Distinctive Features of α-decays of N=153 Isotones

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A recent survey of lifetimes of heavy nuclei by Sood et. al., [1] revealed the surprising observation that in the trans-plutonium region, odd mass nuclei are generally longer-lived than their even-even neighbors. This was sought to be explained by analyzing the α-decay data. Extending this study with a focus on A>250 nuclei, we find that the longest lived odd-mass nucleus in this domain is ^{251}Cf ($t_{1/2}$=898y) and odd-odd nucleus is ^{252}Es ($t_{1/2}$=471.7d). Both these nuclei have N=153, i.e., one nucleon beyond the shell closure. Normally one would expect the singly close shell (SCS) N=152 isotones to be more stable/longer-lived. The comparative situation in respect of SCS (N=152) nuclei and those with one extra neutron (with N=153) is summarized [2] in our Table 1. It is seen that, in all known cases, lifetimes of (SCS+1n) nuclei are an order of magnitude larger than those of closed shell cases. On further analysis, it was found that α-decays of (SCS+1n) nuclei have some other distinctive features which are briefly outlined in the present report.

Table 1: Half lives and decay modes for N=152 and N=153 nuclides under consideration

$_Z$X \ N	152	153
$_{102}$No	^{254}No 51s α: 90 ε: 10	^{255}No 5.1m α: 61 ε: 39
$_{100}$Fm	^{252}Fm 25.39h α: 100	^{253}Fm 3.00d α: 12 ε: 88
$_{99}$Es	^{251}Es 33 h α: 0.5 ε: 99.5	^{252}Es 471.7d α: 78 ε: 22
$_{98}$Cf	^{250}Cf 13.08y α: 99.9 SF: 0.08	^{251}Cf 898y α: 100

First we look at the configuration space around N=152 as sketched in fig.1, wherein the experimentally observed low-energy band heads in N=151 nucleus ^{249}Cf (on the left) and in N=153 nucleus ^{251}Cf (on the right) are plotted indicating the Nilsson orbital quantum numbers for each level. As seen herein, and also in all the other N=(152±1) spectra, a clear gap of >400keV is witnessed across N=152. Since the dominant decay mode in almost all these cases is α-emission, we consider the Viola-Seaborg relation (based on the empirical Geiger-Nuttal Law)

$$\log t_{1/2}(\text{sec}) = \{A(Z) / E_\alpha(\text{MeV})^{1/2}\} + B(Z) \quad \text{-- (1)}$$

which relates the partial α-half life and the energy of emitted α particle.

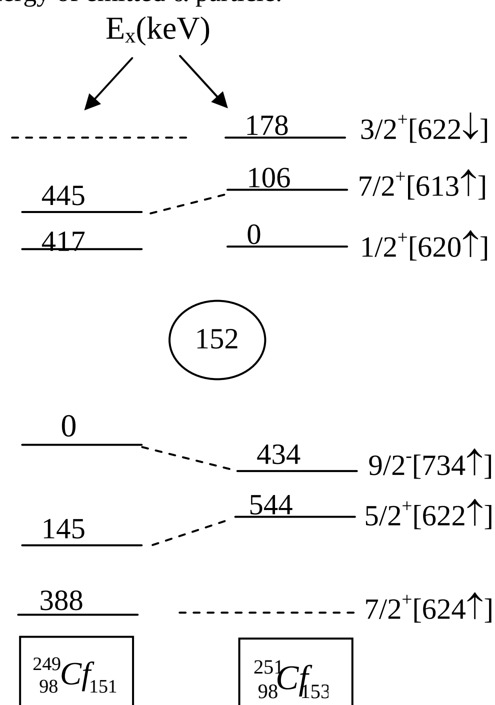

Fig. 1: Experimental band head energies in ^{249}Cf (N=151) and ^{251}Cf (N=153) across N=152 shell.

For odd-A decays, the daughter state having the same configuration as the parent state is favored with Hindrance Factor (HF) of <4.0. Thus for decays of N=153 nucleus into favored states across the N=152, E_α is smaller by ~400 keV and consequently, vide eq.(1), the parent $t^\alpha_{1/2}$ is considerably larger as compared

Table 2: Summary of experimental α-decay data for Odd-A N=153 nuclei (gs: $1/2^+$[620↑]). Entries in each box are I, $\%I_\alpha$ (per 100 α) and HF for 2 lowest rotational levels, with the entries in bold representing the total % I_α for all (including unlisted) rotational levels of each band in daughter nuclei.

