Comparative Analysis of Half-Lives of Odd-A and Even-A Cf (Z=98) Isotopes

K. Vijay Sai *, R. Gowrishankar, K. Venkataramaniah, and P. C. Sood

Department of Physics, Sri Sathya Sai University, Prasanthinilayam - 515134, A.P., INDIA

** email: vjsai.phy.psn@sssu.edu.in*

Introduction

Among man-made nuclear species, nuclides of the Californium (Cf: Z=98) isotopic sequence have certain uniquely distinctive features. This sequence of 14 nuclei, ranging from A=240 to 253, has well determined half-lives ($t_{1/2}$) and decay modes [1], wherein spontaneous fission (SF) is insignificant, except for the peripheral cases, namely ^{240}Cf (SF=2%) and ^{252}Cf(SF=3%). As shown in Fig.1, it includes a set of 5 nuclei (with A = 248 to 252) with $t_{1/2}$ of the order of a year or higher; this set of α-decaying nuclei is centered around N = 152 shell closure. However, the longest lived ($t_{1/2}$ = 898y) member of this sequence, which also happens to be the longest-lived nuclide in the A ≥ 250 domain, is not the singly closed shell nuclide ^{250}Cf (N = 152; $t_{1/2}$ = 13y); it is its odd-mass neighbour ^{251}Cf with one neutron beyond the closed shell structure. We discuss in the following a physical explanation for this unusual occurrence.

Another distinctive feature of this sequence is the fact that all the even-even isotopes, (except ^{242}Cf - 80% α: 20% ε) are β-stable, whereas only 2 of the odd- mass isotopes have this character. Accordingly for a comparative study of the odd-A and even-A cases, we focus on their α-decay characteristics, using the formulation adopted by Sood et al.[2], wherein the basic Viola-Seaborg relation [3]

$$\log t_{1/2}^{\alpha}\,(\mathrm{sec}) = \frac{A(Z)}{(E_{\alpha}^{*})^{1/2}} + B(Z) \quad \text{.........(1)}$$

relates the observed partial α half-lives to the effective (including correction due to electron screening) α energy (in MeV). For g→g transition, E_α is related to Q_α with inclusion of centre of mass energy. In Fig.2, we plot the experimental Q_α values for the even-A (--o--) and odd-A (—●—) Cf isotopes. A sharp drop in the Q_α values is noticed between A=244→246→248 for even-A cases and between A=245→247 for odd-A cases. For the long-lived set (A=248 to 252); odd-A and even-A inclusive, we can write Q_α = 6.24 (12) MeV. The dip in Q_α value for closed shell at N=152 (indicating extra stability) vide eq.(1) is evident in Fig.2.

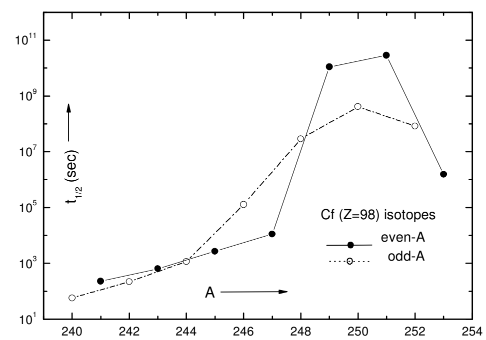

Fig. 1 Plot of experimental half-lives (in seconds/ log scale) for Cf isotopes with A=240-253. The even-A cases are joined by dotted line and odd- A cases by full line.

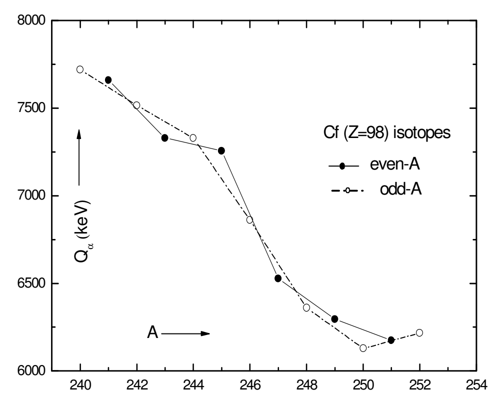

Fig. 2 Plot of Q_α values with other notations same as in Fig. 1.

