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IBA FOR
NOVICE EXPERIMENTALISTS,

I. INTRODUCTION TO IBA:
Mostly Symmetries

II. TESTS IN EVEN-EVEN NUCLEI:
Mostly Transitional Systems

III. SUPERSYMMETRIES:
Theory and Experiment

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THE IBA FOR NOVICE EXPERIMENTALISTS

The following report contains the notes from a series of lectures on the Interacting Boson Approximation (IBA) model. The lectures were presented at Lawrence Livermore National Laboratory on July 28, 30 and August 1, 1982 by Jolie A. Cizewski from Yale University.

The IBA was developed by F. Iachello and A. Arima starting about seven years ago to understand collective quadrupole excitations in medium and heavy mass nuclei away from closed shells. Since then the formalism has been extended to odd-mass nuclei and considerable work has gone into understanding the microscopic construction of the bosons in this model. The IBA has been applied to nuclei as light as Zn and Ge and as heavy as U and Pu; to nuclei near closed shells, such as Mo and Hg; to stable nuclei and nuclei far from stability.

The present lectures were designed to give the experimentalist an introduction to the IBA and to give specific examples of how it could be applied to understand the structure of heavy even and odd mass nuclei. Much of the emphasis was on the symmetries (and supersymmetries) of the model and how the use of symmetries enabled the relatively straightforward understanding of empirical systems as deviations from these symmetries.

The richness of possible applications of the IBA to understanding collective phenomena in nuclei was not fully explored, but rather a few illustrative examples were selected and described in detail. The references, accumulated at the end of this report, provide a more comprehensive, although not complete, list of tests of the IBA in even mass nuclei and the new symmetries in odd mass nuclei. The references also list the main theoretical papers which provide the details of the IBA formalism.

AXIALLY SYMMETRIC SHAPES

NON-AXIAL SHAPES

INTERACTING BOSON APPROXIMATION (IBA) MODEL

DEVELOPED BY: F. IACHELLO (Yale & Groningen)
A. ARIMA (Tokyo)

~ 1975 – PRESENT

MODEL TO EXPLAIN ALL COLLECTIVE
QUADRUPOLE EXCITATIONS IN EVEN-EVEN
NUCLEI WITH $A \geq 100$

ASSUMES DOMINANT COMPONENTS OF
COLLECTIVE EXCITATIONS ARE DUE TO
PAIRS OF PARTICLES, NEUTRONS OR
PROTONS, COUPLED TO ANGULAR
MOMENTUM 0 or 2

CALLS THESE PAIRS BOSONS

s-BOSONS d-BOSONS

IBA - 1

TOTAL NUMBER OF BOSONS N

$$N = n_d + n_s = \frac{|Z - Z_{c.s.}| + |N - N_{c.s.}|}{2}$$

WITHOUT REGARD TO PARTICLE OR HOLE CHARACTER OF NEUTRONS OR PROTONS

Examples: ${}^{148}_{62}\text{Sm}_{86}$ $N = \left| \frac{62-50}{2} \right| + \left| \frac{86-82}{2} \right| = 8$

${}^{162}_{68}\text{Er}_{94}$ $N = \left| \frac{68-82}{2} \right| + \left| \frac{94-82}{2} \right| = 13$

${}^{196}_{78}\text{Pt}_{118}$ $N = \left| \frac{78-82}{2} \right| + \left| \frac{118-126}{2} \right| = 6$

$$H = \epsilon_s \cdot s^\dagger s + \epsilon_d \cdot \sum_m d_m^\dagger d_m + V$$

