Theoretical studies on the stability of heavy and super heavy elements against cluster decay

*R K Biju
School of Pure and Applied physics, Kannur University, Payyanur Campus, Payyanur - 670327, INDIA
** email: bijurkn@gmail.com*

The present thesis is an attempt to understand the stability of heavy and super heavy elements against cluster radioactivity. The radioactive decay of nuclei emitting particles heavier than alpha particle is termed as cluster radioactivity. The cluster decay calculations suggest the interesting possibility of the interplay of closed shell effects of parent and daughter nuclei.

Using the Coulomb and proximity potential model [1, 2], the stability of heavy elements $^{248\text{-}254}$Cf [1] and $^{244\text{-}260}$Fm [2] isotopes against alpha and cluster decay is studied. It is found from the cold valley plots (driving potential versus A_2, mass number of one fragment) of $^{248\text{-}254}$Cf and $^{244\text{-}260}$Fm isotopes that there are deep valleys consisting of several comparable minima and is centered on the doubly magic ^{208}Pb, the lead radioactivity. In the symmetric fission region of the cold valley plots the driving potential decreases with increase in mass number (A_2).The minima in driving potential are obtained around ^{132}Sn, the tin radioactivity. It is evident from the studies that most of these parents are unstable against alpha and heavy cluster (^{46}Ar, ^{48,50}Ca) emissions and stable against all light cluster emissions, excluding ^{8}Be from $^{244\text{-}248}$Fm isotopes. The most probable clusters from these parents are predicted to be ^{46}Ar, ^{48,50}Ca which indicate the role of doubly or near doubly magic clusters in cluster radioactivity [1, 2]. The branching ratios with respect to alpha decay for all the possible cluster emissions from different Cf isotopes are also computed. Geiger-Nuttal plots were studied for various clusters and are found to be linear with varying slopes and intercepts. It is found that inclusion of proximity potential will not produce any deviation to the linear nature of the plots. Nuclear structure effects and shell effects are evident from the observed variation in slope and intercept of Geiger-Nuttal plots.

The stability of even-even super heavy $^{280\text{-}314}$116 [3] and $^{294\text{-}326}$122 [4] isotopes against alpha and cluster decay is studied and hence employed to find the probable proton and neutron shell closures in this region. It is found from the cold valley plots for these isotopes, a deep region consisting of several comparable minima, centered at ^{208}Pb lead valley and another deep region is obtained at ^{298}114 which shows the double magicity of the daughter nuclei at N=184 and Z=114. The present calculations have been done to find the alpha decay half life times and to determine the most probable heavy cluster emissions. Our calculated alpha half life times for ^{290,292}116 isotopes agree well with experimental values. Therefore we presume that the present alpha half lives of other isotopes will be a guide to future experiments, since these isotopes are not yet synthesized. The plots connecting computed Q values and half-lives against neutron number of daughter nuclei were studied for different clusters (^{4}He, ^{10}Be, ^{14,16}C and ^{16,18}O) emitting from various Z=116 isotopes and it is found that the next neutron shell closures occur at N=162, 172 and 184. We have also studied the isotopic and isobaric mass parabola for various clusters emitted from various Z=116 parents. The minima (slope discontinuity) in the mass parabola at Z=114 and N = 162, 172 and 184 indicate the presence of proton and neutron magicity in the super heavy region. Half life measurements for cluster emission may not be possible in the super heavy region because only a few atoms of these short lived nuclei are produced but in future more mass measurements will be available and by noting the minima in mass difference, it will be possible to find neutron and proton magicity in this region. The spontaneous fission of various Z=122 isotopes are also computed using the phenomenological formula [5] and studied the competition between alpha decay and spontaneous fission. It is found that alpha emission is the dominant mode of decay for isotopes with mass number A < 306, and for those with A > 306 spontaneous fission is found to be dominant. The demarcation between alpha decay and spontaneous fission is at ^{306}122, which shows the presence of a spherical neutron shell closure at N = 184. We have also investigated the role of doubly magic daughter ^{304}120, ^{298}114, ^{280}108, ^{276}104 and ^{264}102 nuclei in the decay of nuclei in the super heavy region. Comparing these, the lowest half life is obtained in the alpha decay reaction leading to ^{304}120 daughter nuclei. So the best proton and neutron shell closure in super heavy region is obtained for the nuclei ^{304}120 (Z = 120 and N=184).

