Occurrence of isomer pairs in transfermium nuclei

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Some 25 years ago, Sood and Sheline [1] had carried out a systematic study of long-lived isomer (LLI) pairs in medium-heavy (A=150-190) and heavy (A=225-250) deformed nuclei. Here we report the results of a similar survey for the transfermium (Z>100, A>250) nuclei. This survey reveals several features which are unique to this region as briefly discussed in the following.

Firstly we outline why isomer identification in this region has remained unexplored till very recently. Whereas transuranic nuclides with $Z \leq 100$ can be had in weighable amounts, transfermium nuclei are synthesized in heavy ion fusion-evaporation reactions. For transactinides, the production cross section σ goes down to nanobarns (nb) such that only a few atoms are produced in experiments over a few days to even a month. Earlier, physics research in this region was carried out with 'single atoms' of an element. Evidently 'single atom' studies could not yield precise spectroscopic data on energies/lifetimes of individual nuclear states. It was only after appropriate experimental set up ensuring adequate production in nb cross section reactions along with facilities for the α-γ and/or α-Xray spectroscopy became available [3,4] that information on isomer pairs started coming in.

Condition for the occurrence of isomer pairs is that two closely spaced nuclear states (including g.s.) of a specific nucleus ${}^{A}_{Z}X_{N}$ have $\Delta I \geq 3$. In cases, wherein $\Delta I > 4$, isomeric transition (IT) connecting the two states is insignificant and hence their relative energy ordering, and g.s., remains undefined. Isomer characterization requires knowledge of the single particle (sp) level sequencing for neutrons and also for protons. A schematic drawing of such a level scheme [5] for this region is shown in Fig.1. From this figure, it is clear that, as noted by Sood and Sheline [1], odd-A actinides with A<250 cannot have LLI pairs, since $\Delta I \geq 3$ condition is not fulfilled for any two close-by orbitals in this region.

Also we note from Fig.1 that no two adjacent n-orbitals within N=153-162 range have $\Delta I \geq 3$ and hence no LLI pairs should be expected therein. The presently available experimental information [2] on LLI pairs is summarized in Table 1. We see from this that, contrary to these expectations, LLI pairs have been identified in every odd-N = 151-161 species.

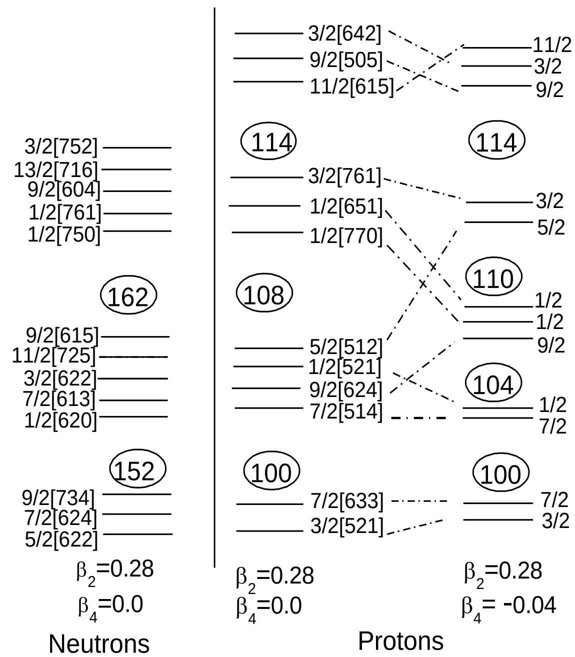

Fig. 1 Schematic single particle level diagram [5] for transfermium region. The energy ordering of levels is only qualitative: it changes significantly for $\beta_4 \neq 0$ and also for varying N:Z ratio.

Inadequacy of sp level scheme to satisfactorily describe the experimental excitation energies of various orbitals in N=151 and N=153 isotones has also been pointed out recently [6,7]. Further, the g.s. configuration of N=155 isotones has been experimentally determined as follows:

${}^{251}_{96}$Cm: 1/2[620]; ${}^{253}_{98}$Cf & ${}^{255}_{100}$Fm: 7/2[613];
${}^{259}_{102}$No & ${}^{261}_{106}$Sg: 3/2[622]. … (1)

However, in the sp picture, all odd-N isotones should have the same orbital as the respective g.s. Also a recent investigation [7] of α-γ decay of ^{261}Sg concluded that $11/2^{-}$[725] isomeric level occurs at $E_x \sim 300$ keV with $t_{1/2}=0.5\mu s$ in ^{253}Fm, while in isotonic ^{257}Rf it has $E_x=70$ keV and $t_{1/2}=4.9s$ (a stupendous increase of 7 orders of magnitude in $t_{1/2}$). In the single particle picture, a given orbital

Table 1: Presently identified [2] isomer pairs in transfermium Nuclei. Listing includes $t_{1/2}$ / E_X (keV) / J^π, wherever available. References are in NSR/NNDC notation.