where V includes all pairwise interactions between bosons

H has group structure $SU(6)$

a) Redefine E_0 by introducing $\epsilon = \epsilon_d - \epsilon_s$

b) For certain forms of V can solve H analytically — SUBGROUPS OF $SU(6)$

IBA LIMITING SYMMETRIES

$$H = \epsilon \sum_m d_m^\dagger d_m + V$$

I. $\epsilon \gg V$ VIBRATIONAL LIMIT
SU (5)

II. $V \gg \epsilon$ SYMMETRIC ROTOR LIMIT
SU (3)

$$V = Q \cdot Q + L^2$$

quadrupole interaction

III. $V \gg \epsilon$ γ -UNSTABLE ROTOR LIMIT
O (6)

$$V = P + T_3 + L^2$$

repulsive pairing and octupole

IBA SU(6) HAMILTONIAN

$$\begin{aligned}
 H = & \epsilon_s s^\dagger s + \epsilon_d \sum_m d_m^\dagger d_m \\
 & + \sum_{J=0,2,4} \frac{1}{2} (2J+1)^{1/2} C_J [(d^\dagger d^\dagger)^{(J)} (dd)^{(J)}]^{(0)} \\
 & + \frac{1}{\sqrt{2}} V_2 [(d^\dagger d^\dagger)^{(2)} (ds)^{(2)} + (s^\dagger d^\dagger)^{(2)} (dd)^{(2)}]^{(0)} \\
 & + \frac{1}{2} V_0 [(d^\dagger d^\dagger)^{(0)} (ss)^{(0)} + (s^\dagger s^\dagger)^{(0)} (dd)^{(0)}]^{(0)} \\
 & + u_2 [(d^\dagger s^\dagger)^2 (ds)^2]^{(0)} + \frac{1}{2} u_0 [(s^\dagger s^\dagger)^{(0)} (ss)^{(0)}]^{(0)}
 \end{aligned}$$

all boson - boson interactions to
Second order

ELECTROMAGNETIC TRANSITIONS

E 2

$$T_m(E2) = (d^\dagger s + s^\dagger d)_m^{(2)} + \chi (d^\dagger d)_m^{(2)}$$

value of χ depends on limit

$$\chi = 0 \quad \begin{array}{l} \text{SU(5)} \\ \text{O(6)} \end{array}$$

$$\chi = -2.958 \quad \text{SU(3)}$$

SELECTION RULES

$$\text{FIRST TERM} \quad \Delta n_d = \pm 1$$

$$\text{SECOND TERM} \quad \Delta n_d = 0$$

M1 - No first order M1 : $T(M1) \propto d^\dagger d$?

SU(5) LIMIT

$$H = \epsilon \sum_m d_m^\dagger d_m + \sum_{J=0,2,4} \frac{1}{2} (2J+1)^\frac{1}{2} C_J [(d^\dagger d)^J (dd)^J]^{(0)}$$

ANHARMONIC VIBRATOR

$$E(N n_d \nu n_\Delta J M) = \epsilon n_d + \alpha \frac{1}{2} n_d (n_d - 1) + \beta (n_d - \nu) (n_d + \nu + 3) + \gamma [J(J+1) - 6 n_d]$$

QUANTUM NUMBERS

$n_d \quad \nu \quad n_\Delta \quad J$

$$\nu = n_d - 2n_\Delta \quad n_d = 2n_\Delta + 3n_\Delta + 1$$

$$J = 2\lambda, 2\lambda-2, 2\lambda-3, \dots, \lambda+1, 1$$

ALTERNATE HAMILTONIAN

MULTIPOLE EXPANSION

$$H = \epsilon \sum_m d_m^\dagger d_m + \kappa \sum \vec{Q} \cdot \vec{Q} \\ + \kappa' \sum L \cdot L + \kappa'' \sum P \cdot P + \dots$$

QQ quadrupole interaction

$$(d^\dagger s + s^\dagger d)^2 + \chi (d^\dagger d)^2 \quad \Delta n_d = 1$$

LL angular momentum

$$(d^\dagger d^\dagger)(d d)^L \quad \Delta n_d = 0$$

PP repulsive pairing

$$(d^\dagger d^\dagger)(s s)^0 \quad \Delta n_d = 2$$

T_3 octupole

$$(d^\dagger d)^3 (d^\dagger d)^3$$

SU(3) LIMIT

$$H = \kappa \sum \vec{Q} \cdot \vec{Q} - \kappa' \sum \vec{L} \cdot \vec{L}$$

SPECIAL SYMMETRIC
ROTOR

$$E(N(\lambda\mu) K J M) =$$

$$(\kappa' - \frac{3}{4}\kappa) J(J+1) + \kappa C(\lambda\mu)$$

where

$$C(\lambda\mu) = \lambda^2 + \lambda\mu + \mu^2 + 3(\lambda + \mu)$$

BOSONS - SYMMETRIC COUPLINGS
N=3 LOWEST CONFIG.

