A study of basic and exotic decay modes of medium, heavy and superheavy nuclei

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In nature an unstable nucleus reaches stable state by emitting either any of the basic decays like α particle, β particle and/or γ radiation or through fission. A new decay called cluster decay, which is intermediate between the α decay and fission, was theoretically and experimentally established in heavy nucleus. The lifetimes of these decay modes vary from seconds to years. The major difficulty in theoretical studies is the formulation of a single model to describe the basic and exotic decay of nuclei belonging to different mass regions, whose lifetime varies between extreme values of seconds to years. The aim of this thesis is to study the characteristics of different decay modes *viz.* alpha, proton, cluster decay and complex fragment emission of medium, heavy and superheavy nuclei [1–5]. Models such as 'Unified Fission Model' (UFM), in which the penetrability of the overlapping region is considered to be the preformation probability, 'Preformed Cluster Model' (PCM) and 'Dynamical Cluster decay Model' (DCM) are employed for the study.

Alpha decay is the primary decay mode of unstable medium, heavy and superheavy nuclei. Fitting of half-lives for 25 even-even nuclei of Ra, Th and U is done by introducing a parameter $\triangle R$, which extends the touching point radius. A linear relation connecting this $\triangle R$ and Q-value of the decay is obtained with certain constraints. Half-lives of even-even isotopes of nuclei with $Z = 82$ to 102 are calculated by using this linear relation, for the use of both linear form of overlapping potential and second order polynomial potential for four different surface energy coefficients, entering the calculations of proximity potential. The results, in both the cases, reveal that the preformation factor of the nuclei Po, Rn, Ra, Th, U, decreases with increase in parent neutron number (N_p) and has a minimum value for N_p= 128. For the nuclei Pu, Cm, Cf, Fm, No, minimum value is noted for N_p= 154. The values of preformation factors clearly show the shell closures at the daughter neutron number $N = 126$ and 152. The penetration probability is found to be the maximum for those nuclei with N_p= 128, which implies that, for the two neutrons outside the closed shell, the probability is more to penetrate the barrier. Among the four surface energy coefficients, half-life calculations using the form due to Myers and Świątecki $\gamma - MS00$ version, match well with the experimental half-life values. α decay half-lives of superheavy elements (SHE) are calculated [1].

Preformation probability (P_0) is calculated using the penetrability of the overlapping potential with second order polynomial form, with WKB approximation, for the charge minimised complete binary spectrum of five elements such as ^{56}Ni, ^{116}Ba, ^{226}Ra, ^{256}Fm and ^{294}X for the use both reduced mass and reduced classical hydrodynamical mass and the results are compared with those calculated using PCM [2]. The WKB calculations with reduced mass, show structural variation corresponding to four nucleon transfer for the complete spectrum of ^{56}Ni and atleast upto ^{20}O corresponding to ^{116}Ba. For heavy systems like ^{226}Ra, ^{256}Fm, ^{294}X these calculations does not show any strong structural variations. Further, the magnitude of P_0 using hydrodynamical mass in WKB method, can be made to match with that due to PCM results by fine tuning the parameter entering the calculations of hydrodynamical mass.

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Half-lives of the cluster decay of 15 cluster emitters for known cluster decay are calculated by using two step model, the penetrability from touching point radius to the point where the total potential meets the Q-value, by assuming preformation factor as one, within PCM. An empirical relation for preformation probability is obtained by fitting the difference between the calculated and experimental half-lives with the different physical quantities such as Q, $Q^{1/2}$, $Q^{3/2}$, mass number of the fragment (A_2) and mass asymmetry (η) of the decay and different combinations among them [3]. P_0 of complete binary spectrum of elements *viz* ^{226}Ra, ^{256}Fm and ^{294}X are evaluated using these empirical relations. These values for ^{226}Ra, ^{256}Fm and ^{294}X shows excellent structure effect for the use of quantities Q, $Q^{1/2}$, $Q^{3/2}$ atleast upto A_2=50, but underestimates and overestimates respectively for the use of $Q^{1/2}$, $Q^{3/2}$ with reference to P_0 calculated due to reduced mass. For the use of Q, both the empirical P_0 and WKB calculations match with each other atleast upto A_2 = 50. The structural variation in P_0 depends mainly on Q rather than on A_2 or η.

Half-lives of 43 proton emitters of proton drip line, with $Z = 51$ to 83, for ground and isomeric states for the emission of proton and alpha, are calculated incorporating the deformation degree of freedom for all the parent nuclei within UFM [4]. Calculated values are in good agreement with the experimental values for proton emission. The branching ratio (BR) of proton emission relative to α decay reveal that, elements with $A = 105$ to 159, $Z = 51$ to 73, prefers to decay via proton emission whereas, as the mass increases beyond A =160, the probability for α decay increases, thereby decreasing the BR for proton emission. We have calculated the half-lives for both alpha and proton emissions for the SHEs with odd-Z (Z=105 to 119 with A = 241 to 287). Calculations reveal that α emission is found to be the primary decay mode, whereas for a few systems proton decay competes with alpha decay. Further we have calculated the half-lives of even-even isotopes of a few clusters such as C, Ne, Mg, Si, Ar and Ca. Amongst the isotopes considered, ^{12}C, ^{20}Ne and ^{24}Mg has the lowest half-life and has the highest preference with $N = Z$ clusters and as we move towards heavier clusters, only clusters with $N \neq Z$ clusters are preferred.

Temperature-dependent mass formula is used to analyse the de-excitation characteristics of the compound system ^{56}Ni* formed in two center-of-mass energies 51.6 and 60.5 MeV, with the entrance channel ^{32}S+^{24}Mg [5]. Even though structural variation is absent in the fragmentation potential, the calculated total light particle (LP) cross section and intermediate mass fragment (IMF) cross section matches with the experimental values. Results of fragmentation potential at different angular momentum ($\ell\hbar$) values, clearly show the preference for the LP emission at low ℓ values, whereas the symmetric fragments are preferred over the asymmetric fission at higher values of ℓ. This is confirmed in the results of P_0 at different ℓ. Contribution from ^{28}Si starts only from $\ell = 30\hbar$ and at low ℓ values ^{1,2}H are preferred. Individual cross sections for the fragments for $A_2 = 12$ to 28 differs from the experimental calculations except for a few fragments, however the total LP cross section as well as IMF cross section are found to be well within the limits.

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