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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 (α, 4n) in-beam γ-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 transitions 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 (α, 2nγ) 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 α-particle beam from the Groningen cyclotron. Coincidence γ-γ 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 $\tau_m > 5$ ns. Angular distributions were measured at six angles between $\theta = 90°$ and 155° 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 theoretical 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 ($\Delta t < 10$ ns) conversion electron spectrum of ^{150}Sm taken for one hour with a 4 nA beam is shown in fig. 1 along with the corresponding γ-ray spectrum. The results, given in table 1, clearly show

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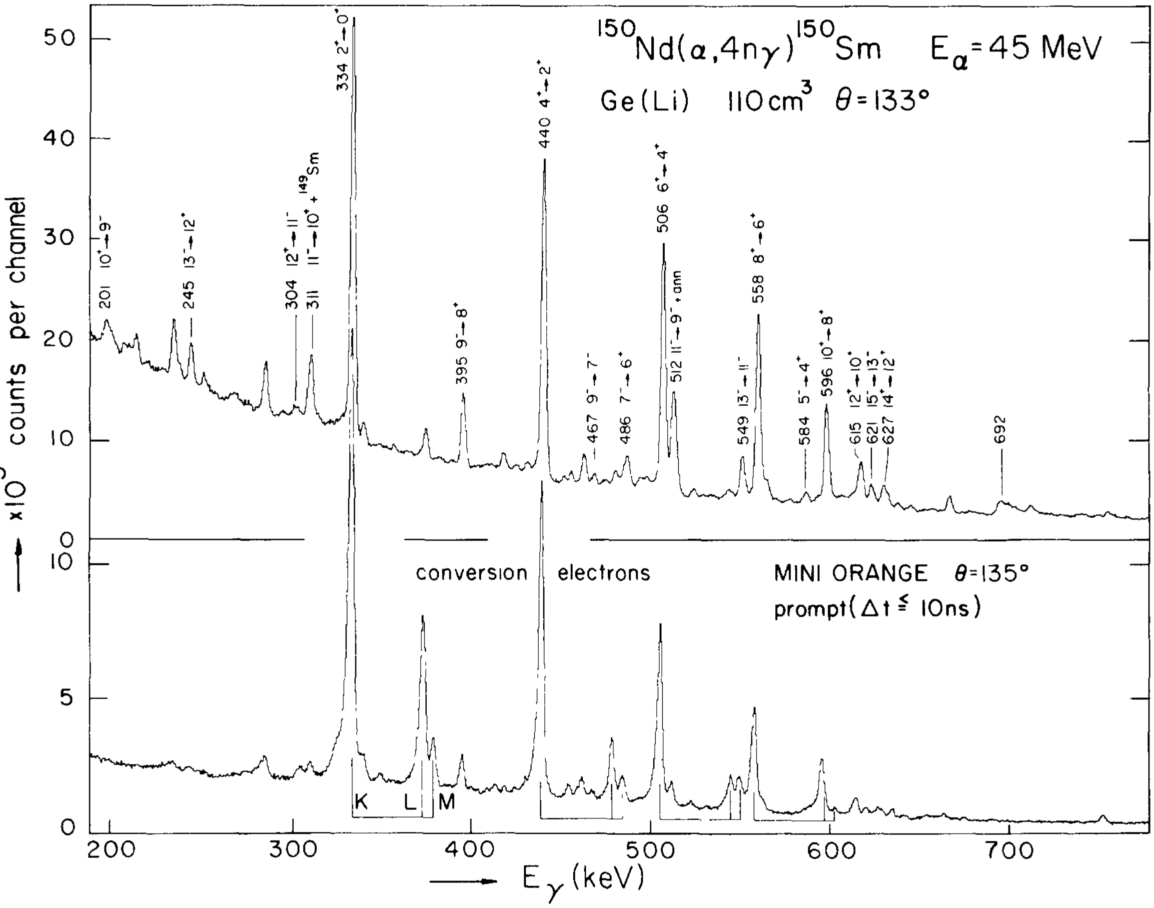

Fig. 1. A conversion electron spectrum of ^{150}Sm (bottom) taken with a 0 7 mg/cm^2 ^{150}Nd target with a corresponding γ-ray spectrum (top) taken with a 5 mg/cm^2 target.