(6,0)

(2,2)

E 2 SELECTION

$$\Delta(\lambda\mu) = 0$$

$$\Delta(\lambda\mu) = 0$$

$$N = 8$$

O(6) LIMIT

$$H = A P_6 + B C_5 + C C_3$$

$$P_6 \sim (d^\dagger d^\dagger)^\circ (d d)^\circ + (d^\dagger d^\dagger)^\circ (s s)^\circ \\ + (s^\dagger s^\dagger)^\circ (s s)^\circ$$

$$C_5 \sim (d^\dagger d)^\cdot (d^\dagger d)^\cdot + (d^\dagger d)' (d^\dagger d)'$$

$$C_3 \sim (d^\dagger d)' (d^\dagger d)'$$

$$E(N, \sigma \tau \nu_\Delta J M) = \frac{A}{4} (N - \sigma)(N + \sigma + 1) \\ + \frac{B}{6} \tau(\tau + 3) + C J(J + 1)$$

QUANTUM NUMBERS

σ

τ

ν_Δ

$$E(\sigma, \tau, L) = \frac{A}{2} (N + \sigma + 4) (N - \sigma) + B \tau (\tau + 3) + C L (L + 1)$$

$A = 100 \text{ keV}$
 $B = 30 \text{ keV}$
 $C = 5 \text{ keV}$

$$\tau = 0, 1, \dots, \sigma$$

$$\tau = 3 \nu_{\Delta} + \lambda$$

$$\nu_{\Delta} = 0, 1, \dots, \frac{\tau - \lambda}{3}$$

$$L = 2\lambda, 2\lambda - 2, 2\lambda - 3, \dots, \lambda + 1, \lambda$$

E2 SELECTION RULES: $\Delta \sigma = 0$
 $\Delta \tau = \pm 1$

0(6) LIMIT

$\tau = 0$
 $\tau = 1$
 $\tau = 3$

CIZEWSKI, ET AL., P.R.L. 40 167 (1978)

QUANTUM NUMBERS

($\sigma\tau v$)
 Δ

E2 SELECTION RULE: $\Delta\sigma=0$ $\Delta\tau=\pm 1$

CIZEWSKI ET AL., P.R.L. 90 167 (1978)

TWO-NUCLEON TRANSFER REACTIONS

START WITH A TARGET A WITH
N BOSONS

BY ADDING TWO PROTONS OR TWO
NEUTRONS GO TO NUCLEUS WITH
 $A+2$ OR $N+1$ BOSONS

OR COULD SUBTRACT TWO PARTICLES
 $A-2$ OR $N-1$ BOSONS

EXAMPLES OF THESE REACTIONS:

(t, p)

$(^3\text{He}, n)$

(p, t)

$(n, ^3\text{He})$

TWO-NEUTRON

TWO-PROTON

$SU(5) \{n_d, n_s\}$

$SU(3) (\lambda, \mu)$

$O(6) (\sigma, \tau, \nu_d)$

INTERACTING BOSON APPROXIMATION MODEL TWO-NEUTRON TRANSFER RELATIONS

SU(5) LIMIT (VIBRATIONAL)

$$I^{\text{VIB}}(N_v \rightarrow N_v + 1) = \alpha_v^2 (N_v + 1) (\Omega_v - N_v)$$

SU(3) LIMIT (ROTATIONAL)

$$I^{\text{ROT}}(N_v \rightarrow N_v + 1) = \alpha_v^2 (N_v + 1) \left(\frac{2N+3}{3(2N+1)} \right) (\Omega_v - N_v - \frac{4(N-1)}{3(2N-1)} N_v)$$

O(6) LIMIT (ν -UNSTABLE)

$$I^{O(6)}(N_v \rightarrow N_v + 1) = \alpha_v^2 \frac{(N+4)(N_v+1)}{2(N+2)} (\Omega_v - N_v - \frac{(N-1) N_v}{2(N+1)})$$

-P.V.

