# ΔK=0 admixed band structures in the odd-odd deformed nucleus $^{176}_{71}Lu_{105}$

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Studies relating to the naturally occurring odd-odd heavy nucleus $^{176}$Lu are of a great interest both from the astrophysical/ nucleosynthesis and the nuclear structure points of view. Its level scheme has been experimentally investigated[1-4], using 9 different processes including Coulomb excitation, n-capture and particle transfer reactions etc. Over 30 two-quasiparticle (2qp) Nilsson configurations and associated rotational bands have been identified therein [1,2]. One of its features, rarely observed elsewhere but in marked evidence herein, is ΔK=0 2qp configuration mixing of several bands. In the present report, we specifically focus on this phenomenon. In particular, we seek a quantitative measure of ΔK=0 mixing in 16 bands comprising of 4 pairs of GM doublets wherein identical $K_T$ and $K_S$ bands pertain to differing (n,p) configurations.

Direct experimental evidence of ΔK=0 admixed $^{176}$Lu bands comes from three different results, namely relative population of same K bands in neutron and proton transfer reactions, inter-band transitions, and comparison of the experimental and theoretical GM splitting energies.

In $^{176}$Lu, the ground state (gs) neutron configuration is $n_0$:7/2$^-$[514] and gs proton is in $p_0$:7/2$^+$[404] orbital. Thus $^{175}$Lu(d,p)$^{176}$Lu reaction selectively populates various n-orbitals coupled to the gs 7/2$^+$[404]$_p$ spectator orbital, while $^{177}$Hf(t,α)$^{176}$Lu proton-pick up reaction selectively populates states with various $p_i$ orbitals coupled to gs 7/2$^-$[514]$_n$ spectator orbital. It so happens that these two complementary reactions populate pairs of identical K-bands, as shown in Table I.

However, the experimental data reveals that the respective population of levels in same K bands pairs is not exclusive in either reaction. This observation clearly signifies that these bands do not have specified pure 2qp configuration and that each same K band has both ($n_0$,$p_i$) and ($n_i$,$p_0$) components. We illustrate this phenomenon by looking at the pair of ($1^+$,$8^+$) GM doublet bands.

**Table I:** Experimental bandhead energies of GM doublet pairs (with identical $K^\pi$ values) in $^{176}$Lu assigned to (A) excited protons coupled to $n_0$: 7/2$^-$[514] orbital (populated in (t,α) reaction) and to (B) excited neutrons-coupled to $p_0$: 7/2$^+$[404] orbital respectively

| (A) Levels from (t,α) | | $p_1$: 9/2$^-$[514] | | $p_2$: 5/2$^+$[402] | | $p_3$: 1/2$^+$[411] | | $p_4$: 7/2$^-$[523] | |
|---|---|---|---|---|---|---|---|---|---|
| $n_0$: 7/2$^-$[514] | $K^\pi$ | $1^+$ | $8^+$ | $1^-$ | $6^-$ | $4^-$ | $3^-$ | $0^+$ | $7^+$ |
| | (keV) | 194 | 488 | 387 | 564 | 723 | 843 | 1057 | 1273 |

| (B) Levels from (d,p) | | $n_1$: 9/2$^+$[624] | | $n_2$: 5/2$^-$[512] | | $n_3$: 1/2$^-$[521] | | $n_4$: 7/2$^+$[633] | |
|---|---|---|---|---|---|---|---|---|---|
| $p_0$: 7/2$^+$[404] | $K^\pi$ | $1^+$ | $8^+$ | $1^-$ | $6^-$ | $4^-$ | $3^-$ | $0^+$ | $7^+$ |
| | (keV) | 339 | 425 | 638 | 766 | 908 | 958 | - | 855 |

