Studies on the Modes of Decay of Normal and Hypernuclei

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The last few decades have witnessed an extensive development in theoretical as well as experimental aspects of nuclear physics. High precision data are available with the advent of new experimental techniques. As the experimental techniques achieved greater perfection various theoretical analysis are also coming in supporting the experimental studies.

The present thesis is a humble attempt to account for the decay modes of normal and hypernuclei. Among normal nuclei, we mainly focus on the superheavy nuclei which have become an important part of the modern nuclear physics. The main tool to investigate such unstable nuclei is to observe their radioactive decay modes. The group of radioactive processes caused by the strong interaction involves various decays namely, alpha decay, proton decay, cluster emission and spontaneous fission. The study mainly highlights the alpha decay and the spontaneous fission of superheavy nuclei.

The studies of hypernuclei have received a great attention during the past few years. Various properties of Λ hypernuclei including the binding and separation energies are studied in the present thesis. The possibilities of the decay modes of hypernuclei triggered by strong interaction, particularly, the alpha decay and the cluster emission are also presented.

This thesis consists of seven chapters. The first chapter gives a brief overview of the historical background of nuclear physics focusing on the decay studies, the superheavy nuclei and the hypernuclei.

The second chapter describes various theoretical formalisms used in the thesis. The major part of the decay studies of superheavy nuclei has been performed using the well established Coulomb and proximity potential model for deformed nuclei (CPPMDN) and the shell-effect-dependent formula of Santhosh et al. The method of calculating alpha half-lives using the CPPMDN is given in detail. The formula for spontaneous fission half-lives previously proposed by our group has been modified by including a shell correction term. The inclusion of the term made the formula more effective in the studies of spontaneous fission half-lives in superheavy region.

The subsequent chapters are devoted to the decay studies. The first part of the third chapter represents the studies on the decay modes and half-lives of the recently synthesized superheavy nuclei using the CPPMDN and the shell-effect-dependent formula. The applicability of shell-effect-dependent formula in predicting the spontaneous fission half-lives in superheavy region is described in detail. A comparison of spontaneous fission half-lives in superheavy region using various theoretical models is performed and the model-to-model variations in the predictions of half-lives are revealed through the study. The other two sections of the third chapter illustrate the extensive studies on the modes of decay of even Z ($104 \leq Z \leq 136$) and odd Z ($105 \leq Z \leq 135$) superheavy nuclei. The mass excess values of most of the nuclei under study are taken from the WS4 mass table. The CPPMDN and the shell-effect-dependent formula respectively are used to calculate the alpha and spontaneous fission half-lives. The obtained results are compared with the values using other theoretical formalisms as well as with the experimental results. The proton and neutron separation energies are evaluated to find the nuclei which may decay through proton and neutron emission. Through these two exhaustive studies the modes of decay of all the superheavy isotopes within the range $104 \leq Z \leq 136$ are predicted. These predictions are expected to open further experimental investigations in superheavy region.

The fourth chapter also deals with the alpha decay chains of various superheavy nuclei. But, in this chapter, instead of using the WS4 mass table, various other mass tables are used for obtaining the energies of alpha decay. The first part of the chapter deals with the decay properties of odd Z superheavy nuclei which include the decay studies of the isotopes of elements with Z = 109 (Mt), 111 (Rg), 113 (Nh), 121, 123 and 125. The second part of the chapter is about the decay properties of even Z superheavy nuclei with Z = 110 (Ds), 122, 124, 126 and 128. Comparisons with the experimental results as well as with other theoretical formalisms are shown in various tables of the respective sections. In the case of the isotopes of Ds, instead of evaluating the decay chains as a whole, the alpha decay, spontaneous fission and proton decay half-lives of the isotopes are given in separate tables. The cluster decay studies of the isotopes of Ds predicted the effects of neutron shell closure at N = 184 and N = 202. The alpha decay studies around the next predicted magic number, Z = 126, unveiled the possibilities of observing different isotopes which decay through alpha emission. The applicability of CPPMDN and shell-effect-dependent formula for predicting the decay modes in superheavy region is revealed through the studies given in the third and fourth chapters.

The fifth chapter deals with the study of cluster decay from heavy and superheavy isotopes. The first part of the chapter deals with the cluster decay studies on heavy nuclei, the nuclei in the trans-lead region. Three different formulae are formulated in this part to calculate the cluster preformation probabilities, based on various quantities such as size of the cluster, proton number of the cluster and daughter nucleus and the Q value for the decay. The half-lives of all the experimentally identified cluster emissions were calculated with preformation using these three formulae. Better agreement with experimental results is obtained while using the formula which connects Q value and the preformation probability. A comparison with other theoretical models is also done. The alpha decay half-lives of the heavy isotopes are calculated using the same formalism and are seen to be in good agreement with the experimental results. In the other section of the chapter, these studies are extended into the superheavy region. The preformation probabilities for the alpha particle and the heavy clusters are calculated with the Q value dependent formula developed in the previous section. In the first part of this section a comparison of the calculated alpha decay half-lives using the new formalism with the experimental results is given. The study explained the applicability of the new method in predicting the alpha half-lives in superheavy region. The probable heavy cluster radioactivities from superheavy nuclei are studied in the remaining part. A theoretical comparison is also performed with the results obtained by different groups. The study suggested that the heavy cluster radioactivity may be comparable or dominant than alpha decay for some of the isotopes of elements with $Z \geq 118$.

The sixth chapter details the studies on the properties of hypernuclei, focusing on the alpha and cluster decay from Λ hypernuclei. In the first part of the study, an extension of Bethe-Weizsäcker mass formula is proposed to evaluate the binding energies of Λ hypernuclei. A new semi-empirical formula, with minimum standard deviation, is also developed for finding the separation energies of Λ hypernuclei. The applicability of these formulae is demonstrated in detail. The second part of the chapter is devoted to the alpha and cluster decay studies from various Λ hypernuclei. The evaluation of the decay half-lives is done by incorporating a Λ -nucleus interaction term in CPPM. Comparisons of the half-lives with normal nuclei are performed in each case. The first study in this part is on the alpha decay of the isotopes of hyper Po nuclei. The alpha and ^{14}C cluster emissions from hyper Ra and hyper Ac nuclei are given thereafter. By comparing the half-lives of hyper isotopes with their corresponding normal nuclear core, it is seen that the inclusion of Λ -nucleus interaction changed the half-lives of the isotopes. The neutron shell closure at N = 126 and the double magicity at Z = 82 and N = 126 were also clear from these studies.

In short, the thesis is focusing on the studies of alpha decay, spontaneous fission and the cluster decay of superheavy isotopes and also the alpha and cluster decays from Λ hypernuclei. Many isotopes in superheavy region are predicted as suitable candidates for experimental detection. Such studies are going to be essential for planning and developing future experimental techniques. Since the thesis dealt with the most relevant topics in the current nuclear physics, the findings put forward here are sure to give an impetus for the future theoretical and experimental inquiries in the respective fields.