Occurrence of low-lying K=8 2qp structures in actinides and beyond

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In an early survey [1] of long-lived isomers in deformed nuclei, it was indicated that such isomers, particularly from the actinide region, are scarcely known, even though the physical considerations point to the existance of many such cases. Guided by this observation, we have undertaken a project to describe / predict the isomers in odd-odd nuclei of transuranic, and even the transfermium region [2-4]. In this context the recent Nuclear Data Sheets (NDS2017) reporting evaluation of mass numbers A=256 and A=258 [5] brought to our attention sketchy information on K=8 states experimentally found in odd-odd actinide ^{256}Es ($t_{1/2}$ = 7.6 h) and in ^{258}Md (21 d). We recall that K=8 isomers had been reported, and analysed, over a decade ago in even-A 246(2)254 Z=96(2)102 [6,7]. Based on these considerations, we undertook a comprehensive examination of the observed, and the expected, low-lying K=8 2qp structures in the transuranic region, aided by the latest available data listings [8].

Firstly, we scan the respective neutron and proton single particle configuration space for the specified mass region [9] as sketched in Fig. 1. Our focus on 2qp K=8 states limits the relevant 1qp orbitals (Ω_i). The K=(Ω_1+Ω_2) = 8 is possible only when one of the 1qp orbital $\Omega \geq 9/2$; specifically K=8 can arise from:

The K=(Ω_1+Ω_2) = 8 = [9/2⊗7/2] …… (1a)
= [11/2⊗5/2] …… (1b)
= [13/2⊗3/2] …… (1c)

With these limiting constraints along with configuration space shown in Fig.1, it is evident that, in principle, only the [9/2⊗7/2] coupled K=8 is physically admissible, in the actinide region, both for even A and for odd-odd species. The (11/2⊗5/2) and (13/2⊗3/2) can yield K=8 2qp structures only in transactinides.

We list in Table 1 all the presently known or predicted K=8 states in heavy (A>245) nuclei. Looking at Fig.1, the lowest K=8 in N=150

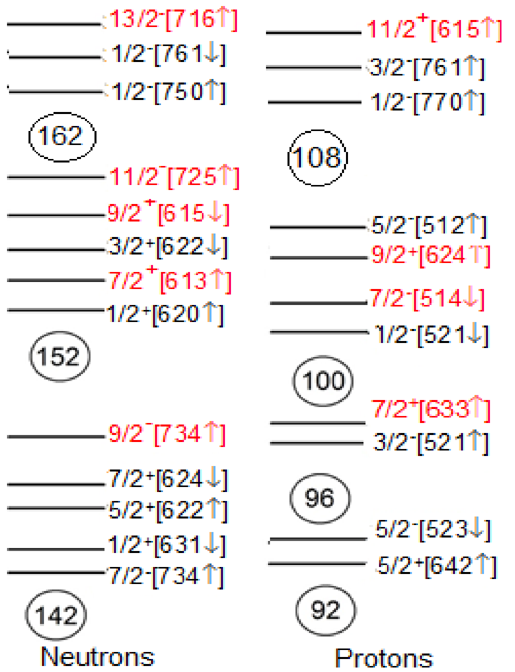

Fig 1: Schematic (not to scale) single particle Nilsson level diagram for actinides and transactinides.

even-A isotones is clearly generated from exciting one of the {7/2$^+$[624]}^{2} neutrons to the nearby 9/2$^-$[734]$_n$ yielding 8$^-${nn:7/2$^+$⊗9/2$^-$} 2qp state. On the other hand, for N=152 isotones, 8$^-$(nn){9/2$^-$[734]⊗7/2$^+$[613]} involving jump across the N=152 major shell gap, is higher lying than the 8$^-$(pp){7/2$^-$[514]⊗9/2$^+$[624]} which is placed at a lower energy. As evident in Table 1 and already noted [6.7], all the even A Z=96(2)102 K$^\pi$=8$^-$ levels listed have remarkably same E_x~1.2 MeV. In our N=152 even A listing we have included ^{256}Rf (Z=104) which has a similar low-lying 8$^-$(pp) isomer.

Next in Table 1(c), we list K=8 (pn) 2qp states which aside from recent NDS2017 [5] data

Table 1: Long lived K=8 2qp structures presently known (with indicated $t_{1/2}$) / predicted in heavy actinides and transactinides.