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 (α, 4n) and (α, 2n) [9, 10] reactions and for ^{150}Sm of the relative excitation functions in the (α, 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 $E_g(J=2n) = n\epsilon_2 + \frac{1}{2}c_4\, n(n-1)$ for the GSB and $E(J = 2n + 3) = E_g + \epsilon_3 + c_5 n$ 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 ϵ_2 the quadrupole and ϵ_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

Table 1
Energies and angular distribution coefficients of γ-rays and internal conversion coefficients from the ^{100}Mo, $^{150}Nd(\alpha, 4n)^{100}Ru$, ^{150}Sm reactions at $E_\alpha = 45$ MeV

$J_i^\pi \to J_f^\pi$	$E_\gamma^{a)}$ (keV)	A_2/A_0 ($\times 10^2$)	A_4/A_0	α_K^{exp}	$\alpha_K^{th\,b)}$ ($\times 10^5$)	$E_\gamma^{a)}$ (keV)	A_2/A_0 ($\times 10^2$)	A_4/A_0	α_K^{exp}	$\alpha_K^{th\,b)}$ ($\times 10^4$)
		^{100}Ru						^{150}Sm		
$2^+ \to 0^+$	539 7	22±2	− 4±3		375 c)	334.0	25±3	− 8±5		320 c)
$4^+ \to 2^+$	687.4	24±2	− 7±3		195 c)	439.6	27±3	− 7±5		148 c)
$6^+ \to 4^+$	850 0	28±6	−15±7	110±17	112	505.7	26±5	−14±8	97±10	103
$8^+ \to 6^+$	985 2	25±2	− 5±3	70±9	79	558.3	27±5	−10±8	77±12	80
$10^+ \to 8^+$	1024.0	28±3	− 5±3	95±20	73	596.3	24±5	−12±8	74±12	68
$12^+ \to 10^+$						615.1	18±10	−12±7	61±10	63
$14^+ \to 12^+$						627.5	16±9	−12±7	49±15	60
$7^- \to 5^-$	424.3	36±8	− 2±10	900±500	750					
$9^- \to 7^-$	552.2	26±5	−10±5	700±400	355	467.5			140±40	125
$11^- \to 9^-$	727 7	33±6	− 9±7	170±70	166	512.0			75±20	99
$13^- \to 11^-$	932.4	28±8	−11±9	150±50	91	549.5	21±5	−19±8	110±30	83
$15^- \to 13^-$	1036.3	43±12	3±14	<300	75	620.8	16±9	− 9±15	55±12	62
$5^- \to 4^+$	1301 6	−31±3	6±4	26±13	21	584 5	−20±9	6±14	< 30	27
$7^- \to 6^+$	876 7	−32±4	0±6	45±10	42	486.1	−28±9	5±14	55±25	40
$9^- \to 8^+$	443.3	−33±8	3±10	<250	196	395.3	−29±4	− 2±17	78±20	64
$11^- \to 10^+$						311.2	−22±13	1±20	95±25	116
$13^- \to 12^+$						244 9	− 8±4	− 8±4		
$10^+ \to 9^-$						200.6	−25±13	12±20		
$12^+ \to 11^-$						304.1	−16±10	25±16		120

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

sponding J^π values 13^- or 15^-, which is in agreement with the assumed coupling mechanism and with the interpretation of the backbending as being due to band crossing.

