A_3 (Case-I) and A_1+ A_3+ A_2 (Case-II) are considered for the present study within the three cluster model which accounts for the interaction between the fragments. The potential energy surfaces are calculated using the three-cluster model for the two arrangements, and the ternary fragmentation yield values are calculated for the ternary combination from each bin possessing the minimum potential energy. For each excitation energy, the temperature of the three fragments is iteratively computed conserving the total energy. Obtained results indicate that at higher excitation energies, the Sn region associated with other two fragments posses larger yield values for Case - I arrangement, whereas the true ternary region is found to be a favourable region for both cases at low excitations and for Case - II at higher excitation energies. The distribution of fragment temperatures corresponding to different excitation energies for some fixed third fragments is also studied.

References

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