$^{A}_{Z}X$	E_x (keV)	$t_{1/2}$	K^{π} (config)
(a) N=150 Even-A isotones			
$^{246}_{96}Cm$	1180	?	8^-:nn[$7/2^+ \otimes 9/2^-$]
$^{248}_{98}Cf$	1260	?	8^-:nn[$7/2^+ \otimes 9/2^-$]
$^{250}_{100}Fm$	1198	1.9s	8^-:nn[$7/2^+ \otimes 9/2^-$]
$^{252}_{102}No$	1254	110ms	8^-:nn[$7/2^+ \otimes 9/2^-$]
(b) N=152 Even A isotones			
$^{254}_{102}No$	1296	265ms	8^-:pp[$7/2^- \otimes 9/2^+$]
$^{256}_{104}Rf$	1400	17μs	8^-:pp[$7/2^- \otimes 9/2^+$]
(c) Odd-Odd Actinides			
$^{254}_{99}Es_{155}$	448		8^-:pn[$7/2^- \otimes 9/2^+$]
$^{256}_{99}Es_{157}$	0+x	7.6h	8^+:pn[$7/2^+ \otimes 9/2^+$]
$^{252}_{101}Md_{151}$	150	?	8^+:pn[$7/2^- \otimes 9/2^-$]
$^{258}_{101}Md_{157}$	0	51d	8^-:pn[$7/2^- \otimes 9/2^+$]
$^{254}_{103}Lr_{151}$	150	?	8^+:pn[$7/2^- \otimes 9/2^-$]
(d) Odd-Odd Transactinides			
$^{264}_{107}Bh$		?	8^+:pn[$5/2^- \otimes 11/2^-$]
$^{276}_{109}Mt$		?	8^+:pn[$11/2^+ \otimes 5/2^+$]
$^{274}_{111}Rg$		?	8^+:pn[$3/2^- \otimes 13/2^-$]

for ^{256}Es and ^{258}Md, are mostly from our investigations [2-4]. A more detailed analysis of ^{256}Es, including characterization of its gs is presented elsewhere in the current SNP2019 proceedings. The listing in Table 1(c) also includes a similar 8^-(pn) in ^{254}Es at relatively high energy (448 keV) which is not an isomer. The 2qp configuration for this ^{254}Es 448 keV level, which is populated by a favoured α-decay from ^{258}Md (8^-), is deduced to be same as that of the parent.

Coming to the mostly unexplored transactinides region, although a number of experiment at GSI and other laboratories have identified isomer pairs in several nuclei with Z>101 [10], so far no K=8 structures have been reported for any nucleus in this region. A recent theoretical study [11] of expected 'long-lived high-K ground state in SHE' has mentioned the three (listed in Table 1(d)) K=8 2qp structures.

Specifically looking at the configuration space just around N=162, Z=108 (subshell gap), we find the following K=8 2qp structure in

$^{268}_{107}Bh_{161}$: 8^+{n:11/2[725]⊗p:5/2[512]}

Proceeding beyond the (162,108) subshell, we come across the following corresponding K=8 2qp occurrence.

$^{272}_{109}Mt_{163}$: 8^+{n:13/2[716]⊗p:3/2[761]}

It may be mentioned that in both these cases the K=8 state has an intruder n state namely $11/2^-$ and $13/2^-$. However, it may be noted that ^{272}Mt (8+) α-decay to the ^{268}Bh (8+) is highly hindered since it involves change of both n and p orbitals. In the domain just below the (162,108) subshell we also come across (9/2, 7/2) pairing for even A nuclei both in the proton and neutron side generating K=8 nn and pp 2qp states. Also again for the odd-odd nuclei we have a pair of K=8 states from (9/2,7/2) and (7/2,9/2) constituents.

Thus we find that the odd-odd heavy actinide and also the transactinide regions provide a rich ground for exploring the occurrence of K=8 and other 2qp high spin states. We continue to investigate on this problem further.

References

[1] P.C. Sood and R K Sheline, Nucl. Instr. Methods **B24/25** (1987) 473.

[2] R Gowrishankar *et al.*, DAE Symp. On Nucl. Phys. **57** (2012).

[3] R Gowrishankar *et al.*, DAE Symp. On Nucl. Phys. **63** (2018) 132.

[4] P. C. Sood et al., DAE Symp. On Nucl. Phys. **63 (2018) 94.**

[5] B. Singh, Nucl. Data Sheets **141** (2017) 327; **144** (2017) 297.

[6] P. J. Greenlees et al., Phys. Rev. **C78** (2008) 021303.

[7] A. P. Robinson et al., Phys. Rev. **C78** (2008) 034308.

[8] ENSDF, XUNDL, NUDAT and NWC continuously updated data bases at NNDC (Brookhaven NY**) August 2019 version**.

[9] A. K. Jain et al., Rev. Mod. Phys**. 62** (1990) 393.

[10] F.P. Heßberger et al., Eur. Phys. J. **A41**, (2009) 145 and **A52** (2016) 328.

[11] P. Jachimowicz *et al.*, Phys. Rev. **C92**, (2015) 044306.