Beths & Mortensen
— IBA-1

TARGET MASS

P.R.L. 43,616(79)²⁶
... IBA-2 DUVAL + BARRETT

6^+
 4^+
 3^+
 2^+
 0^+

4^+
 2^+
 0^+

2^+

0^+

VIBRATIONAL
SU(5)

8^+ 4^+ — 4^+
 3^+
 2^+ — 2^+
 0^+ —

6^+

4^+

2^+

0^+

ROTATIONAL
SU(3)

4^+
 2^+

2^+

6^+
 4^+
 3^+
 0^+

0^+

4^+
 2^+

2^+

0^+

Y-UNSTABLE
O(6)

$SU(5)$

$$H \sim \epsilon n_d$$

$SU(3)$

$$H \sim \kappa Q \cdot Q$$

$O(6)$

$$H \sim \kappa' P \cdot P + T_3 (d^\dagger d)^3 (d^\dagger d)^3$$

$$\overbrace{\nu_{\Delta}=0 \quad | \quad \nu_{\Delta}=1}^{\sigma = \sigma_{\max} = N}$$

$$\overbrace{\quad}^{\sigma = N-2}$$

$$\overbrace{\quad}^{\sigma = N-4}$$

$$\tau_0 \text{ --- } 0^+$$

$$\tau_5 \text{ --- } 2^+$$

$$\tau_3 \text{ --- } 2^+$$

$$\tau_1 \text{ --- } 2^+$$

$$\tau_0 \text{ --- } 0^+$$

$$\tau_4 \text{ --- } 2^+$$

$$\tau_3 \text{ --- } 6^+ \text{ --- } 4^+ \text{ --- } 3^+ \text{ --- } 0^+$$

$$\tau_2 \text{ --- } 4^+ \text{ --- } 2^+$$

$$\tau_1 \text{ --- } 2^+$$

$$\tau_0 \text{ --- } 0^+$$

E2 Selection Rules
 $\Delta \sigma = 0$ $\Delta \tau = \pm 1$

O(6) WAVE FUNCTIONS

BASIS STATES - SU(5) LIMIT

$$J^{\pi}(n_d n_p n_{\Delta})$$

$$^{196}\text{Pt}$$

$$N = 6$$

$$0_1^+ = .4330 \ 0^+(000) + .7500 \ 0^+(210) \\ + .4910 \ 0^+(420) + .0945 \ 0^+(630)$$

$$0_3^+ = -.6847 \ 0^+(000) - .0791 \ 0^+(210) \\ + .6728 \ 0^+(420) + .2689 \ 0^+(630)$$

$$2_1^+ = +.6124 \ 2^+(100) + .7319 \ 2^+(310) \\ + .2988 \ 2^+(520)$$

$$T(E2) = \alpha (d^\dagger s + s^\dagger d) \Rightarrow \Delta n_d = \pm 1$$

RELATIVE E2 TRANSITION PROBABILITIES

	O(6)	^{196}Pt	^{192}Os	^{186}Os	SU(3)
$\frac{2_2 \rightarrow 0_1}{2_2 \rightarrow 2_1}$	0	7×10^{-6}	0.105	0.30	0.70
$\frac{3_1 \rightarrow 2_1}{3_1 \rightarrow 4_1}$	0	0.0014		0.72	2.50
$\frac{4_2 \rightarrow 4_1}{4_2 \rightarrow 3_1}$	∞	> 3.5	1.2		SMALL (~ 0.02)
$\frac{4_2 \rightarrow 3_1}{4_2 \rightarrow 2_2}$	0	< 0.31	0.81		2.23
$\frac{2_3 \rightarrow 3_1}{2_3 \rightarrow 0_2}$	1.25	0.60		0.20	SMALL (~ 0.02)

— SU(6)

— O(6) — SU(3)

Pt - Os NUCLEI

REGION $O(6) \rightarrow SU(3)$

O^+ STATES PARAMETER
FREE

OTHER PROPERTIES -

ESSENTIALLY ONE
PARAMETER

$\sim QQ/\text{PAIR}$

DEFORMED NUCLEI

$SU(3)$ β γ bands
degenerate.

