Configuration assignment to the ^{156}Pm isomers

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Level structures of transitional nuclei (A≈150–160), particularly of neutron-rich species, are of a great interest, but are rather poorly defined. In this context, the latest Nuclear Data Sheets (NDS) evaluator for A=156 mass chain [1,2] remarked that assigning of a configuration to Z = 61 isotope ^{156}Pm ground state (gs) by Hellstrom et al. [3], and relating it to the 26.7-s activity present problems. In the present report, we critically examine this situation, taken together with more recent related experimental results [4] and Rotor Particle Model calculations [5].

Characterisation of the 26.7-s ^{156}Pm was undertaken by Hellstrom et al.[3] based on its decay to levels in ^{156}Sm; they concluded that 'the angular momentum of ^{156}Pm gs is at least 4 units', and that 'a consistent picture of ^{156}Pm decay is only found if gs is assumed to have $I^{\pi}K = 4^{-}4$' with most likely configuration:

$$4^{-} \{p_1: 5/2\,[413] + n_0: 3/2\,[521]\} \qquad (A)$$

wherein we have added subscripts on p/n to denote their excitational order as experimentally observed [2] in the neighbouring odd-mass isotope/isotone.

The NDS evaluator Reich [1] argued that this two-quasiparticle (2qp) configuration for the 4^{-} level, being a higher-lying singlet member of this GM doublet cannot be accepted as ^{156}Pm gs, since its GM triplet partner with $I^{\pi}K=1^{-}1$ has to lie lower. He further opined that if the 4^{-} is indeed the gs and also has the expected p_0:5/2[532] orbital as its constituent, the n-orbital has to have $K^{\pi}=3/2^{+}$ with the most likely possible configuration:

$$4^{-} \{p_0: 5/2\,[532] + n_3: 3/2\,[651]\} \qquad (B)$$

More recently, Shibata et al.[4], in their study of ^{156}Nd decay, identified an excited state isomer (t < 5s) in ^{156}Pm which de-excites with an 150.3 keV M3 transition to 26.7-s gs. This experimental observation of a higher-lying low-spin isomer conclusively rules out the (A) configuration assignment of Hellstrom et al.[1]. Shibata et al.[4], without any further analysis, just referred to the previously suggested [1] assignment (B) for 4^{-} ^{156}Pm gs and invoked GM rule to propose that the 150 keV isomer has $I^{\pi}=1^{-}$, being the singlet state of the GM doublet with previously suggested configuration (B).

However, whereas NDS evaluator [1], adopted the p_0:5/2[532] orbital, as a constituent of ^{156}Pm gs, he somehow missed out checking the proximity of the suggested n-orbital 3/2[651] to the gs in adjacent N=95 isotones. A scan of the latest NDS evaluated database [2] yields the following values for the observed excitation energies of the 3/2[651] n-orbital in the respective N=95 odd-A isotones:

Experimental E_x : 3/2[651]
^{157}Sm (571 keV); ^{159}Gd (602 keV);
^{161}Dy (678 keV); ^{163}Er (619 keV). …… (1)

Clearly any levels arising from coupling of this n-orbital (at E_x > 570 keV) with any p-orbital will lie above ~500 keV in the N=95 odd-odd nucleus; in particular, such a 2qp configuration, e.g., that in (B), cannot correspond to the gs of the N=95 ^{156}Pm nucleus.

We had earlier reported [5] the results of our calculation of the bandhead energies of various 2qp configurations using Quasiparticle Rotor Model (QPRM) with experimental inputs for the 1qp energies from neighbouring odd-A isotopes/isotones and for the GM splitting energies and Newby odd-even shift parameters from adjacent odd-odd nuclei. Therein it was concluded that the two ^{156}Pm isomers constitute the GM doublet having the 2qp configuration:

$$4^{+}_{gs} \{p_0: 5/2\,[532] \pm n_0: 3/2\,[521]\}\,1^{+}_{150} \qquad (C)$$

with $I^{\pi}K=4^{+}4$ as ^{156}Pm gs and the 150.3 keV isomer having $I^{\pi}K=1^{+}1$.

We now proceed to critically examine the evidence from ^{156}Pm decay[1,3], i.e., log ft values to specific levels in ^{156}Sm, which was said to rule out positive parity and to favour negative parity for ^{156}Pm gs. Essentially, this includes 3 sets of log ft values which are discussed one by one in the following:

(I). Significant β-feeding of two levels around 2.5 MeV, which have almost identical γ-decays to 2^{+}, 2^{-}, 4^{+} and 4^{-} levels in ^{156}Sm, indicating I=3 assignment. Log ft values of 5.51 and 5.82 are indicative of allowed β branches, and hence same parity for both these levels as that of the parent. These data do not establish, or favour, negative parity for the parent state; they are equally consistent with its positive parity.

(II). β-feeding of 6^{+} rotational level of the ground ($K^{\pi} = 0^{+}$) band with log ft = 9.0; this has been interpreted as indicative of 1^{u} transition, and hence favouring negative parity of the parent state. This argument overlooks the significant fact that this β-branch involves ΔK=4, and hence is highly K-forbidden, in addition to ΔI effect. Presumably the reported log ft needs to be re-checked.

(III). The supposedly decisive evidence for negative parity for parent state comes from the feeding of 1515 keV 5^{-} level with log ft = 5.95 which is hence 'termed' as an allowed transition with Δπ=0 and ΔI=1. However, this interpretation is not as conclusive as presumed. Using the comprehensive global database for evaluated log ft values by Singh et al.[6], we find 27 cases of 1f (Δπ=yes) transitions with log ft ≤ 6.1 just in the surrounding mass range 146 ≤ A ≤ 167. Even more significantly, β-decay of our core nucleus ^{155}Pm ($I^{\pi}_{gs}=5/2^{-}$: our p_0 orbital) has [2] a β-branch with log ft =5.9 to 1362.1 keV ^{155}Sm level with an unambiguous $3/2^{+}$ assignment based on n-capture and subsequent γ-decays. By analogy, our β-branch with log ft =5.95 to 1515 keV ^{156}Sm 5^{-} level can as well be a Δπ=yes transition, and hence consistent with 4^{+} assignment for the parent state.

Summarising, we conclude that the configuration (A) with 4^{-} as ^{156}Pm gs is not acceptable, since it requires a lower-lying low-spin GM triplet partner, whereas a low spin isomer has since been experimentally identified at 150.3 keV above the 24.6-s gs. Configuration (B) is also not acceptable, since its constituent n-orbital 3/2[651] is observed at excitation energy of more than 570 keV in every one of the N=95 odd-A isotones; consequently this 2qp configuration will appear certainly at more than 500 keV above the corresponding lowest state in the N=95 odd-odd ^{156}Pm. Configuration (C) has been shown to be consistent with all the known experimental inputs, including the observed log ft values for β-feedings to ^{156}Sm levels which were earlier interpreted to exclusively suggest a negative parity parent state. The fact that the two isomers are connected through an M3 (ΔI=3, Δπ=no) transition, directly yields $I^{\pi}=1^{+}$ for the higher isomer. This spin-parity matches the

$1^{+}1$ {p_0: 5/2 [532] - n_0: 3/2 [521]}

assignment for the GM singlet partner of 4^{+} gs; their observed separation of 150 keV is also similar to the experimental GM splitting of this configuration in isobaric ^{156}Eu and other odd-odd neighbouring nuclei.

References

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