Decay analysis of different nuclear systems using collective clusterisation approach

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Introduction

Scientific literature reveals that the process of clusterisation takes place from largest scale of universe, galaxies to smallest scale, quarks. It will be highly surprising, if there is no clustering in the nuclear domain. This process of clusterisation at different scales of universe motivates the present thesis work to study the nuclear reaction dynamics through the process of collective clusterisation. The clustering is found to be important in number of nuclear phenomenon such as alpha clustering in light nuclei and cluster radioactivity (CR) etc. The quantum mechanical fragmentation theory (QMFT) based on process of collective clusterisation, led to the prediction of cluster radioactivity (CR) in 1980 and was confirmed experimentally in 1984 [1].

The QMFT based fragmentation potential comprises of binding energies (BE) (liquid drop energy (V_{LDM}) + shell corrections (δU)), Coulomb potential (V_c) and proximity potential (V_P). For the present work we have separated contribution of V_{LDM}(T=0) and δU (T=0) in order to investigate the role of shell corrections in the decay of the radioactive nuclei through the preformation probability via fragmentation potential. The PCM has been further developed, for the study of the decay of excited compound nuclear system to the dynamical cluster model (DCM). The DCM has been applied successfully to study the different decay processes of the different mass regions of the periodic table, except lighter nuclear systems. In the present work, the DCM is applied to study the different decay mechanisms i.e. compound nucleus (CN) and non compound nucleus (nCN) processes of very light mass compound nuclei.

The only free parameter of DCM is neck length parameter (ΔR), which is optimized with reference to available experimental data. Within DCM, ΔR have been shown to represent the barrier modification characteristics. It points out that the fitted values of ΔR simply results in corresponding barrier lowering parameter (ΔV_B) for a particular reaction i.e. barrier lowering is an inbuilt property of DCM. We have explored first time the role of ΔR in the predictability of DCM. By utilizing this property of ΔR, we are able to predict the fusion cross section ($\sigma_{fus.}$) for those reaction for which the experimental data is not available. The present thesis work will help the research groups in the form of theoretical backup for such reactions.

Calculations and discussions

First, in order to explore the role of shell corrections exlicity, selected radioactive parent nuclei have been investigated for their ground state decay within the the collective clusterisation approach of PCM, specifically, which lead to ^{208}Pb daughter nucleus always through emission of clusters i.e. ^{14}C, ^{18,20}O, ^{22,24,26}Ne, ^{28,30}Mg and ^{34}Si. In this study the importance of δU is very well explored in the process of CR. We find that without δU, experimentally observed clusters clusters are not strongly minimized or preformed. The results explicitly explore that the V_{LDM} along with δU plays a crucial role to give proper understanding of the process of CR [2].

Further, the the reformulation of PCM i.e. DCM is applied to study the decay of very light mass excited compound systems ^{32}S* and ^{31}P* formed in ^{20}Ne+^{12}C and ^{19}F+^{12}C reactions, respectively, at an excitation energy

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E^*_{CN}=60 MeV [3]. We have investigated the target like yield, i.e., C-yield (σ^C_{yield}), which contains fusion-fission (ff) decay cross-section σ_{ff} and deep inelastic orbiting (DIO) cross-section, σ_{orb} in the decay of ^{32}S* and ^{31}P*. It is observed that for ^{32}S* system there is a competition between ff and DIO processes, while, for ^{31}P* there is a contribution of σ_{ff} only. The comparative analysis of C-Yield for the considerations of spherical and oriented nuclei, shows similar results with the only difference of the values of ΔR, which are more for the later case and very well compared with the experimental data for both the considerations. The effect of excitation energy on the target like carbon yield in the decay of ^{32}S* shows the rise in σ_{ff} with increasing energy [3].

The DCM is further applied for the comparative analysis of intermediate mass fragments IMFs (Z = 3-6) and light particles LPs (Z≤2) in the decay of ^{26,27,28,29}Al* formed in the reactions ^{16,18}O+^{10,11}B [4]. Within collective clusterisation approach of DCM we find that, for IMFs having Z=3, 4, 5 and 6 the range of mass minima's is $\sum_{i=5}^{8} A_i$, $\sum_{i=8}^{9} A_i$, $\sum_{i=9}^{13} A_i$ and $\sum_{i=11}^{15} A_i$, respectively. With increase in the mass of CN, Z=6 becomes more prominent as compared to its neighboring fragments which is also the case with experimental data. It has been observed that the σ_{LPs} are in good comparison with the available experimental data for ^{28,29}Al*, but this is not so for ^{26,27}Al*. It is to be noted here that once we switch to spherical consideration, then we could nearly fit the LPs data. We have also conformed the Bohr's hypothesis via the entrance channel independence for compound nucleus ^{28}Al* formed through ^{18}O+^{10}B and ^{19}F+^{9}Be channels at same excitation energy.

The ΔR value, within the DCM, makes special case of interest and investigation here. It has been observed that the value of empirically fitted ΔR^{emp} can be fixed uniquely for a particular set of reactions induced by the same projectile at the same incident energy E_{lab} (in MeV) [5]. Interestingly, for a given projectile at a fixed E_{lab} on different targets, we are able to calculate/ predict the σ_{fus} for all the reactions under study. This work provides an excellent platform to analyze those reactions which are difficult to study experimentally.

The application of established predictability of DCM has been made to predict the σ_{fus} for the CN $^{60}Zn^*$,$^{60}Ni^*$ and $^{60}Fe^*$ formed in the reactions ^4He+^{56}Ni, ^4He+^{56}Fe and ^4He+^{56}Cr, for which the experimental data is not available [6]. In order to fix the ΔR_{emp} and further investigations of the decay of CN having same A=60, the available experimental data for σ_{fus} of $^{44}Ti^*$, $^{48}Ti^*$ and $^{68}Ge^*$ formed through ^4He induced reactions at $E_{lab}\sim$ 10, 13, 17 MeV have been used. We have investigated the effect of N/Z ratio in the decay of CN under study. The transition in the decay modes is analyzed with the changing N/Z values i.e. the LPs, IMFs as well as SFs from the CN.

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