MOST DEFORMED NUCLEI
 β band above γ band

INTRODUCE PAIR TO IBA $SU(3)$
H TO PUSH UP β band

^{168}Er $N=16$

W.F. DAVIDSON, et al. J. Phys. G7,
455, 843 (1981)

^{168}Er

WARNER et al.

$$H = -\kappa \vec{Q} \cdot \vec{Q} - \kappa' \vec{L} \cdot \vec{L} + \kappa'' \vec{P} \cdot \vec{P}$$

$\kappa \quad \kappa'$ Fixed FROM $2_1^+ \quad 2_2^+$

κ'' VARIED TO CALCULATE
REST OF LEVEL SCHEME

$$T(E2) = \alpha (d^+s + s^+d)^{(2)} + \beta_1 \frac{(d^+d)^{(2)}}{\sqrt{5}}$$

$$\beta_1/\alpha = -2.958 \quad \text{SU(3)}$$

$$0 \quad \text{O(6)}$$

$$\frac{B(E2: 0_1 \rightarrow 2_2)}{B(E2: 0_1 \rightarrow 2_1)} \Rightarrow \beta_1/\alpha = -0.68$$

$$(-0.85)$$

FIG. 4. Comparison of the calculated and experimental summed $B(E2)$ strengths from states in the γ -band. For each initial state, the bars represent the sum of all observed or calculated transitions to either the γ -band or ground band.

FIG. 5. Comparison of the calculated and experimental summed $B(E2)$ strengths from states in the 0_2^+ and 0_3^+ bands. For each initial state, the bars represent the sum of all observed or calculated transitions in a given final band. The normalisation for each case is defined in Tables II and III. The symbol (a) denotes that no experimental information was available for the strength of the intraband transition in these cases. The symbol (b) denotes that the experimental upper limit for this transition has been plotted.

SUMMED $B(E2)$ STRENGTHS
 $J_{\pi}^i \rightarrow \text{FINAL BAND}$

FIG. 1. Energies and major SU(3) wave function amplitudes (absolute values) for 2^+ states in the lowest band vs magnitude of SU(3) symmetry breaking. $N = 18$. Note that $K''/4K$ is used as the symmetry-breaking parameter because of its close relation to PAIR/QQ as is evident from the definitions below Eq. (1).

2^+ STATES

168 Er PAIR/QQ ~ 1.0

A LOT OF $\Delta K = 0$ MIXING
LITTLE $\Delta K = 2$ MIXING

E2 TRANSITIONS IN ^{168}Er

MIXING BETWEEN "FUNDAMENTAL"
CONFIGURATIONS

DIRECT $\beta \rightarrow \gamma$ TRANSITION
IN $\text{SU}(3)$

GEOMETRY REDEFINES
 β -VIBE IN EACH NUCLEUS

F-BOSONS π - BANDS

$$E(3^-) \quad (d+f)^{1,2,3,4,5^-}$$

6 parameters

APPROXIMATE H:

$$H \sim H_c + \epsilon_f n_f + \Gamma [Q^{(2)}(f^+f)^{(2)}]^{(0)} + \Lambda [(d^+f)^{(3)}(f^+d)^{(3)}]^{(0)}$$

$$Q^{(2)} = (d^+s + s^+d)^{(2)} + \chi (d^+d)^{(2)}$$

Fig. 8 Comparison of the energy levels as calculated in the IBA model with the experimental energy levels. The three high-lying NPB's are from ref. 9).

J. KONJUN, ET AL., NUCL. PHYS. A352, 191 (1981)

OTHER PHENOMENOLOGICAL IBA

IBA-2

distinguishes between π, ν
 $N_{\pi} \quad N_{\nu} \quad d_{\nu} \quad s_{\nu}$

microscopic predictions of
 trends in parameters

IBA-2 + Coexistence

Near closed shells or subshells
 H_g

also Mo, Cd, Te

Figure 15. Calculated energy spectra in ^{136}Xe . The circles, squares, and triangles denote the experimental values.

Figure 16. Calculated energy spectra in ^{136}Ba . The circles, squares, and triangles denote the experimental values.

Figure 17. Energy spectra of even-even nuclei, for fixed proton number, $n_p = 2N_\pi = 6$, and varying neutron number, $0 \leq n_n \leq 32$, in the simple-orbit approximation.

