Volume 171, number 2,3 PHYSICS LETTERS B 24 April 1986

OCTUPOLE EXCITATIONS IN O(6) NUCLEI

J. ENGEL

A.W. Wright Nuclear Structure Laboratory, Yale University, New Haven, CT 06511, USA

Received 20 January 1986

The coupling is discussed of an octupole boson to an O(6) core in the interacting boson approximation, and the results are applied to several platinum isotopes.

Many of the low-lying negative-parity states in the rare-earth region of the periodic table have been successfully interpreted as octupole ($L^\pi = 3^-$) shape vibrations around a spherical or quadrupole deformed ground-state shape. These vibrations have been discussed in different contexts; a quasiparticle RPA was applied [1] systematically throughout a large part of the rare-earth region and f bosons have been incorporated into the interacting boson approximation (IBA) to describe negative-parity excitations phenomenologically. In the latter model, the coupling of an f boson to the usual s and d bosons in the U(5) and SU(3) analytic limits was discussed very early on [2] and successfully applied in a description of samarium isotopes [3]. However, an analysis of the coupling to an O(6) [4] core – that is, a γ-unstable or triaxial nucleus – has never appeared. In what follows we discuss this case and apply the results to the low-spin negative-parity states in ^{190}Pt–^{196}Pt.

The collective positive-parity states in many nuclei have been fit by an O(6) IBA hamiltonian of the form

$$H = -\kappa Q^{\mathrm{sd}} \cdot Q^{\mathrm{sd}} + \kappa' L \cdot L \,, \tag{1}$$

where

$$Q^{\mathrm{sd}}_\mu = d^\dagger_\mu s + s^\dagger \tilde{d}_\mu \,, \tag{2}$$

$$L_\mu = \sum_{\alpha\beta} \langle 2\alpha, 2\beta | 1\mu \rangle \mathrm{d}^\dagger_\alpha \tilde{\mathrm{d}}_\beta \,,$$

$$\tilde{d}_\mu = (-)^\mu d_{-\mu} \,,$$

and the dot stands as usual for the scalar product of two tensors. The spectrum associated with this hamiltonian is shown in ref. [4]; a characteristic feature is a low-lying γ band. In the spirit of previous IBA studies of f coupling, we have added to the above hamiltonian an additional piece

$$H' = \epsilon n_{\mathrm{f}} + \beta Q^{\mathrm{f}} \cdot Q^{\mathrm{sd}} \,, \tag{3}$$

where

$$Q^{\mathrm{f}}_\mu = \sum_{\alpha\beta} \langle 3\alpha, 3\beta | 2\mu \rangle f^\dagger_\alpha \tilde{f}_\beta \,, \tag{4}$$

and n_{f} is the number of f bosons. Although we were not able to diagonalize this interaction analytically, we examined the results numerically for several different sets of parameter values; the states organize themselves into a regular pattern, an example of which appears in fig. 1. This result is reminiscent of that obtained when coupling a particle of half-integer spin to an O(6) core in the interacting boson–fermion approximation [5].

We now turn to the nuclei ^{190}Pt–^{196}Pt, where O(6) is known [6] to provide a reasonable approximation to the positive-parity energy levels and a good description of transition rates. These isotopes were studied some years ago [7] in terms of a "semi-decoupled model" in which the negative-parity states could be expressed as linear combinations of two-quasiparticle states in a triaxial one-body field. The results of these calculations indicate that states with $J \leqslant 4$ are essentially of octupole phonon type (coherent coupling of quasiparticles to $L = 3$) while those with $J \geqslant 5$ have different structure. This conclusion

0370-2693/86/\$ 03.50

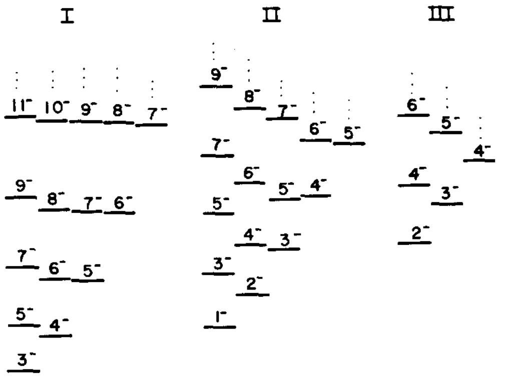

Fig. 1. The spectrum of negative-parity states produced by the hamiltonian $H + H'$ (defined in eqs. (1) and (3)). The parameters have the values $\kappa = 0.1$, $\kappa' = 0$, $\beta = 0.1$. The parameter ϵ is arbitrary here as is, accordingly, the scale in the figure. There are six total bosons, five of s–d type and one f. Bands are labeled I, II, ... The in-band E2 transitions are generally larger than the interband transitions, and within a band those connecting states on different levels of the inverted triangles are larger than those connecting states on the same level.

is reflected in the present study as well. The lowest negative-parity states in ^{194}Pt and ^{196}Pt are in fact 5^- states, a feature not reproduced naturally in the IBA. The locations of the lowest 6^-, 7^-, 9^-, and 11^- states, observed in some of the Pt isotopes, are also not well reproduced by the interaction we have chosen. However, the observed states with $J \leqslant 4$ seem to be described quite well. Fig. 2 shows the experimental and predicted energies of these states. The predictions were obtained by first fitting the positive-parity states as well as possible in the O(6) limit and then choosing the values of ϵ and β to fit the 3 negative-parity states in ^{194}Pt. All the rest of the levels are predicted without any additional parameters.

