Theoretical studies on the decay of heavy nuclei from ground state and as an excited compound system formed in heavy ion reaction

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Introduction

The present scenario of nuclear physics is highly interesting to both the experimentalists and the theoreticians. The advancement in the heavy-ion beam technologies, and the studies on the heavy-ion fusion reactions have resulted in the fast growth of the nuclear chart especially in the superheavy (SH) mass region. Even though both experimental and theoretical studies have been performed in the heavy and SH region of nuclei, understanding the nuclear stability-instability in the SH mass region still remains to be a mirage. But, the alpha decay studies in the SH region have given the experimentalists an urge to reach the shore of magic island or the island of stability around Z=120, 124 or 126 and N=184. At present, the synthesis and the study on the various decay mechanisms of both the heavy and the superheavy nuclei (SHN) have been the hottest topic in nuclear physics. So, the present work encompasses the detailed study on the decay mechanisms of both heavy and SHN, a comparison with the available experimental data and theoretical predictions on the decay half lives (alpha, cluster and spontaneous fission) of some unknown SH isotopes. The decay of excited compound systems formed in heavy ion reactions is also an area of interest in our studies.

Within the Coulomb and proximity potential model (CPPM) [1] and the Coulomb and proximity potential model for deformed nuclei (CPPMDN) [2], a wide range of studies have been performed on the alpha decay of heavy [3,4] and SHN [2,5], cluster decay of heavy[6,7] and SHN [1], and also on the decay of excited compound nuclei.

The Coulomb and proximity potential model for deformed nuclei

In CPPMDN, the modified version of CPPM, the potential energy barrier is taken as the sum of deformed Coulomb potential, deformed two-term proximity potential and the centrifugal potential, for the touching configuration and for the separated fragments. For the pre-scission region, simple power law interpolation has been used. The details on these models could be seen in the Refs. [1,2].

Results and discussion

The details on the results obtained through the studies are given below.

(a) Alpha decay studies of heavy and SHN

The initial investigations were on the alpha decay from heavy nuclei, and the isotopes of Eu (Z=63) [5] and Bi (Z=83) [3] were considered for the study, for which the experimental data were available. While in the case of alpha decay studies of Eu isotopes (with $130 \leq A \leq 153$), the decay between the ground state energy levels of the parent and daughter nuclei alone were considered, in the case of Bi isotopes (with $184 \leq A \leq 224$), in addition to the ground state to ground state decays, the ground state to isomeric states and isomeric states to isomeric states were also considered, keeping the minimum possible value of angular momentum to be the basis of such considerations. On comparison with the available experimental data, it could be observed that the computed decay half lives of the naturally occurring ^{151}Eu and the ^{209}Bi were in good agreement with each other, and the alpha decay half lives for the rest if the isotopes were hence predicted. The influence of the neutron shell closure, N=82 on ^{145}Eu and ^{209}Bi with the highest half lives and N=126 on ^{147}Eu and ^{211}Bi with the least half lives, could also be demonstrated through the present study.

The next move was to study the alpha decay from SHN. The alpha decay chains of the recently synthesized SHN with Z=115 (with 271≤A≤294) [2], Z=117 (with 270≤A≤301), Z=118 (with 271≤A≤310), the experimentally attempted Z=120 (with 272≤A≤319) [4], and the yet-to-be synthesized SH element with Z=119 (with 274≤A≤313), were considered for the study, and these studies on the alpha decay and spontaneous fission, could be considered as the first theoretical study to be performed on the decay chains of SHN. The computed decay half lives for the isotopes $^{287,288}115$, $^{293,294}117$, $^{294}118$ and $^{298,299}120$ were compared with the available experimental data and were found to be agreeing well with each other. Hence, the decay half lives and the mode of decay (through the spontaneous fission studies) of a number of unknown isotopes of these elements have been predicted, and have also been computed and compared with other theoretical models too. The proton decay studies on the isotopes of Z = 120, have also been done, and this helped in detecting that the isotopes with 273≤A≤291 to be the probable proton emitters those lie outside the proton drip line. Thus the observations on the isotopes $^{284\text{-}286}115$, $^{288\text{-}292}117$, $^{289\text{-}293}118$, $^{280,281,292\text{-}299}119$ and $^{293\text{-}297,300,301}120$ could be of great help for the future experimental studies in the area of SHN.

(b) Cluster decay studies of heavy and SHN

In this part of the study, initially, for the cluster decay studies on heavy nuclei [6,7], all the known clusters ranging from ^{14}C to ^{34}Si, including the odd clusters ^{15}N,^{23}F,^{25}Ne,^{29}Mg and ^{33}Si, from various parent isotopes ranging from Fr (Z=87) to Cm (Z=96), leading to the doubly magic ^{208}Pb (or its neighbours), have been counted in. The computed half lives agree well with all the available experimental values, and the cluster decay half lives for the unknown decays were also computed and predicted using CPPM and also using other theoretical models. The phenomenon of odd-even staggering (OES) observed in the odd-cluster decays has also been demonstrated. The role of shell closure in cluster decays, and the dominance of neutron shell closure (N=126) over proton shell closure could be revealed through these studies.

While studying the cluster decay of SHN [1], the light even-even clusters in the range ^{4}He to ^{24}Ne from the even-even parent isotopes in the range Lv (Z=116) to Z=124, leading to the predicted doubly magic $^{298}114$ (or its neighbours), have alone been considered. Here also, the role of neutron shell closure, in daughter nuclei, on cluster decays could be clearly evidenced through the low values of the cluster decay half lives at N=184. The studies on the cluster decay from the SHN could thus endorse and indicate towards a new island of stability for the cluster radioactivity as $^{298}114$, after the experimentally observed ^{208}Pb.

(c) Study on the decay of excited compound nuclei

In this part of the study, as an extension of one of our earlier work, the decay of excited compound nuclei formed in heavy ion reactions has been discussed by taking $^{56}Cr^{*}$ to be the specimen compound nucleus. The asymmetric entrance channel ^{32}S+^{24}Mg through which $^{56}Ni^{*}$ is formed have been considered for the decay study, and the total cross section, the light charged particle (LC) cross section and the intermediate mass fragment (IMF) cross section have been evaluated. The available experimental data on the total cross sections, LC production cross sections and IMF cross section for the entrance channel ^{32}S+^{24}Mg were compared with the evaluated values, and could be seen to be in good agreement with each other. So, the total cross section, IMF cross section and LC cross section for the decay of $^{56}Ni^{*}$ that could be formed through another asymmetric entrance channel ^{36}Ar+^{20}Ne, for different ECM values, have also been studied and predicted. Hence, these studies could also be extended to other excited compound nuclei.

References

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