MICROSCOPIC

BALANTEKIN, BARS, IACHELLO, NP A370, 284
(1981)

SUPER - SYMMETRY

ALL EARLIER SYMMETRIES APPLIED EITHER
TO BOSE OR TO FERMI SYSTEMS

ie **BOSONS** $\longleftrightarrow$ **BOSONS**
 OR
 FERMIONS $\longleftrightarrow$ **FERMIONS**

MORE COMPLEX SYMMETRY WOULD PLACE
BOSONS AND FERMIONS IN SAME MULTIPLY

ie **COULD HAVE OPERATIONS THAT**
 BOSONS $\rightleftharpoons$ FERMIONS

**SAME EIGENVALUE EQUATION FOR FERMI
AND BOSE SYSTEM**

$$N = N + M$$

F. IACHELLO RECENTLY PREDICTED
SUPERSYMMETRY STRUCTURE IN Pt-Ir-O_s

COUPLE $j = 3/2$ fermion (g.s. Ir)
to O(6) boson (Pt cores)
O_s

IF ONE LOOKS AT ONLY ONE NUCLEUS
SPIN (6)

IF ONE LOOKS AT TRANSITIONS BETWEEN
OR SUM-RULES

U(6/4)

QUANTUM NUMBERS

N-# of BOSONS M-# of FERMIONS

	$(\sigma_1 \sigma_2 \sigma_3)$	$(\tau_1 \tau_2)$	ν_Δ
O(6):	σ	τ	ν_Δ

Spin(6) / SUPERSYMMETRY

E_x ENERGIES:

$$E(N, M, (\sigma_1, \sigma_2, \sigma_3), (\tau_1, \tau_2), \gamma_A, J, M_J) = \\ -\frac{A}{4} [\sigma_1(\sigma_1+4) + \sigma_2(\sigma_2+2) + \sigma_3^2] \\ + \frac{B}{6} [\tau_1(\tau_1+3) + \tau_2(\tau_2+1)] + C J(J+1)$$

even-A $\sigma_2 = \sigma_3 = 0$ $\tau_2 = 0$

$$E_x = -\frac{A}{4} \sigma(\sigma+4) + \frac{B}{6} \tau(\tau+3) + C J(J+1)$$

odd-A $\sigma_2 = |\sigma_3| = \frac{1}{2}$ $\tau_2 = \frac{1}{2}$

$$E_x = -\frac{A}{4} [\sigma(\sigma+4) + \frac{3}{2}] + \frac{B}{6} [\tau(\tau+3) + \frac{3}{4}] \\ + C J(J+1)$$

even A: $\sigma = N, N-2, \dots, 0 \text{ or } 1$; odd A $\sigma = N+\frac{1}{2}, N-\frac{1}{2}, \dots, \frac{1}{2}$ so

E2 Selection: $\Delta T = \pm 1$
 $\Delta F = 0$

E2: $\Delta T = 0, \pm 1$
 $\Delta F = 0$

$\sigma = 7$ $\nu_{\Delta} = 0 \mid \nu_{\Delta} = 1$	$\sigma = 5$ $\nu_{\Delta} = 0$	$\sigma = 7 + 1/2$ $\nu_{\Delta} = 0 \mid \nu_{\Delta} = 1/2 \mid \nu_{\Delta} = 1$	$\sigma = 7 - 1/2$ $\nu_{\Delta} = 0 \mid \nu_{\Delta} = 1/2$
$\tau = 3 - 6^+$	$\tau = 1 - 2^+$	$\tau = 7/2 - 15/2^+$	
$\quad - 4^+$		$\quad - 13/2^+$	
$\quad - 3^+$		$\quad - 11/2^+$	
	$\tau = 0 - 0^+$	$\quad - 9/2^+$	
		$\quad - 7/2^+$	
		$\quad - 5/2^+$	$\tau = 3/2 - 7/2^+$
			$\quad - 5/2^+$
			$\quad - 1/2^+$
$\tau = 2 - 4^+$		$\tau = 5/2 - 11/2^+$	
$\quad - 2^+$		$\quad - 9/2^+$	
		$\quad - 7/2^+$	$\tau = 1/2 - 3/2^+$
		$\quad - 5/2^+$	
		$\quad - 3/2^+$	
$\tau = 1 - 2^+$		$\tau = 3/2 - 7/2^+$	
		$\quad - 5/2^+$	
		$\quad - 1/2^+$	
$\tau = 0 - 0^+$		$\tau = 1/2 - 3/2^+$	
$\sigma_2 = \sigma_3 = 0 \quad \tau_2 = 0$		$\sigma_2 = \sigma_3 = 1/2 \quad \tau_2 = 1/2$	

