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NEGATIVE PARITY BANDS IN $^{100}$Ru AND $^{150}$Sm AND
THE INTERACTING BOSON APPROXIMATION

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Ground-state band members up to $J^\pi = 10^+$ in $^{100}$Ru and up to $14^+$ in $^{150}$Sm and odd-spin negative parity states
up to $15^-$ in both nuclei have been identified from ($\alpha$, $4n$) in-beam $\gamma$-ray and conversion electron spectra. The data
are interpreted in terms of interacting quadrupole and octupole bosons.

Strikingly regular patterns ("bands") of energy
levels not belonging to the ground-state bands (GSB)
are found in a number of vibrational and transitional
nuclei. These levels are characterized by energy spacings
which increase regularly with the spin, by fast E2 tran-
sitions within the bands and by apparent regularities
in the competing deexcitation modes. Particularly
good examples of these features are the negative parity
bands (NPB) which recently were reported for $^{126,128}$Ba
[1] and for the $N=88$ isotones $^{152}$Gd [2], $^{156}$Er [3, 4]
and more tentatively for $^{154}$Dy [5].

The NPB seen in $^{156}$Er [4] and in $^{126,128}$Ba [1] have
been interpreted as a rotational band built on a two-
quasiparticle state. Alternative interpretations of the
NPB in transitional nuclei have been proposed in terms
of vibrational type excitations of a $K_{\pi} = 0^-$ octupole
band [3], and of an octupole vibration coupled either
to a deformed core [6] or to a spherical core [2].

Iachello and Arima have shown that this coupling
can be treated in a simple way within the frame work of the
Interacting Boson Approximation (IBA) model [7, 8].

Transitional and vibrational nuclei which are expected
to exhibit bands arising from such couplings can be
found e.g. in the mass regions $A \approx 100$ and 150. This
paper presents relevant experimental evidence for
$^{100}$Ru and $^{150}$Sm, which are both six neutrons away
from a major closed shell. The GSB and several states
supposed to belong to side bands in $^{100}$Ru and $^{150}$Sm
have been established in previous work, particularly in
($\alpha$, $2n\gamma$) reactions [9, 10]. The present investigation
verifies and extends this information, specifically on
the high-spin members of both GSB and NPB.

Metallic self-supporting targets of $^{100}$Mo and $^{150}$Nd
enriched to about 97% were bombarded with a 45 MeV
$\alpha$-particle beam from the Groningen cyclotron. Coincidence
$\gamma-\gamma$ events and their relative time delays were
recorded on magnetic tape by a PDP-15 computer.

Gamma-time and electron-time spectra (see below)
were also recorded, with the RF signal of the cyclotron
as time reference. No evidence was found for delayed
transitions with $\tau_{\text{delay}} > 5 \text{ ns}$. Angular distributions were
measured at six angles between $\theta = 90^\circ$ and $155^\circ$ with
a 110 cm$^3$ Ge(Li) detector at a distance of 20 cm from
the target. The data were analysed with a computer
code based on the equations of Poletti and Warburton
[11], modified to allow for a Gaussian distribution of
the populations of the magnetic substates. The theore-
tical curves for all possible spin combinations were
fitted to the data in a least-squares procedure with the
width of the Gaussian population distribution and the
quadrupole/dipole amplitude mixing ratio as parameters.
The measured mixing ratios are consistent with pure
dipole character of the interband transitions between
NPB and GSB members. The parities of the observed
levels were established from measurements of internal
conversion coefficients with a mini-orange spectrometer
[12]. A prompt ($\Delta t < 10 \text{ ns}$) conversion electron spec-
trum of $^{150}$Sm taken for one hour with a 4 nA beam is
shown in fig. 1 along with the corresponding $\gamma$-ray
spectrum. The results, given in table 1, clearly show

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E2 character for the intraband transitions and E1 character for the interband transitions. This proves the negative parity of the side bands both in $^{100}$Ru and $^{150}$Sm.

