Dynamical aspects of decay of exotic nuclear systems

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Introduction

The inquisitive nature of human mind has led to investigation of the matter from subatomic to astronomical scale. The quest of mankind started with making their environment livable in response to various surrounding conditions, resulted into number of discoveries and innovations. During last two centuries the scientific platform got widened, largely, with marvelous advancements in science and technology. Eventually, the work of exploration of matter got highly accelerated with contributions from explorers (scientists) in the field, cut across various nationalities around the world. The studies related to the heavy-ion (HI) fusion reactions and associated nuclear decays are at the forefront of nuclear research these days. Theoretically, various models have been developed to address the process of HI collisions in different mass regions. As the aim of this thesis is to study the decay dynamics of exotic nuclear systems, so the most of the nuclear systems under study are the neutron-rich or proton rich. In this thesis, the ground state (T=0, ℓ=0) decay of proton rich drip line nuclei are studied under the formalism of preformed cluster decay model (PCM) based on the quantum mechanical fragmentation theory(QMFT). The dynamical cluster-decay model (DCM), which is an extension to PCM, have been used to study different nuclear emissions from hot (T$\neq$0) and rotating ($\ell\neq$0) neutron rich and neutron deficient composite systems formed in HI reactions [1]. The benefit of DCM is that it treats the binary fragmentation of emitting compound nucleus as light particles (LPs), Intermediate mass fragments (IMFs) as well as symmetric mass fragments (SMFs), on equal footings which is not the case with other fission and statistical models. The only free parameter of DCM, the neck length parameter (ΔR), is optimized with reference to the available experimental data. We have also explored the role of ΔR in the HI reactions at low energy within DCM.

Calculations and Discussions

Firstly, the reaction dynamics of ^{12}C HI induced compound systems $^{24,25}Mg^*$ via respective entrance channels ^{12}C+^{12}C and ^{13}C+^{12}C are explored within the collective clusterization approach using the DCM. Except from experimentally observed ^{6,7}Li and ^{7,8,9}Be fragments ^{5}He, ^{10,11}B and ^{11,12}C fragments have also been studied. The effect of pairing coefficient have been explored and results show the minute change in clustering effects due to inclusion or non-inclusion of it, as the change in pairing energy coefficient at the given temperature of the reaction is not much significant. We see the enhancement in preformation probability of the fragments having the α-cluster structure in their complementary fragments. Secondly, the role of level density parameter has been investigated for both the spherical and deformed configurations. It is found that by changing level density parameter there is enhancement in ℓ- summed up preformation probability which accordingly affects the yields of the respective fragments. The DCM calculated cross sections follow the trend of experimental observations. The experimentally

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observed ^{6,7}Li and ^{7,8,9}Be fragments having complementary fragments ^{18}F and ^{16,18}O i.e. having α-cluster structure contributes more towards the yield as compared to fragments with absence of α-cluster [2].

Further, the ^{12}C HI induced reactions extended to explore the dynamics of neutron-rich light mass compound nuclei $^{24,25,26,27}Mg^*$ formed in $^{12,13,14,15}C +^{12} C$ fusion reactions, respectively, at different $E_{C.M.}$ values within DCM. A fusion enhancement is observed as we go from CN having even number of neutrons to CN with odd number of neutrons. The reactions involving light exotic nuclei show fusion enhancements compared to stable nuclei as projectile and are of astrophysical significance. Interestingly, it is found that the only parameter of the DCM, the neck-length parameter ΔR related to the barrier-lowering is in linear relation with σ_{Fusion} at chosen incident laboratory energy. The fusion enhancement is found to be larger for odd neutron number nuclei which indicates the influence of unpaired neutrons on fusion cross sections. The DCM calculated fusion cross sections are in good comparison with the available experimental data for the given reactions [3].

Next, the effects of shell closure (proton shell closure Z = 82) in the decay of CN having having A $\sim$ 200 formed through ^{19}F induced reactions, at different E_{lab}. The decay of neutron deficient CN ^{194}Hg*, ^{200}Pb*, ^{203}Bi* and ^{207}At* formed in ^{19}F+^{175}Lu, ^{19}F+^{181}Ta, ^{19}F+^{183}W and ^{19}F+^{188}Os reactions, respectively, have been studied using DCM. In DCM, the collective fragmentation potential is calculated within Strutinsky macro-microscopic method and empirical shell corrections are taken from Myres and Swiatecki. The deformations of the interacting nuclei are taken here upto quadruple deformations. The results show that LPs having Z close to and on either side of the 82 spherical proton shell closure are strongly preformed in comparison to asymmetric fragments but for ^{207}At* LPs are weakly preformed due to the fact that they are having Z little away from the proton shell closure, particularly at higher ℓ-values. The calculated σ_{LPs} are in good agreement with the experimental data [4].

Finally, the investigation of the alpha (α) emission as competing mode of one proton emission using the PCM was carried out. To explore the competing aspects of α and one proton radioactivity, we have chosen emitters present immediately above and below the Z = 82 shell closure i.e. ^{177}Tl and ^{185}Bi by taking into account the effects of deformations (β_2) and orientations of outgoing nuclei. The minimized values of fragmentation potential and maximized values of preformation probability (P_0) for proton and alpha fragment demonstrated the crucial role played by even Z - even N daughter and shell closure effect of Z = 82 daughter, in ^{177}Tl and ^{185}Bi, respectively. The higher values of P_0 of the one proton further reveal significance of nuclear structure in the proton radioactivity. From the comparison of proton and α decay, we see that the former is heavily dominating with larger values of P_0 in comparison to the later. Theoretically calculated half-lives of one proton and α emission for spherical and deformed considerations have also been compared with available experimental data [5].

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