Stability of deformed and super deformed Gd and Hg parents against alpha and cluster decay

Sabina Sahadevan and * K. P. Santhosh
P G Department of Physics & Research Centre, Payyanur College, Payyanur - 670327, INDIA
** email: kpsanthosh@eth.net*

Introduction

The α-decay studies coupled with the cluster decay results have been used to point out the closed shell effects of the nuclei involved in the decay for quite some time now. The Z = 64 sub shell was first predicted by Rasmussen et al., [1] from the study of α - decay energies and Gupta et al., [2] have used the alpha and cluster decay results to predict the ^{100}Sn and ^{132}Sn daughter radio activities. Further a deformed radioactivity at Z = 74-76 and N = 98-104 was also noted through cluster decay results.

In this paper we have investigated the alpha and cluster decay properties of the $^{144-158}$Gd and the $^{176-196}$Hg even – even isotopes. All these isotopes are of particular interest for study because of the varied behavior they present with respect to their shapes. Furthermore super deformed (excited) bands have been experimentally observed in $^{146-150}$Gd and the $^{189-198}$Hg isotopes.

Results and discussion

The Coulomb and Proximity model [3] has been used to calculate the half lives and other characteristics of the nuclei under study. The driving potential versus A_2 (mass of one fragment) graphs were studied and it was found that the potential energy minima occur at ^{4}He and at all the other typical clusters for almost all the nuclei. The interesting result that comes up from these plots is the change of clusters at certain isotopes, i.e., for the same mass number there is a shift in the cluster emitted to the next lower atomic number. There are changes in clusters at ^{146}Gd with the first change in cluster at ^{24}Mg and going on up to ^{70}Ge. A similar change in clusters is seen at ^{152}Gd and at ^{158}Gd but here the change starts at ^{40}Ar and at ^{22}Ne respectively. Moving on to the Hg isotopes changes in clusters emerges at ^{178}Hg, ^{186}Hg and ^{194}Hg with the first change at ^{28}Si, ^{20}Ne and ^{16}O respectively.

The change in clusters appears at those nuclei where a change in shape is occurring correspondingly. In $^{142-144}$Gd quadrupole bands have been observed and the nuclei ^{143,144}Gd are considered to have triaxial shapes for these quadrupole bands [4, 5]. For the low spin states in the neutron deficient Gd isotopes the deformation decreases with increasing neutron number and a spherical shell structure develops when the shell closure at N = 82 is approached which indicates a shape change at the ^{146}Gd isotope from triaxial to spherical. According to the calculations of Patra et al., [6] shape transitions from oblate to prolate and prolate to oblate are observed at A =178 and A = 188 respectively for the Hg isotopes. According to these observations, whenever a systematic change in cluster occurs at a particular isotope a corresponding shape transition should occur there.

Alpha decay results

The $\log_{10}(T_{1/2})$ value for the alpha decay is plotted against the mass numbers of the parent and is presented in figure 1.

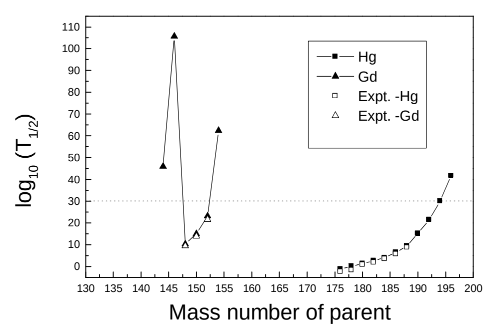

Fig. 1 Alpha decay half lives versus mass number of parent nuclei

The decay half lives show that all the Hg isotopes considered are instable with respect to alpha decay. From figure 1 it is seen that with the exception of ^{196}Hg all the other Hg nuclei have their alpha decay half lives within the present experimental limit of 10^{30}s. The Gd isotopes ^{148,150,152}Gd nuclei are alpha instable, ^{144}Gd is weakly stable while ^{146}Gd, ^{154}Gd, ^{156}Gd and ^{158}Gd are stable with respect to alpha decay. The lowest alpha decay half lives amongst all the nuclei are got for the $^{176\text{-}188}$Hg parent nuclei. The above noted instability of the $^{176\text{-}188}$Hg nuclei points to the (deformed) closed shell effects of the $^{172\text{-}184}$Pt daughter nuclei at Z ≈ 76 coupled with a magic or semi-magic nature of their neutron shells with N = 94, 96, 98, 100, 102, 104 and 106.