The effect of deformations on half lives for the alpha and cluster emissions from $^{248-254}$Cf and even-even $^{244-260}$Fm isotopes [2] is also investigated. The Coulomb and proximity potential model is modified by incorporating the quadraople and hexadecapole deformations of the decaying parent nuclei along with that of emitted cluster and daughter nucleus in the ground state. The computed alpha decay half life are compared with the corresponding experimental values and is found that the present values (with including quadrupole deformation β_2) are in good agreement with experimental data. It is also found that the inclusion of quadrupole deformation reduces the height and width of the barrier (increases the barrier penetrability) and hence the decrease of half life.

The cluster formation probabilities [6] are computed for different clusters ranging from carbon to silicon for the parents in the trans-tin (^{112}Ba to ^{126}Sm parents) and trans-lead region (^{221}Fr to ^{242}Cm parents). It is found that in trans-tin region the ^{12}C, ^{16}O, ^{20}Ne and ^{24}Mg clusters have maximum cluster formation probability and lowest half lives as compared to other clusters. In trans-lead region the ^{14}C, ^{18,20}O, ^{23}F, ^{24,26}Ne, ^{28,30}Mg and ^{34}Si clusters have the maximum cluster formation probability and minimum half life, which show that alpha like clusters are most probable for emission from trans-tin region while non-alpha clusters are probable from trans-lead region. These results stress the role of neutron proton symmetry and asymmetry of daughter nuclei in these two cases.

A new semi-empirical model [7] is proposed for determining the half lives of radioactive nuclei exhibiting cluster radioactivity. The parameters of the formula are obtained by making a least-square fit to the available experimental cluster decay data. The semi-empirical formula works well in all the experimentally observed cluster decays and is also applied to alpha decay of parents with *Z*=85–102.

The possibility of finding long lived super heavy elements by comparing the computed alpha decay half lives with the spontaneous fission half-lives [8] are also studied. Super heavy nuclei which have relatively small alpha decay half-life times compared to spontaneous fission half lives will survive fission and thus can be detected in the laboratory through alpha decay. It is found from the studies that the isotopes $^{246-256}$Fm, $^{252-260}$No, $^{256-262}$Rf, $^{260-266}$Sg, $^{264-270}$108, $^{268-276}$110, $^{272-280}$112, $^{274-284}$114, $^{278-290}$116, $^{280-294}$118, $^{284-300}$120 and $^{288-304}$122 will survive fission and can be synthesized and identified via alpha decay. Thus this work on spontaneous fission versus alpha decay of super heavy elements will be a guide to future experiments. A new semi empirical formula [9] is also proposed for determining the spontaneous fission half life time with minimum parameters; the predictions are compared with experimental data and other empirical formulas.

References

[1] R K Biju et al,Pramana J.Phys.**70**,617(2008)
[2] K P Santhosh, R K Biju and S Sabina, Pramana J. Phys. **73**, 1059 (2009)
[3] K P Santhosh and R K Biju, Pramana J. Phys. **72**, 689 (2009)
[4] K P Santhosh and R K Biju, J.Phys.G: Nucl. Part. Phys. **36**, 015107 (2009)
[5] Z Ren and C Xu, Nucl.Phys.A **759**,64(2005)
[6] K P Santhosh, R K Biju and S Sabina, Nucl. Phys. A **838**, 38 (2010)
[7] K P Santhosh, R K Biju et al, J. Phys. G: Nucl. Part. Phys. **35**, 085102 (2008)
[8] K P Santhosh, R K Biju et al, J.Phys.G: Nucl. Part. Phys. **36**, 115101 (2009)
[9] K P Santhosh, R K Biju and S Sabina, Nucl. Phys. A **832**, 220 (2010)