Decay and structure studies of drip line and unstable nuclei in various mass region

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Stability of the nucleus is obligatory for the existence of nuclei. It depends on many factors such as neutron to proton ratio, binding energy, shell gap/magic numbers, etc. The unstable or radioactive nuclides lie on either side of the stable nuclides in the nuclide chart. Drip lines are the boundary lines which encloses all the nuclei. The proton drip line is the boundary line towards the proton-rich side and neutron drip line is the boundary line towards the neutron-rich side. In addition to the basic alpha decay studies, exotic decay modes of light, medium, heavy and superheavy nuclei are studied in this thesis.

Exotic nuclei are the nuclei with N/Z ratio much smaller or much larger and their disintegration results in different exotic decays such as proton emission, neutron emission etc. One-proton emission is an exotic decay process when the unstable nucleus near the proton drip line emits a proton and two-proton emission, which is also an exotic decay, occurs when one-proton emission is energetically forbidden. They occur in proton-rich or neutron-deficient nuclei and one-proton emission specifically occurs in odd Z nuclei.

Based on the preformed cluster model, using the cluster core model, the exotic two-proton nuclei are studied. The experimentally established nuclei such as ^{45}Fe, ^{48}Ni, ^{54}Zn and ^{67}Kr and the theoretically proposed ^{19}Mg, ^{30}Ar, ^{34}Ca, ^{62}Se, ^{66}Kr and ^{71}Sr nuclei are investigated [1-3]. The studies are carried out in terms of simple potential energy surfaces for all possible cluster plus core configurations and it is used to calculate the preformation probability by solving the Schrodinger equation of motion in mass asymmetry coordinate. The fragmentation potential energy and preformation probability helps in identifying the possible two-proton emitters. The results obtained are substantiated with the Q-value systematics analysis.

Halo nucleus is another type of exotic nucleus, where it has a core nucleus which is surrounded by a halo of protons or neutrons which makes the nucleus spatially expanded. The two - body break up of halo nuclei is reported earlier using the cluster core model, and three cluster model which is developed for the studies of ternary fission is applied here for the first time to study the three-body break up [4]. The potential energy is calculated as the summation of the mass excesses of the three fragments, Coulomb potential and nuclear proximity potential. The results reveal that the three-body break up does not result always with 2n and/or 2p as a cluster. Further, the three-body structure of 2n/2p halo are initially formed as a three body structure with 1n or 1p as one of the cluster which finally results in the amalgamation of the remaining nuclei to form a core by donating either 1n and/or 1p to result on a 2n or 2p cluster plus core. The results are substantiated with the results of preformation probability.

A model independent and ℓ-dependent four parameter empirical formula is proposed for calculating the half-life period of both ground state and isomeric one-proton emitters [5,6]. In this formula, the Q-dependence is taken similar to Geiger-Nuttall law, but for different ℓ-values. The logarithmic half-lives of the experimental data corresponding to different ℓ-values of different proton emitters are fitted against the charge number of the daughter and Q-value. It is seen from the experimental data that, the half-lives corresponding to the different angular momentum ℓ associated with the transitions linearly vary as a function of the inverse square root of the Q-values. The choice of a particular exponent value is 0.8 on the Z_1 charge dependence. The slope and intercept as a function of ℓ value is considered to reduce the number of parameters and to unify the formula.

A simple formula involving only four parameters applicable to different ℓ-values are obtained. The logarithmic half-lives are calculated and compared with the experimental values and other available theoretical estimates.

After the success of calculation of half-- formula, the study is extended to calculate the half-life period of exotic two-proton emission. A similar formula is proposed for the two-proton emitters by retaining the same form. Four parameters of the formula are fitted using the results of effective liquid drop model [7] and are found to fairly agree with the known experimental half-lives as well as with other theoretical model predictions [8]. The formula obtained for one-proton emitters and two-proton emitters are used to predict possible one- and two-proton emitters in the superheavy mass region, ranging from the charge number 100 to 120, for $\ell = 0$ [9-11] .

The empirical formula proposed to calculate the half-life period of proton emitters is generalized to find the half-life period of fine structure alpha emitters [12]. The alpha decay half-lives of odd-odd nuclei, odd-even nuclei, even-odd nuclei and even-even nuclei in different ranges for different ℓ-values are calculated and compared with experimental values which agreed well. The half-lives of combined odd-odd, odd-even, even-odd and even-even nuclei are also calculated and compared with the experimental values which shows fair agreement. The applicability of the combined equation to some other ground state isotopes in the heavy mass region also agrees well with the experimental values. Apart from the proton emission region, this work shows that the proposed formula can be used for the non-proton emitters also.

Using the cluster core model, neutron emitters are studied for the first time [13]. The experimentally confirmed and non confirmed nuclei are investigated in terms of potential energy surfaces for all possible cluster-core configurations. Separation energy calculations are also analyzed to further substantiate the result. Using the proposed formula, half-life period of one- and two-neutron emitters are also calculated which shows fair agreement and proved once again that this formula can be used for non-proton emitters also.

From all the results, it can be concluded that, a generalized form of a four parameter formula (wth different set of constants) with ℓ-dependence is proposed for various decay modes such as one-proton, two-proton, one-neutron, two-neutron, alpha etc. The potential energy surface and preformation probability studies are also done for two-proton emitters, two-neutron and two-proton halo nuclei.

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