Distinctive Features of $\alpha$-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 $\alpha$-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 $^{251}\text{Cf}$ ($t_{1/2} = 898\text{y}$) and odd-odd nucleus is $^{252}\text{Es}$ ($t_{1/2} = 471.7\text{d}$). 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 $\alpha$-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

<table>
<thead>
<tr>
<th>$N$</th>
<th>$X$</th>
<th>$t_{1/2}$</th>
<th>${\alpha}$</th>
<th>$\varepsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>152</td>
<td>$^{102}\text{No}$</td>
<td>51s</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>$^{254}\text{No}$</td>
<td>5.1m</td>
<td>61</td>
<td>39</td>
</tr>
<tr>
<td>153</td>
<td>$^{100}\text{Fm}$</td>
<td>25.39h</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$^{252}\text{Fm}$</td>
<td>3.00d</td>
<td>12</td>
<td>88</td>
</tr>
<tr>
<td>153</td>
<td>$^{99}\text{Es}$</td>
<td>33h</td>
<td>0.5</td>
<td>99.5</td>
</tr>
<tr>
<td></td>
<td>$^{251}\text{Es}$</td>
<td>471.7d</td>
<td>78</td>
<td>22</td>
</tr>
<tr>
<td>153</td>
<td>$^{98}\text{Cf}$</td>
<td>13.08y</td>
<td>99.9</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>$^{250}\text{Cf}$</td>
<td>898y</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

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 $^{249}\text{Cf}$ (on the left) and in $N=153$ nucleus $^{251}\text{Cf}$ (on the right) are plotted indicating the Nilsson orbital quantum numbers for each level. As seen herein, and also in all the other $N=(152\pm 1)$ spectra, a clear gap of $>400\text{keV}$ is witnessed across $N=152$. Since the dominant decay mode in almost all these cases is $\alpha$-emission, we consider the Viola-Seaborg relation (based on the empirical Geiger-Nuttal Law)

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

which relates the partial $\alpha$-half life and the energy of emitted $\alpha$ particle.

<table>
<thead>
<tr>
<th>$E_\alpha(\text{keV})$</th>
<th>$t_{1/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>178</td>
<td>3/2$^+_1$[622$^\downarrow$]</td>
</tr>
<tr>
<td>445</td>
<td>106</td>
</tr>
<tr>
<td>417</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>434</td>
<td>9/2$^+_1$[734$^\uparrow$]</td>
</tr>
<tr>
<td>544</td>
<td></td>
</tr>
<tr>
<td>388</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1: Experimental band head energies in $^{249}\text{Cf}$ ($N=151$) and $^{251}\text{Cf}$ ($N=153$) 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 $N=152$, $E_\alpha$ is smaller by $\approx 400$ keV and consequently, vide eq.(1), the parent $t_{1/2}^{\alpha}$ 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_α (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.

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

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

For discussing other distinctive features of N=153 decays, we refer to Table 2, wherein the main α branches, their intensities, %I_α 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 255No decay, I_α (fav) is barely 11% and in 253Fm decay, it is 25% while in 251Cf 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 255No and 253Fm decays). Another distinctive feature noticed herein is that 1/2^+[620^↑]→7/2^+[613^↑] branch in 255No decay has I_α~16% (even more than I_α (fav)), while for 1/2^+[620^↑]→7/2'[624^↓] branch in 251Cf 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 252Es (Z=99) presents a perplexing situation. NDS evaluators [3] had assigned an I_π=5- spin-parity to 252Es 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 256Md decay, and concluded that a 4^+{p:7/2[633] ⊗ n:1/2[620]} assignment for 252Es 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_π=6+ band levels in 248Bk; the 5-→6+ transition requires an L=1 partial wave (parity change) which almost always is highly hindered. Further the NDS adopted 252Es α-decay [3] shows only 1.02% α’s going into the suggested 5- favored state at 590 keV in 248Bk. In sharp contrast 96% of the α’s from 254Es decay go into the favored state. In view of these considerations, experimental re-investigation of 252Es α-decay is certainly needed.

References