N config / ^{A}X	$9/2^-$[734↑]	$5/2^+$[622↑]	$7/2^+$[613↑]: 255	$1/2^+$[620↑]
^{255}No	9/2 1.9 1400 11/2 4.2 460 **6%**	5/2 45.5 14 7/2 11.9 37 **64%**	7/2 11.9 12 9/2 4.2 21 **16%**	1/2 8.9 4.1 3/2 2.4 9.7 **14%***
^{253}Fm	9/2 1.3 3200 11/2 6.7 350 **8%**	5/2 42.7 25 7/2 9.8 72 **61%**	- $7/2^+$[624↓]: 251	1/2 23.2 3.0 3/2 2.4 23 **28%**
^{251}Cf	9/2 2.6 5100 11/2 12.5 510 **16%**	5/2 27.6 31 7/2 4.0 130 **35%**	7/2 2.5 170 9/2 0.8 240 **4%**	1/2 35.4 2.6 3/2 3.3 19 **44%**

* In ^{255}No decay, another level at 703 keV (I_α=2.8%) with HF=3.6 is also indicated.

to the half life of N≤152 nuclei wherein no such shell gap exists.

For discussing other distinctive features of N=153 decays, we refer to Table 2, wherein the main α branches, their intensities, $\%I_\alpha$ per 100 α's and HF are shown for α decays of the 3 odd-A, N=153 nuclides into the indicated band levels of the respective daughter nuclei. As summarized in Table 2, in all the known cases of α-decays of N=153 nuclei, I_α(fav) is not even 50%. In the case of ^{255}No decay, I_α(fav) is barely 11% and in ^{253}Fm decay, it is 25% while in ^{251}Cf decay it is 44%. This feature is in sharp contrast to the α-decays of N≠153 nuclei, wherein I_α(fav) >85% (in many cases ≥ 95%) which is very similar to the g→g decays of neighboring e-e nuclei.

In N=153 decays, maximum α intensity appears to go into $1/2^+$[620↑]→$5/2^+$[622↑] branch (>60% in both ^{255}No and ^{253}Fm decays). Another distinctive feature noticed herein is that $1/2^+$[620↑] →$7/2^+$[613↑] branch in ^{255}No decay has I_α≈16% (even more than I_α(fav)), while for $1/2^+$[620↑] →$7/2^+$[624↓] branch in ^{251}Cf decay, I_α=3% only (with I_α(fav)=44%). One other feature observed in $1/2^+$[620↑] →$9/2^-$[734↑] branches in all 3 cases is that while HF~10^3 for $9/2^-$ band head level, that for its $11/2^-$ rotational level is an order of magnitude smaller. Explanation of these features in terms of asymptotic quantum number selection rules is being investigated.

The case of the doubly odd N=153 nucleus ^{252}Es (Z=99) presents a perplexing situation. NDS evaluators [3] had assigned an $I^\pi=5^-$ spin-parity to ^{252}Es gs corresponding to the 2qp configuration 5^-{p:3/2[521] ⊗ n:7/2[613]} which, however, conflicts with the fact that 153rd neutron, in all known cases, unambiguously occupies (see our fig 1 & Table 2) ½[620] orbital. Recently, Sainath et al. [4] have re-examined the situation with the inclusion of α-γ coincidence data following ^{256}Md decay, and concluded that a 4^+{p:7/2[633] ⊗ n:1/2[620]} assignment for ^{252}Es gs is consistent with all the available experimental results. In the present context, the 5^- assignment appears untenable on the basis of the observation that 96% of the α's from its decay populate a $K^\pi=6^+$ band levels in ^{248}Bk; the 5^-→6^+ transition requires an L=1 partial wave (parity change) which almost always is highly hindered. Further the NDS adopted ^{252}Es α-decay [3] shows only 1.02% α's going into the suggested 5^- favored state at 590 keV in ^{248}Bk. In sharp contrast 96% of the α's from ^{254}Es decay go into the favored state. In view of these considerations, experimental re-investigation of ^{252}Es α-decay is certainly needed.

References

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