Sl. No	${}^A_Z X$	Isomer 1 $t_{1/2}$	E_X	J^π	Isomer 2 $t_{1/2}$	E_X	J^π	Reference
				[A]: Odd A – Odd N				
1.	${}^{255}_{104}Rf_{151}$	1.6s	?	?	0.8s	?	?	2009Fo02
2.	${}^{257}_{104}Rf_{153}$	5.5s	0	$1/2^+$[620]	4.9s	70	$11/2^-$[725]	2010St14
3.	${}^{261}_{106}Sg_{155}$	195ms	0	$3/2^+$[622]	9.0μs	~200	$11/2^-$[725]	2009He20 2010Be16
4.	${}^{261}_{104}Rf_{157}$	78ms	?	?	1.9s	?	?	2011Ha13
5.	${}^{263}_{106}Sg_{157}$	1.0s	?	?	0.12s			1997Ho13
6.	${}^{265}_{108}Hs_{157}$	1.9ms	0	($9/2^+$, $11/2^-$)	0.3ms	~300	($3/2^+$, $1/2^+$)	2009He20
7.	${}^{265}_{106}Sg_{159}$	16.2s	?	?	8.9s	~150	$9/2^+$	2008Du09
8.	${}^{267}_{108}Hs_{159}$	52ms	0.0	$9/2^+$[615]	0.8s	?	?	2004Mo40
9.	${}^{271}_{110}Ds_{161}$	1.63ms	0.0	$9/2^+$[615]	69ms	?	?	2004Mo40
				[B]: Odd A – Odd Z				
10.	${}^{253}_{103}Lr_{150}$	1.32s	?	?	0.67s	?	?	2009He20
11.	${}^{255}_{103}Lr_{152}$	3.1s	0	$1/2^-$[521]	2.53s	~37	$7/2^-$[514]	2009Ka02
12.	${}^{257}_{105}Db_{152}$	2.3s	0	$9/2^+$[624]	0.67s	~37	$1/2^-$[521]	2010He11
				[C]: Odd N – Odd Z				
13.	${}^{254}_{101}Md_{153}$	10m	?	?	28m	?	?	NDS105(2005)959
14.	${}^{258}_{101}Md_{157}$	51.5d	0	(8)	57m	?	?	NDS94(2001)131
15.	${}^{258}_{105}Db_{153}$	4.7s	?	?	1.8s	?	?	2009He20
16.	${}^{262}_{107}Bh_{155}$	83ms	?	?	22ms	?	?	2009He20

should have nearly the same E_x and $t_{1/2}$ at same deformation in an isotonic sequence.

As suggested by Asai *et al.* [7], these variations in sp energies are due to the 'influence of rapidly decreasing β_4 value with increasing atomic number'. For the n-deficient nuclei produced in cold fusion reactions at GSI, β_4 has a value around -0.04. Significant rearrangement of sp levels results as β_4 is changed from 0 to -0.04 for fixed β_2, as shown in Fig.1 for protons. The neutron sp levels also undergo similar rearrangement, bringing the high-spin ($11/2^-$, 9/2+) levels in close proximity to the low spin levels ($1/2^+$, $3/2^+$, $1/2^-$). These variations result in the occurrence of LLI pairs in the N=151-161 domain.

K-isomers are another category of isomers appearing in this region. Calculations estimate the neutron pairing gap between N=152 and N=162 shell gaps to be around 500 keV. Experimentally low-lying (≤1MeV) isomers having high K values, corresponding to 2qp structures, have been identified [2] in several e-e nuclei. K-isomers are also expected, and seen, around 1MeV in a few odd-A nuclei.

Since most of the data in Table 1 has come within last 3-4 years, it may be just a preview of more extensive information likely to come out within next few years from upgraded facilities having more intense beams and considerably improved α-γ / α-CE spectroscopic set ups. Detailed and precise information on energy levels of SHE nuclei is awaited to better understand the structure of these long-lived isomer pairs.

References

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