The IBA model also gives a simple relationship [8] for the B(E1)/B(E2) branching ratios for transitions depopulating the NPB states

$$\frac{B[\mathrm{E1}; (J=2n+3)^- \to (J=2n+2)^+]}{B[\mathrm{E2}; (J=2n+3)^- \to (J=2n+1)^-]} = \frac{n+1}{n} C ,$$

where C is a constant for a given nucleus. Thus the B(E1)/B(E2) values are expected to vary smoothly with boson number n with differences smaller than a factor of two. The experimental B(E1)/B(E2) values in units of $10^{-5}\,\mathrm{b}^{-1}$ are 0.9 ± 0.2 and 3.3 ± 0.6 for the decay of the 7^- and 9^- states in ^{100}Ru and 21 ± 4, 10 ± 3 and 12 ± 2 for the decay of the 9^-, 11^- and 13^- states in ^{150}Sm, respectively. The experimental ratio 0.27±0.10 of the B(E1)/B(E2) values for the decay of the 7^- state relative to that of the 9^- state in ^{100}Ru deviates by a factor of four from the calculated ratio 1.12. On the other hand the experimental ratios 1.7±0.6 and 0.8±0.3 for the decay of the 9^- and 11^- states relative to that of the 13^- state in ^{150}Sm are in fair agreement with the calculated ratios 1.11 and 1.04, respectively. Since the transition probabilities are very sensitive to configuration mixing, which is absent in this simple version of the IBA model this agreement can be considered satisfactory. Similar results have been reported [14] for ^{162}Er. However, we bring attention to the observed $12^+ \to 11^-$ and $10^+ \to 9^-$ transitions in ^{150}Sm, for which the corresponding B(E1)/B(E2) values are (2.4±0.6) and $(4.8 \pm 1.2) \times 10^{-5}\,\mathrm{b}^{-1}$. These transitions are forbidden in the first approximation of the IBA model, while the measured B(E1)/B(E2) ratios are on the average a factor of four smaller than those of the transitions depopulating the NPB levels.

In summary we may conclude that the main properties of the observed GSB and NPB populated in ^{100}Ru

