Dynamics of different fission mechanisms using fragmentation approach

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Introduction

The experimental evolution of the 'accelerators and detectors' led the incredible progress in the field of nuclear fission. Theoretical interpretation of experimental outcomes is very challenging and important task, because it manifests the interesting dynamical aspects of the nuclear fission process. The main emphasis in this thesis is to investigate the dynamics of several compound nucleus (CN) and non-compound nucleus (nCN) fission mechanisms of light and heavy nuclei formed in nuclear reactions, which involve different type of projectiles, e.g., light particles, loosely bound nuclei and stable heavy ions.

The investigation is performed by using the collective clusterization technique of dynamical cluster-decay model (DCM) [1, 2], thereby the contribution of light particles in the decay process is also investigated along with the fission process. The collective fragmentation potential is calculated using macro-microscopic method, which in turn helps to estimate the mass fragmentation and corresponding cross-sectional yields in the decay channel. Here, the structural information of fissioning nuclei is obtained by calculating the preformation probability (P_0) of the nascent fragments. The fission analysis is legitimate only if it is studied at several energies across the barrier. At such higher energies, the incorporation of temperature (T), angular momentum (ℓ), deformation and orientation effects become important, which are duly included in this study. The calculated cross-sections for different fission mechanisms compare nicely with the experimental data, and some predictions are made which can be verified via future experiments. Besides induced fission, spontaneous fission (SF) occurring at the end of α-decay chains of superheavy nuclei (SHN) is also explored in this thesis.

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Calculations and Results

First, the DCM (for $\ell = 0$ case) is employed to study the spontaneous fission (SF) of $^{266}_{103}$Lr, $^{266}_{104}$Rf, $^{266-268}_{105}$Db, $^{281}_{111}$Rg and $^{282}_{112}$Cn SHN appearing as end products in α-decay chains. The temperature effects are incorporated in terms of recoil energy (E_R) of residual SHN, left after neutron evopartaion from the CN. The competition between α-decay and SF of SHN is examined, and it is observed that SF is the prominent decay mode for all studied SHN. The mass distributions of afermentioned SHN are clearly symmetric, and the energetically favoured nascent fragments are identified. The calculated SF half-lives show nice agreement with the experimental data.

The fission decay analysis is further extended for the case of light particle and heavy ion induced reactions. First, a wide range of incident neutron energies (i.e. E_n=32.8-59.9 MeV) is explored to study $n+^{232}$Th$\rightarrow^{233}$Th* and $n+^{238}$U$\rightarrow^{239}$U* reactions. The mass distributions are examined by choosing both spherical and β_2-deformed fragmentation. The study suggests that the asymmetric fission is dominant decay mode for both actinide nuclei. However, a small hump around the asymmetric fragments is observed for ^{233}Th* nucleus, which is not seen in the mass distribution of ^{239}U* nucleus. This outcome is in acoordance with the experimental observation. Further, a relative fission decay analysis of four actinide nuclei, i.e., ^{233}Th*, ^{233}Pa*, ^{239}U*, ^{239}Np* is carried out, which are formed under same conditions. Besides this, a comaprative study of n-induced reaction with p-induced reaction is carried out for Th and U nuclei. The investigation is carry out further by studying the various CN [evaporation residue (ER) and fusion fission (ff)] and nCN [quasi fission (QF) and fast fission (FF)] decay processes of ^{216}Th* produced in heavy-ion induced reaction (^{32}S+^{184}W) at across barrier energy window 118.8 MeV$\leq E_{c.m.} \leq$195.9 MeV. The anomalous behaviour of calculated fission anisotropies (A) for ^{216}Th* nucleus advocate the existence of nCN contributions, such as QF and FF. The capture excitation functions σ_{Cap} are obtained by adding the DCM-calculated CN and nCN contributions. The calculated cross-sections show good agreement with the experimental measurements, and the contribution of evaporation residue component is predicted to be rather small. The compound nucleus formation probability P_{CN} is estimated as a function of $E_{c.m.}$, which in turn suggest that maximum contribution from CN channel is approximately 65%.

The study of fission mechanism is extended further by analyzing the impact of tightly bound and loosely bound projectile on same target. In the first case, the possibility of evaporation residue and fission decay of light compound nuclei i.e. ^{68,70}Ge* formed in ^{4,6}He+^{64}Zn reactions, is examined. It is observed that these nuclei mainly decay via ER channel, and the contribution of fission cross-sections is negligibly small. For the case of ^{68}Ge* nucleus, the calculated cross-sections of ER channels show nice agreement with measured ER data. On the other side, the ER channels of ^{70}Ge* nucleus formed in loosely bound projectile induced reaction, show some deviation from experimental measurements due to the possible presence of breakup+transfer channels. By applying relevant energy corrections, the breakup+transfer excitation functions are estimated. The comparison of complete fusion excitation functions of tightly bound '^{4}He' and loosely bound '^{6}He' projectile induced reactions indicate the sub-barrier enhancement and above-barrier suppression in the fusion excitation functions of ^{6}He+^{64}Zn reaction. Next, the fission decay is examined for various ^{212,213,215,217}At* isotopes formed in tightly (^{3,4}He) and loosely bound (^{6,8}He) projetile induced on heavy mass target (^{209}Bi). By optimizing appropriate neck-length parameter (ΔR), the fission excitation functions are obtained for ^{212,213,215}At* nuclei at above barrier energies, where the experimental data is available. The DCM calculations are extended at below barrier region for these nuclei, and to other reaction ^{8}He+^{209}Bi$\rightarrow^{217}$At*, using the systematics of ^{212,213,215}At* isotopes. The N/Z dependence of fission cross-sections and most probable decaying fragments, is explored in view of fragmentation structure and related cross-section yields.

Finally, the fine structure effects in the fission fragments of ^{201}Bi*, ^{206}Po*, ^{211}At*, ^{212}Rn*, ^{216}Ra*, ^{227}Pa* and ^{228}U* nuclei produced in ^{19}F-induced reactions are analyzed at near and above barrier energies. The interplay between two modes of fission i.e. symmetric (Sym) and asymmetric (Asym) in the fission fragment mass distributions is investigated. For present set of calculations the symmetric to asymmetric fission peak ratio is less than unity (P_{Sym}/P_{Asym}<1), which inturn suggests the dominance of asymmetric fission for above mentioned compound nuclei. The role of shell corrections and deformations of fragments in the fission dynamics is duly addressed. The study of fission fragment mass distributions is further extended to the isotopic analysis of above mentioned preactinide and actinide nuclei at common $E_{c.m.}\approx$80 MeV near the barrier. It is observed that the lighter isotopes exhibit symmetric fission distribution, whereas heavier ones prefer to decay via asymmetric path. A transition between symmetric and asymmetric fission occurs around fissioning nuclei with N/Z$\approx$1.4, showing the triple humped mass distribution suggesting comparable contribution of symmetric and asymmetric fission.

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