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$N = 7$
 $N = 7 \quad M = 0$

$N = 8$
 $N = 7 \quad M = 1$

odd Au

$$\frac{B(E2: 3/2_2^+ \rightarrow 3/2_1^+)}{B(E2: 3/2_2^+ \rightarrow 1/2_1^+)} = 0$$

SPIN(6) / SUPERSYMMETRY

$$^{193}\text{Au} : 0.11$$

$$^{195}\text{Au} : 0.29$$

$$^{197}\text{Au} : 0.70$$

J. WOOD, priv. comm.

Phys. Rev. C29 1788 (1981)

BALANTEKIN, et al. NP A370, 284 (1981)

even-A: $B(E2: 2^+ \rightarrow 0^+)$

odd-A: $\frac{1}{3} [B(E2: 7/2 \rightarrow 3/2) + B(E2: 5/2 \rightarrow 3/2) + B(E2: 1/2 \rightarrow 3/2)]$

PARTICLE TRANSFER

$\text{---} U(6|4)$

$\text{== Spin}(6)$

$$\Delta \sigma = \pm \frac{1}{2}$$

$$\Delta \tau = \pm \frac{1}{2}$$

$$\frac{\sigma = 6\frac{1}{2}}{\tau = \frac{1}{2}} \quad 3\frac{1}{2}^+$$

$$\frac{\tau = 3\frac{1}{2}}{\quad} \quad 3\frac{1}{2}^+$$

Os($^3\text{He}, d$) Ir

	E_x	J^π	S	E_{xp}	S_{rel}	T_{hy}
^{193}Ir	0	$3\frac{1}{2}^+$	0.67	≈ 1.00	1.00	
	180	$3\frac{1}{2}^+$	0.04	0.06	0	
	460	$3\frac{1}{2}^+$	N.O.	—	0	
^{191}Ir	0	$3\frac{1}{2}^+$	0.70	≈ 1.00	1.00	
	179	$3\frac{1}{2}^+$	0.06	0.09	0	

R.H. Price, et al. N.P. A176, 338 (1971)

RATIO OF STRENGTHS, S, FOR STATES $(\sigma_1 \tau_1)$

$$\frac{S(N - 1/2, 1/2)}{S(N + 1/2, 1/2)} \approx \frac{N}{N+4} \sim 0.70$$

ONLY TWO STATES, BOTH $J = 3/2$, WILL BE SEEN

	E_x	J^π	S_{exp}	S_{rel}	S_{thy}
^{193}Ir	0	$3/2^+$	1.6	$\equiv 1.00$	$\equiv 1.00$
$N=7$	180	$3/2^+$	0.11	0.07	0
	460	$3/2^+$	1.1	0.69	0.64
	73	$1/2^+$	$\lesssim 0.5$		

D.G. BURKE, E.R. FLYNN, R.E. BROWN, J.W. SUNIER, J.A.C

P.R.L. 46, 1264 (1981)

$$P_t(\vec{r}, \alpha)$$

	E_x	J^π	S_{exp}	S_{rel}	S_{thy}
^{193}Ir	0	$3/2^+$	1.6	$\equiv 1.00$	$\equiv 1.00$
$N=7$	180	$3/2^+$	0.11	0.07	0
	460	$3/2^+$	1.1	0.69	0.64
	73	$1/2^+$	$\lesssim 0.5$		
^{195}Ir	0	$3/2^+$	2.1	$\equiv 1.00$	$\equiv 1.00$
$N=6$	234	$(3/2^+)$	0.33	0.16	0
	287	$3/2^+$	0.49	0.23	0.60
	70	$1/2^+$	0.75		
^{197}Ir	0	$3/2^+$	3.5		
$N=5$	52	$1/2^+$	1.2		

(α, t) or $({}^3\text{He}, d)$

REACTIONS

TARGET IR N BOSONS
 + 1 FERMION

FINAL Pt N BOSONS

OPERATOR Q DESTROYS
 ONE FERMION

MEASURED Spectra

Vergnes, et al.