Table 1: Data for g→g and the favoured transitions for ^{249}Cf and ^{251}Cf α-decays. $t^{\alpha}_{1/2}$ (calc) is from our eq.(1); the respective hindrance factors HF (in the last column) labeled NDS are from the latest Nuclear Data Sheets and those labeled SEF correspond to ratio of $t^{\alpha}_{1/2}$ (expt.) to $t^{\alpha}_{1/2}$ (calc)

^{A}X	Parent config.	Daughter config	^{A}Y	E_x (keV)	E_{α}^{*} (MeV)	% I_{α}	$t^{\alpha}_{1/2}$ (expt) (s)	$t^{\alpha}_{1/2}$ (calc) (s)	HF NDS(SEF)
^{249}Cf	$\frac{9}{2}$[734]	$\frac{7}{2}$[624]	^{245}Cm	0	6.295	2.46	4.47 x 10^{11}	4.98 x 10^{7}	6150 (8976)
^{249}Cf	$\frac{9}{2}$[734]	$\frac{9}{2}$[734]	^{245}Cm	388	5.908	82.2	1.34 x 10^{10}	4.93 x 10^{9}	1.80 (2.72)
^{251}Cf	$\frac{1}{2}$[620]	$\frac{9}{2}$[734]	^{247}Cm	0	6.175	2.7	1.05 x 10^{12}	1.99 x 10^{8}	4800 (5270)
^{251}Cf	$\frac{1}{2}$[620]	$\frac{1}{2}$[620]	^{247}Cm	404	5.774	35	8.08 x 10^{10}	2.80x10^{10}	2.60 (2.89)

Fig.3, is a plot of experimental $t^{\alpha}_{1/2}$ (sec) as a function of $(E_{\alpha}^{*})^{-1/2}$. As expected from the Gieger-Nuttal law and our eq.(1), data for the even-even isotopes fall on a straight line; a least squares fit to these points using eq.(1) yields for Cf (Z=98) sequence the following values:

A = 155.2499; B = -54.1794 ……..(2)

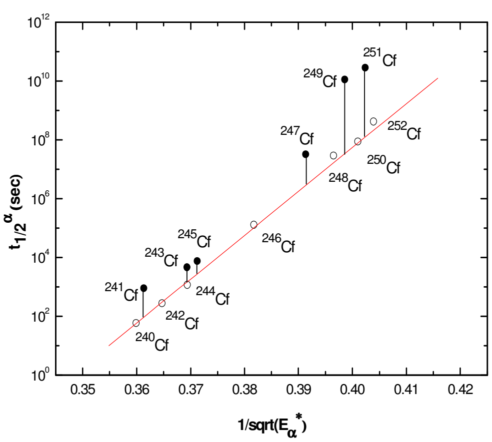

Fig. 3 Partial Alpha half-lives for Cf isotopes

The remarkable observation from Fig. 3 is that experimental $t_{1/2}$ value for each of the odd-A isotopes exceeds those predicted by using eqs.(1&2); this feature is much more pronounced for ^{249}Cf and ^{251}Cf. We find that, for odd-A cases, g→g transition is greatly hindered (HF ~ 10^{3}) due to non-overlap of the odd nucleon wave functions; on the other hand, α-branch to an excited state, having the same configuration as the parent, is favoured (HF ≤ 4). The results of our calculations for the g→g and also the favoured transitions are listed in Table 1 for ^{249}Cf and ^{251}Cf decays. The exceptionally large $t_{1/2}$ for these 2 cases arises from the fact that the favoured state herein lies at ~400 keV in the daughter nucleus, bringing in corresponding reduction in E_{α}^{*} and consequential large increase in the half-life of the respective parent.

References

[1] Tuli J K, Nuclear Wallet Cards 8th ed. (2005)

[2] Sood P C, Sastri OSKS, Jain R K, J. Phys. G: Nucl. Part. Phys. **35** (2008) 065104.

[3] Rasmussen J O, Aplha-, Beta- and Gamma-Ray Spectroscopy, (1966), (Amsterdam: North-Holland), p714