Role of Multipole Deformations and Coplanar or Noncoplanar Collisions in the decay of Hot and Rotating Compound Nuclei.

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Introduction

The forefront area of Nuclear Physics Research involves the Heavy-ion Reactions(HIR) to study the fundamental nature of matter, gaining deeper insight into nuclear dynamics. To study the low-energy Heavy-ion reactions theoretically, various models have been developed to study the various processes of Compound Nucleus(CN)-formation/ or decay, fusion-fission(ff), and quasi-fission(qf), which are supposed to be based on the Gamow's theory of α-decay of quantum tunnelling or the statistical model based nuclear fission. Thus, theoretical developments have been made prefacing the different statistical and non-statistical codes to study the HIR in which the Dynamical Cluster-decay Model (DCM), given by Gupta and Collaborators [1], is based on Quantum Mechanical Fragmentation Theory (QMFT). In DCM the decay of hot and rotating CN is studied, which is a reformulation of Pre-formed Cluster Model (PCM) for ground state, spontaneous cluster-decay phenomenon. Within the DCM, the decay of CN is treated in two steps: first the quantum-mechanical Preformation Probability P_0 of the cluster to be pre-born inside the nucleus and then the penetration P of cluster through the interaction barrier like in Gamow theory of α-decay via quantum tunnelling, calculated by solving the Schrödinger equation in mass asymmetry (η) and in R-coordinate by using the WKB integral method. Thus, in terms of these probabilities, for ℓ partial waves, the CN decay/ formation cross section for each fragmentation (A_1, A_2), is

$$\sigma_{A_1,A_2} = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P; \qquad k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \tag{1}$$

The QMFT-based Fragmentation potential comprises of Binding energies, Nuclear Interaction potential, Coulomb potential and Rotational energy, where the role of deformations $\beta_{\lambda i}$, λ=2,3,4 and temperature-dependance is also taken into consideration.

Discussion and Results

In this thesis, DCM is applied to study the radioactive ^{220}Th* CN [2] formed through various entrance channels ^{16}O+^{204}Pb, ^{40}Ar+^{180}Hf, ^{48}Ca+^{172}Yb and ^{82}Se+^{138}Ba at near barrier energies, where experimentally, instead of fission, the Evaporation Residue (ER) cross sections are measured. First, the DCM calculations for the formation and decay of ^{220}Th* CN are made for β_{2i}-alone, with the corresponding "optimum" orientations θ_i^{opt} and coplanar nuclei ($\Phi=0^o$). The fragmentation potential $V(\eta)$ is used to identify the "cold" target-projectile (t-p) combinations referring to the potential energy minima based on "hot" fusion configurations since it supports the asymmetric fission mass distribution, observed in experiments. In addition to all the (t-p) combinations already used in experiments (mentioned above), a number of other reactions based on ^{6}Li, ^{26}Mg and ^{86}Kr beams are predicted. For the decay process, neck-length parameter ΔR, which for a fixed value, fits the total ER cross section nicely but *not* the individual decay channel cross sections. In particular, the unobserved 1n and 2n decay channel cross sections are over-estimated, and observed ones under-estimated, compared to experimental data. Thus, choosing different ΔR-values for each decay channel, i.e., different reaction time scale for each decay channel, the unobserved 1n, 2n cross sections are made negligibly small, and the 3n and 5n fitted nicely exactly

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to give the CN decay cross section, whereas 4n cross section calls for the empirical non Compound Nucleus(nCN) contribution, which in turn allows us to predict the ff cross section.The best fitted ΔR's are found to be independent of the entrance channels, despite their very different cross sections, in conformity with our earlier works. Furthermore, the mass asymmetry and magic shell structure of nuclei play an important role in entrance channel effects leading to the largest decay cross section for the most asymmetric and doubly magic (t-p) combination, the magicity taking over asymmetry for both the channel and (total) ER cross sections. Also, the variation of both CN formation and survival probabilities P_{CN} and P_{surv} with E^* fit in with the known systematic of other radioactive CN studied so far, thereby giving credence to our DCM-analysis of $^{220}Th^*$.

As a next step in sophistication of our calculation, we investigate the role of higher multipole deformations β_{3i} and β_{4i} with corresponding "compact" orientations θ_{ci} for both cases of co-planar (Φ=0^o) and noncoplanar ($\Phi \neq 0^o$) configurations, studied for the decay of $^{220}Th^*$ CN, extending our above mentioned work of β_{2i}-alone with θ^{opt} and Φ=0^o, all within the framework of DCM [3]. For the decay of CN $^{220}Th^*$, the mass fragmentation potential V(A_i), more so the preformation yields $P_0(A_i)$, show an asymmetric fission mass distribution, in agreement with one observed one in experiments, irrespective of large changes (by 36^o and 34^o), respectively, in θ_{ci} and Φ_c. Interestingly, one again the 3n- and 5n-decay channels fit exactly, i.e., are always the pure CN decays, the 4n-decay channel shows the presence of large ($\sim$95%) nCN content, and thus is independent of adding or not adding (β_{3i}, β_{4i}), and noncoplanarity, i.e., 3n and 5n cross section fit exactly and the magnitude of nCN cross section in 4n decay channel remains the same within <1% for each case. However, this result is not general, rather the CN-specific. Furthermore, the near constancy of best fitted R_a ($\equiv \Delta R$) with E^*, independent of the entrance channel nuclei, allows us to predict the decay channel cross sections σ_{xn} for reactions not yet studied experimentally.

Finally, the role of using different nuclear interaction potentials, say, the SEDF- based ETF approach with densities in frozen-density approximation, in comparison to the above used proximity, pocket formula of Blocki *et al.*, is also studied. The DCM calculations show the near-independence of nCN cross section on nuclear interaction potential. However, it still remains to be seen if the excitation functions in the decay of $^{220}Th^*$ CN are also nuclear force independent.

Concluding, the present study using deformation effects upto hexadecupole and including Φ degree-of-freedom, i.e., two nuclei taken in the same plane (coplanar; Φ=0^0) as well as out of plane (noncoplanar; $\Phi \neq 0^0$), and using different nuclear interaction potentials like Proximity Formula of Blocki *et al.* and Skyrme Energy Density Formalism, being independent of all the variables, presents a theoretical manifestation of the nCN content in the decay of $^{220}Th^*$ formed through different entrance channels and that the empirically determined nCN cross section $\sigma^{emp.}_{nCN}$ is *not* an artefact of our calculations and thus could be measured in experiments, as expected of rare-earth targets.

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