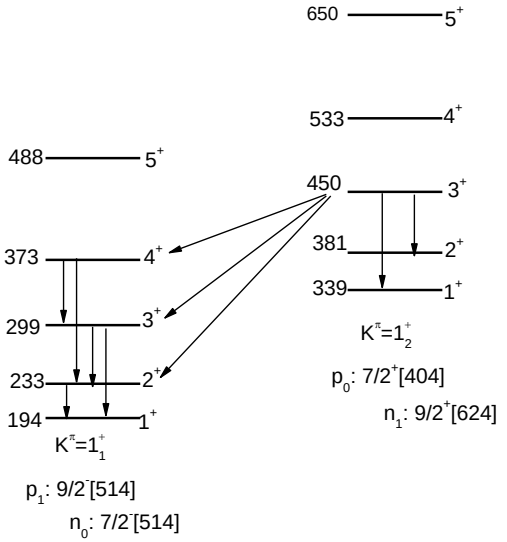


**Fig. 1:** Two $K^{\pi} = 1^{+}$ band levels in $^{176}$Lu, indicative of significant ΔK=0 admixtures in both bands.

In Fig. 1, we show the experimentally observed energies and decay patterns of the two $K^{\pi}=1^{+}$ bands. In this figure, we have only included decay linking 450 keV $3^{+}_{2}$ level for illustrative purpose. Similar decays are observed for all other levels too. Pure 2qp configurations would require no inter-band transitions, whereas experiments yield significant intensity for each of such ΔI = 0,1 connecting transitions.

Comparison of the observed and the calculated pure 2qp GM splitting energies (in keV) also indicate a large ΔK=0 admixture in each of the involved bands. Experimental $E_{GM}$ for the $8^{+}$(488 keV) and $1^{+}$(194 keV) doublet is 219 keV in sharp contrast with the value 141 keV calculated for a pure 2qp doublet with the indicated configuration. The corresponding values are 12 keV (Expt) to be compared with 107 keV (theory) for the $8^{+}$(425 keV) and $1^{+}$(339 keV) doublet.

An estimate of the band admixtures in the two $K^{\pi}=8^{+}$ bands may be obtained by examining the respective reaction cross sections for the two $9^{+}8$ levels listed in Table II. Average of the respective cross section ratios in each column of Table 2 is around 4, which corresponds to an 80:20 % admixture in each of the bands. The 488 keV $K^{\pi}=8^{+}$ band configuration is ~80%

**Table II:** Experimentally determined differential cross sections $\frac{d\sigma}{d\Omega}$ (in μb/sr) for populations of the two $I^{\pi}K=9^{+}8$ levels in $^{176}$Lu indicated reactions

| $E_x$( $I^{\pi}K=9^{+}8$) | $\frac{d\sigma}{d\Omega}$(t,α) | rel. $\frac{d\sigma}{d\Omega}$(t,α) |
|---|---|---|
| 682 keV | 13.2 | 2.8 |
| 615 keV | 2.4 | 6.8 |

[p:9/2$^{-}$ ⊗n:7/2$^{-}$] and ~20%[p:7/2$^{+}$ ⊗ n:9/2$^{+}$] and vice-versa for lower 425 keV $K^{\pi}=8^{+}$ band. Two-band mixing calculations with this input data yield ΔE(unperturbed) ~38 keV for the two $K^{\pi}=8^{+}$ bands in comparison with the observed ΔE=63 keV for the admixed (perturbed) bands.

Cross section data for the $K^{\pi}=1^{+}$ bands do not help to decide the configurations, since the intensity is distributed over many rotational levels and very week peaks fall in the noise domain. However, analysis of the in-band E2/M1 mixing ratios in this case can be used to estimate the mixing amplitudes [5]. This procedure, which involves evaluation of configuration dependent E/M moments, yields ~30% of [p:9/2$^{-}$ ⊗ n:7/2$^{-}$] configuration admixture in the 194 keV based $K^{\pi}=1^{+}$ band levels which has dominant ~70% [p:7/2$^{+}$ ⊗ n:9/2$^{+}$] component. The 399 keV $1^{+}$ band has the similar admixtures of the two 2qp configurations in the reverse order. Detailed analysis in respect of ΔK=0 admixture in the other same K band pairs shown in Table I, and also in similar pairs involving both p & n excited orbitals, are in progress.

## References

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