It is interesting to consider transitions to and from these states, very few of which have been well measured as of now. Table 1 presents predictions for relative E2 strengths; the transition operator used is just $T^{E2}_{\mu} = \alpha_2 Q^{sd}_{\mu}$. It bears noting that the $2^- \to 1^-$ is larger than the $2^- \to 3^-$ in the light Pt's where the strength of the $Q^{sd} \cdot Q^{sd}$ interaction is smaller, that is, as the relative strength of the quadrupole–octupole

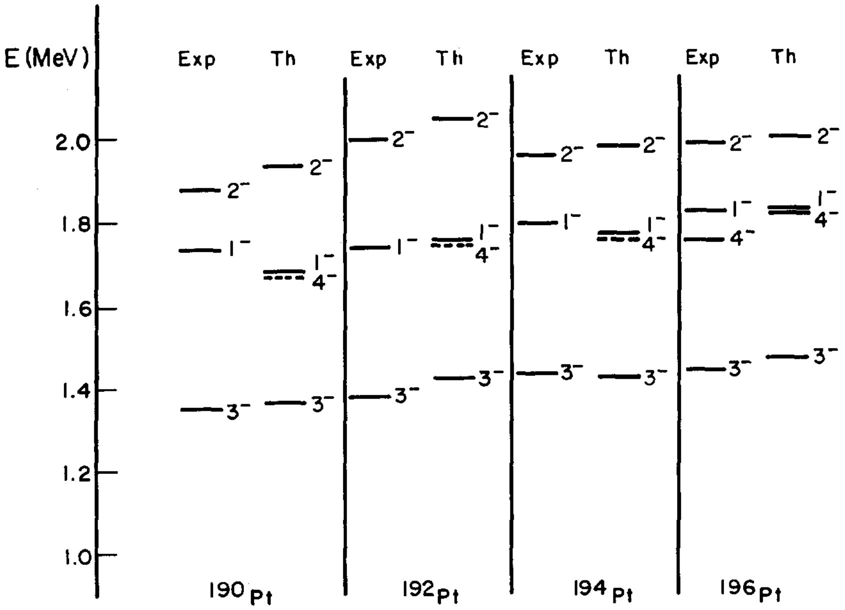

Fig. 2. Fits to the low-spin negative-parity states in the Pt isotopes. The parameters in H of eq. (1) are: ^{190}Pt: $\kappa = 0.048$, $\kappa' = 0.011$; ^{192}Pt: $\kappa = 0.052$, $\kappa' = 0.011$; ^{194}Pt: $\kappa = 0.054$, $\kappa' = 0.012$; ^{196}Pt: $\kappa = 0.058$, $\kappa' = 0.010$. The parameters in H' were fixed at $\epsilon = 0.910$, $\beta = 0.030$, for all the isotopes.

Table 1
B(E2) strengths (in e^2 b^2).

Transition	^{190}Pt	^{192}Pt	^{194}Pt	^{196}Pt
$2^- \to 1^-$	0.283	0.190	0.118	0.062
$2^- \to 3^-$	0.121	0.114	0.103	0.091
$2^- \to 4^-$	0.102	0.063	0.034	0.016

Table 2
Energy (MeV)/B(E3) strength to ground state (in 10^{-1} e^2 b^3).

Initial state	^{190}Pt	^{192}Pt	^{194}Pt	^{196}Pt
3_1^-	1.36/1.01	1.42/1.44	1.44/1.12	1.47/1.13
3_2^-	2.04/0.34	2.12/0.57	2.15/1.01	2.18/1.61
3_3^-	2.18/1.89	2.31/1.84	2.30/1.38	2.30/0.52

interaction grows, the in-band (see fig. 1, which depicts strong coupling) transitions dominate those between bands.

Our model predicts the existence of several higher-lying 3^- states that have not been reported in the literature. If the E3's are generated by the transition operator $T_k^{\mathrm{E3}} = \alpha_3(f^\dagger s + s^\dagger \tilde{f})_k^3$ (a natural choice for collective octupole phonons) the B(E3) strength to the ground state is predicted to spread out over two or more of the 3^- states. Table 2 shows the predicted energies and E3 strength to the ground state of the first three 3^- states in each of the four isotopes. In several cases, the second 3^- has comparable or larger strength than the first. An f–d term may be added to T_k^{E3} should the measured transitions behave differently.

Based on experience with f bosons in other rare-earth nuclei, we suspect the model in the form presented here will fail to describe E1 transitions. However, small admixtures of a p boson could provide a remedy. In a recent study of negative-parity states in the $N = 88$ isotones [8], the chronic failure of the one-body E1 operator to describe transitions was corrected by adding a p boson to the model.

We have outlined here some of the features expected in octupole excitations in γ-unstable nuclei. More data on the transitions to and from the negative-parity states in nuclei such as platinum are welcome, particularly to test the spreading of the E3 strength. While the description provided above is suggestive, more experimental information is needed to determine whether there really are octupole bosons in O(6) nuclei.

I would like to thank F. Iachello for useful discussions. This work was performed in part under the US Department of Energy, Contract No. DE-AC02-76ER03074.

References

[1] P. Vogel and K. Neergard, Nucl. Phys. A145 (1970) 33.
[2] A. Arima and F. Iachello, Ann. Phys. 99 (1976) 253; 111 (1978) 201.
[3] O. Scholten, F. Iachello and A. Arima, Ann. Phys. 115 (1978) 325.
[4] A. Arima and F. Iachello, Ann. Phys. 123 (1979) 468.
[5] O. Scholten, Progress in particle and nuclear physics, Vol. 14, ed. A. Faessler (Pergamon, New York).
[6] R. Casten and J. Cizewski, Nucl. Phys. A309 (1978) 477.
[7] H. Toki, K. Neergard, P. Vogel and A. Faessler, Nucl. Phys. A279 (1977) 11.
[8] C. Han, D. Chuu, S. Hsieh and H. Chiang, Phys. Lett. B 163 (1985) 295.