P.R.L. 46, 584
(1981)

$\left\{ \begin{array}{l} \text{no ang. dist.} \\ \text{no } A_y \end{array} \right\}$ ^{NEW} RESULTS-
Blasi, et al.

→ no clear knowledge of
l or j transfer

VERGNES, BURKE, *et al.* P.R.L. 46, 584 (1981)
 N. Blasi, *et al.*

KNOW MANY SINGLE
PARTICLE ORBITALS

g.s. $d_{3/2}$

~ 500 keV $s_{1/2}$ $d_{5/2}$ $g_{7/2}$
 -1000

CAN BE PART OF
BOSONS

ONLY $d_{3/2}$ transfer

$\Rightarrow$ ONLY 0^+ STATES
IN Pt

VERGNES, BURKE, et al. P.R.L. 46, 584 (1981)
 N. Blasi, et al.

SUPERSYMMETRY / SPIN(6) REQUIRES

- 1) GOOD $O(6)$ BOSON CORE
- 2) SINGLE $d_{3/2}$ odd particle
- 3) PARTICULAR FORM OF V_{BF}

PERTURBED SPIN(6)

CHANGE V_{BF} :

$$V_{BF} = -\Lambda_1 [(d^\dagger \bar{d})' (a^\dagger \bar{a})']^0 \\ - \Lambda_3 [(d^\dagger \bar{d})^3 (a^\dagger \bar{a})^3]^0 \\ - \Pi \left[[(d^\dagger s)^{(2)} (a^\dagger a)^2]^0 + [(s^\dagger d)^2 (a^\dagger \bar{a})^2]^0 \right]$$

Π term is significant —
determines much of Spin(6)
wavefunctions $J^\pi(\sigma, \tau, \nu_\Delta)$

$$|3/2_1^+ \rangle = -.78 [3/2 \cdot 0^+(700)] \\ + .62 [3/2 \cdot 2^+(710)]$$

$$|3/2_3^+ \rangle = .62 [3/2 \cdot 0^+(700)] + .78 [3/2 \cdot 2^+(710)]$$

$$H_c = \beta [(d^\dagger s + s^\dagger \tilde{d})^{(2)} (a_{y_2}^\dagger \tilde{a}_{y_2} - a_{x_2}^\dagger \tilde{a}_{x_2})^{(2)}]$$

OTHER SUPERSYMMETRIES

$U(5/2) \dots\dots$

$\frac{1}{2} \oplus su(5) \text{ or } su(3) \dots\dots$

NEW CLASS

$U(6/12) : \frac{1}{2}, \frac{3}{2}, \frac{5}{2} \oplus o(6)$
 $\quad \quad \quad \underbrace{\quad \quad \quad}_{L=0 \quad L=2}$

"ORBITAL ANG. MOM."		L
4	$\frac{7}{2}$ =====	2
	$\frac{5}{2}$ =====	
2	$\frac{3}{2}$ =====	1
	$\frac{1}{2}$ =====	
2	$\frac{5}{2}$ =====	1
	$\frac{3}{2}$ =====	

3 $\frac{7}{2}$
=====

2 $\frac{5}{2}$
=====

1 $\frac{3}{2}$
=====

(610)

$L=0 \quad \frac{1}{2} \quad \tau=0$
 (700)

195 pt ?

SUPERSYMMETRIES IN NUCLEI ?

APPROXIMATE :

$^{191,193}\text{Ir}$ ^{193}Au (^{195}Au , $^{197}\text{Au}^2$)
Os - Pt cores

PERTURBED

$^{193} - ^{197}\text{Ir}$ $^{193} - ^{201}\text{Au} ?$

SIMPLER APPROACH TO
COMPLEX ODD-A
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