On taking a comparison of the normal deformed and super deformed nuclei, it can be seen that the normal deformed nuclei ($^{176\text{-}188}$Hg nuclei) are better alpha emitters than the super deformed ones ($^{190\text{-}196}$Hg nuclei). In the case of the Gd isotopes the alpha decay half lives get influenced by the shell closure effects of the nuclei involved in the decay process. The super deformed ^{146}Gd nucleus is stable for alpha emission while the super deformed ^{148,150}Gd nuclei are alpha instable. The extremely large half life of the ^{146}Gd is attributed to the N = 82 spherical shell closure while the instability of the ^{148,150}Gd are due to N = 82 and N ≈ 82 shell closure in the ^{144}Sm and ^{146}Sm daughter nuclei respectively.

Cluster decay results

The N=Z cluster and N≠Z cluster results are studied separately for each set of parent nuclei and they reveal spherical shell closures at both the parent and the daughter nuclei. A rise in $T_{1/2}$ values for all clusters at ^{146}Gd isotope is observed which is due to the N = 82 spherical shell closure of the parent. The N = 82 spherical daughter shell closure is clearly obtained from the cluster studies. For eg, in the case of the Gd parents there are dips in half lives for ^{8}Be emission from ^{150}Gd isotope, ^{16}O decay from ^{154}Gd, ^{12}C decay from ^{152}Gd and ^{14}C cluster emission from ^{154}Gd where the daughters are the N=82 magic ^{142}Nd, ^{138}Ba, ^{140}Ce and ^{140}Ce nuclei respectively. Similarly in the case of Hg parents, the minima occur at ^{180}Hg parent for the decay of ^{32}Si cluster with daughter ^{148}Dy having N=82 shell closure; then there are dips at ^{178}Hg parent for ^{30}Si cluster decay, ^{180}Hg parent for ^{34}S cluster decay and ^{182}Hg parent for ^{36}S cluster decay, all of which have daughter nuclei (^{148}Dy, ^{146}Gd and ^{146}Gd respectively) with N=82 spherical shell closure.

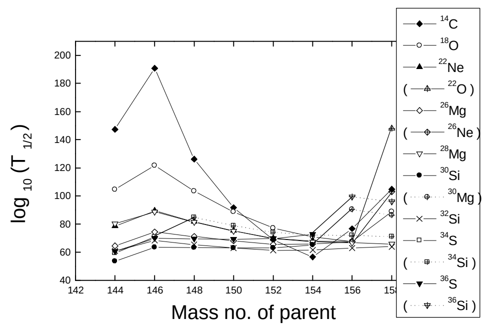

Fig. 2 Cluster decay half lives for Gd parents emitting N≠Z clusters against mass number of parent nuclei

Again there is a dip at the ^{154}Gd parent for all the N≠Z clusters as is evident from figure 2. This dip is explained on the basis of the reinforcing and switching of shell gaps in nuclei [7, 8] according to which the Z = 64 shell is spherically closed only when the corresponding neutron number is a magic one (in this case N = 82). Similar to α decay results it is found that the super deformed nuclei are more stable against cluster decay than the normal deformed ones.

References

[1] J O Rasmussen et al, Phys. Rev. **89** (1953) 33
[2] R K Gupta et al, Phys. Rev. C **47** (1993**)** 561
[3] K P Santhosh et al, Pramana J. Phys. **58** (2002) 611
[4] R M Lieder et al, Nucl. Phys. A **671** (2000) 52
[5] R M Lieder et al, Eur. Phys. J A **21** (2004) 37
[6] S K Patra et al, Phys. Rev. C **50** (1994) 1924
[7] J H Hamilton et al, Rep. Prog. Phys. **48** (1985) 631
[8] J H Hamilton et al, J. Phys. G **10** (1984) L87