In the rotor-particle model for an axially symmetric nucleus, the rotational band quantum number $K$ defined as $K=I_3$ based on the vector relation $\vec{I} = \vec{R} + \vec{J}$. In this formalism [1], the total Hamiltonian includes a Rotation-Particle Coupling (RPC), namely $\vec{I}\cdot\vec{J}$ term. When treated as a perturbation, it gives rise to coupling (henceforth termed Coriolis Band Mixing (CBM)) between different rotational bands with $\Delta K=\pm 1$. Mixing between bands with $\Delta K>1$ is then described through stepwise CBM application. Presently we focus on the somewhat less discussed $\Delta K=0$ Non-Coriolis Band Mixing (NCBM). Such a situation arises, since, $I^K$ does not uniquely define a nuclear state, which is more appropriately described using the Nilsson model asymptotic quantum numbers $[Nn\Lambda\Sigma]$. In our study we use the current databases while discussing specific level schemes.

While discussing this question in the context of $\beta$-decay [3] we pointed to an early remark of Mottleson and Nilsson that ‘a selection rule associated with $N$ should be somewhat stronger than the rules connected with other asymptotic quantum numbers’. Since parity is a good quantum number, the lowest order NCBM is expected to be significant for closely spaced $\Delta N=2$ bands. An examination of Nilsson level diagrams (vide Fig 5.3 of ref.1) reveals that the sharply down-sloping of $1/2\,[660]$ and also $3/2\,[651]$ neutron orbitals occur very close in energy respectively with the sharply up-sloping $1/2\,[400]$ and $3/2\,[402]$ orbitals for $\delta \sim 0.3$ (normal for well deformed nuclei). A survey of corresponding experimentally observed energy levels indeed shows that NCBM occurs in almost every known case of $N=89(2)/97$ isotones. The current data tables [2] explicitly record that in each case the $1/2\,[660]$ level has a significant $1/2\,[400]$ component and vice-versa. The same observation holds for each known pair of $3/2^+$ levels. Illustrative instances of such cases are listed in Table.1 for odd-A nuclei. This feature is also seen for even-A, both the even-even and odd-odd, nuclei of the region as seen evident in the following illustrative experimental data [2,4]: 

\[
156^\text{Gd}_{92}: 2138 \text{ keV } 7
\]
\[
\text{[nn:11/2[505][3/2][651] & 3/2[402]]}
\]
\[
164^{\text{Ho}}_{99}: 833 \text{ keV } 4(\Lambda_T) \text{ and } 925 \text{ keV } 3(\Lambda_S)
\]
\[
\text{[p:7/2[525] \& n:1/2[660] & 1/2[400]]}
\]

Direct experimental evidence for band mixing comes from various reaction processes, population and decay modes, and intraband-vs-interband transition rates. In particular, particle transfer studies provide quantitative estimates for this feature in 2qp bands in even-A nuclei as discussed in our earlier report for the odd-odd nucleus $^{159}$Lu [5]. Presently we report on side-by-side examination of 2qp bands in extensively studied even-even $^{166}$Er and odd-odd $^{166}$Ho [2].

### Table 1: Illustrative instances of experimental [2] bandhead energies (in keV) of $\Delta N=2$ mixed $\Delta K=0$ pairs of $K=1/2^+$ and also $K=3/2^+$ bands in lighter odd-A rare earth nuclei.

<table>
<thead>
<tr>
<th>$N$</th>
<th>$\frac{A}{2}$</th>
<th>$E_x: 1/2^+([660] &amp; 1/2^+[400])$</th>
<th>$E_x: 3/2^+([651] &amp; 3/2^+[402])$</th>
</tr>
</thead>
<tbody>
<tr>
<td>89</td>
<td>$^{156}_{66}\text{Gd}$</td>
<td>95</td>
<td>328</td>
</tr>
<tr>
<td>91</td>
<td>$^{155}_{62}\text{Sm}$</td>
<td>415</td>
<td>735</td>
</tr>
<tr>
<td>93</td>
<td>$^{155}_{62}\text{Sm}$</td>
<td>903</td>
<td>1282</td>
</tr>
<tr>
<td>95</td>
<td>$^{161}_{66}\text{Dy}$</td>
<td>608</td>
<td>773</td>
</tr>
<tr>
<td>97</td>
<td>$^{163}_{66}\text{Dy}$</td>
<td>738</td>
<td>884</td>
</tr>
</tbody>
</table>

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In this study we have focused on a highly NCBM pair of \( K^\pi = 4 \) levels composed of \( (n_1 \otimes n_2) \) and \( (p_1 \otimes p_2) \) orbital pairs as shown in Fig. 1, and experimentally observed \([6]\) in \(^{168}_{66}\text{Er}_{100}\) spectra as listed in Table 2. A series of particle transfer reaction studies by Burke \textit{et al.} \([6]\) concluded that the 1094 keV \( 4^+_1 \) level NCBM configuration is \( 70\%(n_1n_2)+25\%(p_1p_2) \) whereas the 1905 keV \( 4^+_2 \) level is \( 60\%(p_1p_2)+32\%(n_1n_2) \). The \( 3^-_1 \) and \( 3^-_2 \) counterpart of this pair of doublets has <10\% NCBM components. Our comparative study of e-e and o-o neighbours establish that the same pairs of nn and pp orbitals constitute pair of GM doublets bands (Fig. 1) experimentally identified in the o-o neighbour \(^{166}\text{Ho}\), as listed in Table 2. We term this occurrence as ‘Analogous Doublets in odd-odd and even-even Nuclei’. Detailed analysis of the scope and characteristics of this feature are under investigation.

**References**