The decay schemes for the GSB and NPB in $^{100}$Ru and $^{150}$Sm are given in fig. 2. Spin assignments are based on the combined evidence of the measured angular distributions, of the conversion coefficients, of the comparison of relative γ-ray intensities in the $(\alpha, 4n)$ and $(\alpha, 2n)$ [9, 10] reactions and for $^{150}$Sm of the relative excitation functions in the $(\alpha, 2n)$ reaction [10]. Brackets indicate spin assignments which do not satisfy the confidence criteria as recommended by Nuclear Data Sheets.

In the IBA model the eigenvalues of the interacting boson Hamiltonian are given [7, 8] as $E_g(J = 2n) = n e_2 + \frac{1}{2} c_4 n(n - 1)$ for the GSB and $E(J = 2n + 3) = E_g + e_3 + c_5 n$ for the odd-spin NPB in the case of total alignment of angular momentum. Here $n$ denotes the quadrupole phonon number, $c_4$ and $c_5$ the quadrupole-quadrupole and quadrupole-octupole interaction strengths, respectively, and $e_2$ the quadrupole and $e_3$ the octupole boson energies. With four free parameters per nucleus a fairly accurate description of the experimental energies in the GSB and NPB can be obtained (cf. fig. 2). The GSB shows deviations above the $10^+$ or $12^+$ states, where backbending may be expected to occur which is not accounted for by this simple model. It is satisfying to notice that there is little or no sign of backbending in the NPE at the corre
The table below presents the energies and angular distribution coefficients of γ-rays and internal conversion coefficients from the $^{100}$Mo, $^{150}$Nd(α, 4n)$^{100}$Ru, $^{150}$Sm reactions at $E_α = 45$ MeV.

<table>
<thead>
<tr>
<th>$J^π_1$→$J^π_f$</th>
<th>$E_γ$ (keV)</th>
<th>$A_2/A_0$ (×10^2)</th>
<th>$A_4/A_0$ (×10^4)</th>
<th>$α_K^{exp}$ (×10^5)</th>
<th>$E_γ$ (keV)</th>
<th>$A_2/A_0$ (×10^2)</th>
<th>$A_4/A_0$ (×10^4)</th>
<th>$α_K^{exp}$ (×10^5)</th>
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<tr>
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<tr>
<td>2⁺→0⁺</td>
<td>539.7</td>
<td>22±2</td>
<td>4±3</td>
<td>375</td>
<td>334.0</td>
<td>25±3</td>
<td>8±5</td>
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<td>687.4</td>
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<td>7±3</td>
<td>195</td>
<td>439.6</td>
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<td>7±5</td>
<td>148</td>
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<td>-15±7</td>
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<td>505.7</td>
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<td>5±3</td>
<td>70±9</td>
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<td>27±5</td>
<td>-10±8</td>
<td>77±12</td>
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<tr>
<td>10⁺→8⁺</td>
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<td>5±3</td>
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<td></td>
<td></td>
<td>615.1</td>
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<td>61±10</td>
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<td></td>
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<td>627.5</td>
<td>16±9</td>
<td>-12±7</td>
<td>49±15</td>
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<td>36±8</td>
<td>2±10</td>
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<td>6±4</td>
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<td>-29±4</td>
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<td>78±20</td>
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<td>3±10</td>
<td>&lt;250</td>
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<td>1±20</td>
<td>95±25</td>
</tr>
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<td>244.9</td>
<td>-8±4</td>
<td>8±4</td>
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<td>12±20</td>
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<td></td>
<td>304.1</td>
<td>-16±10</td>
<td>25±16</td>
<td></td>
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</table>

a) Experimental errors are ±0.3 keV.
b) The theoretical conversion coefficients correspond to unmixed transitions with the lowest possible multipolarity.
c) Experimental value normalized to theory.
Fig. 2. Experimental information on the $^{106}$Ru and $^{150}$Sm decay schemes obtained from the (α, 4n) reactions compared with the results of IBA calculations. Relative γ-ray intensities are given in brackets. The 3− state in $^{150}$Sm was not observed, see ref. [13] and refs. mentioned therein. The IBA parameters $\varepsilon_2$, $\varepsilon_3$, $\varepsilon_4$ and $\varepsilon_5$ are 450, 2249, 148 and -260 keV for $^{106}$Ru and 356, 1077, 66 and -47 keV, respectively, for $^{150}$Sm.

and $^{150}$Sm by (α, 4n) reactions are well accounted for by the simple IBA model.

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