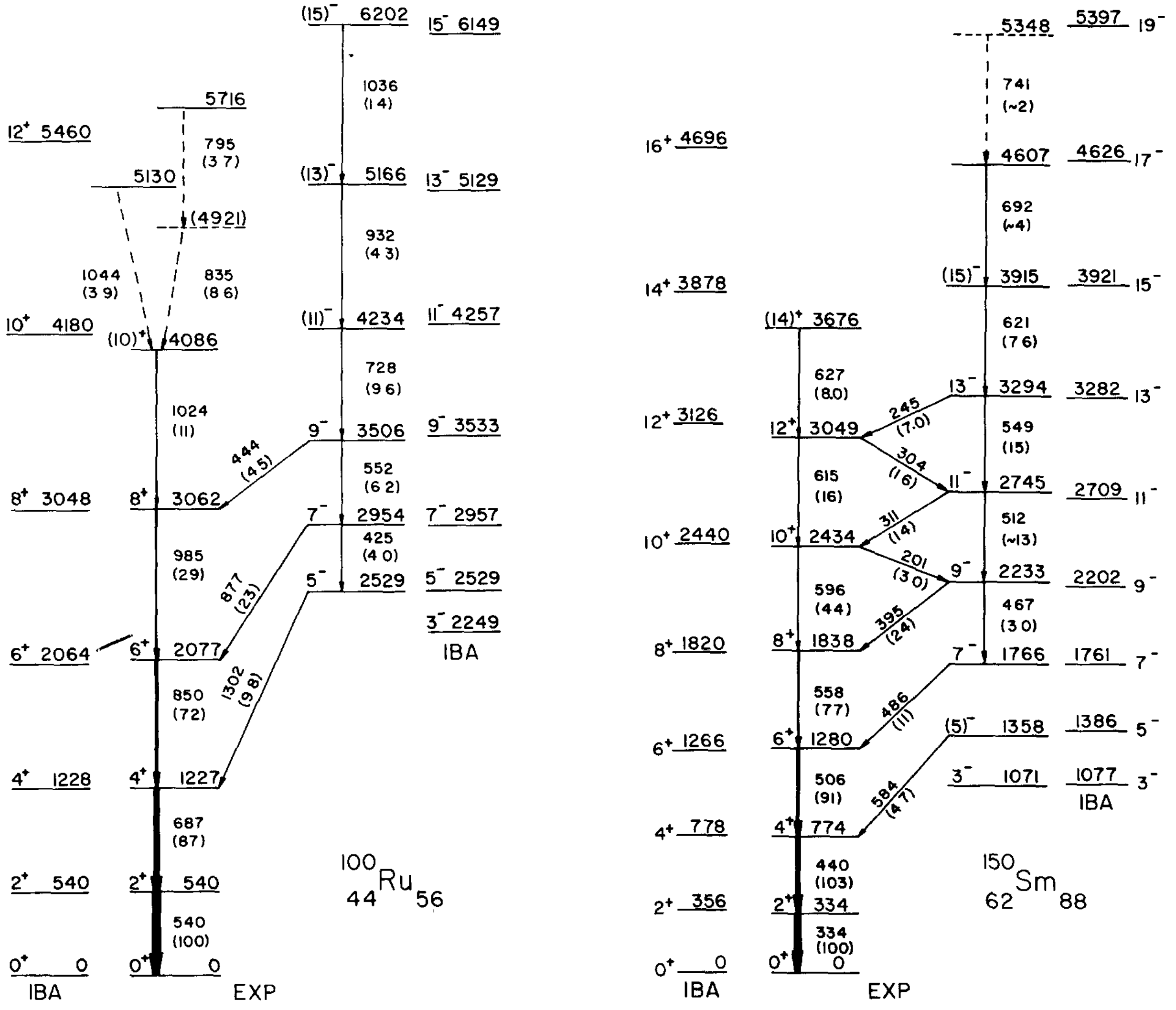

Fig. 2. Experimental information on the ^{100}Ru and ^{150}Sm decay schemes obtained from the (α, 4n) reactions compared with the results of IBA calculations. Relative γ-ray intensities are given in brackets. The 3^- state in ^{150}Sm was not observed, see ref. [13] and refs. mentioned therein. The IBA parameters ϵ_2, ϵ_3, c_4 and c_5 are 450, 2249, 148 and −260 keV for ^{100}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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References

[1] C. Flaum, D. Cline, A.W. Sunyar and O.C. Kistner, Phys. Rev. Lett. 33 (1974) 973.

[2] D.R. Zolnowski, T. Kishimoto, Y. Gono and T.T. Sugihara, Phys. Lett. 55B (1975) 453.
[3] Y. Gono, D.R. Zolnowski, D.R. Haenni and T.T. Sugihara, Phys. Lett. 49B (1974) 338.
[4] A.W. Sunyar, Brookhaven National Laboratory, Upton, N.Y., private communication.
[5] H. Beuscher et al., Proc. Int. Conf. on Reactions between Complex Nuclei, Nashville (1974) p. 189.
[6] M. Nomura, Phys. Lett. 55B (1975) 357.
[7] F. Iachello, Proc. Int. Conf. on Nuclear Structure and Spectroscopy, Amsterdam (1974) vol. 2, p. 163; F. Iachello and A. Arima, Phys. Lett. 53B (1974) 309.
[8] A Arima and F. Iachello, Phys. Lett. 57B (1975) 39.
[9] C.M. Lederer, J.M. Jaklevic and J.M. Hollander, Nucl. Phys. A169 (1971) 449.
[10] J. Kownacki, Z. Sujkowski, H. Ryde and I. Adam, Proc Int. Conf. on Nuclear Structure and Spectroscopy, Amsterdam (1974) vol. 1, p. 103; and to be published.
[11] A.R. Poletti and E.K. Warburton, Phys. Rev. 137 (1965) B595.
[12] J. van Klinken and K Wisshak, Nucl. Instr. 98 (1972) 1 and J. van Klinken, S.J. Feenstra, K. Wisshak and H. Faust, Nucl. Instr., to be published.
[13] F. Bečvář, R.E. Chrien and O.A. Wasson, Nucl. Phys. A236 (1974) 173.
[14] M. Fenzl et al., Z. Physik A273 (1975) 163