The Core-Particle-Hole Coupling model of odd-odd nuclei with microscopic cores

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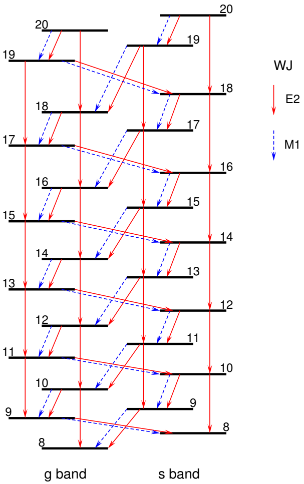
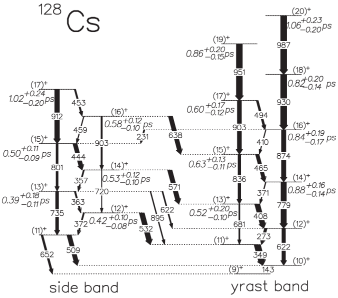
Outline

1. Properties of partner (twin, doublet) bands in odd-odd nuclei
2. The Core-Particle-Hole Coupling model
3. The S symmetry and its consequences
4. Some examples of microscopically calculated cores

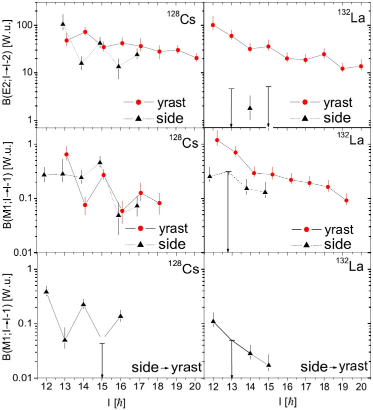
Some properties of partner bands in odd-odd nuclei





- Almost degenerate g and s bands
- Similar EM properties of g and s bands
- Staggering of $\Delta I = 1$ transitions

Properties of partner bands cont.



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Core-Particle-Hole Coupling model

$$|\mathrm{odd}-\mathrm{odd}, i\rangle = \sum_{j,k,m} U^i_{jkm} |\mathrm{core}, j\rangle |\mathrm{p}, k\rangle |\mathrm{n}, m\rangle$$

$$H_{\mathrm{o-o}} = H_{\mathrm{core}} - \chi Q q_{\mathrm{p}} - \chi Q q_{\mathrm{n}} - \chi' q_{\mathrm{p}} q_{\mathrm{n}} + h_{\mathrm{p}} + h_{\mathrm{n}}$$

$Q, q_{\mathrm{p,n}}$ — quadrupole operators

Cores:

- Bohr Hamiltonian (FQ, full quadrupole), (β, γ, Ω);
  inertial functions and potential energy:
  - given by analytic formulas
  - calculated microscopically
- rigid rotor (DF, Davydov-Filipov); (Ω); [$\tilde{\beta}, \tilde{\gamma}$ — fixed]

One-particle part:

p$h_{11/2} \otimes \mathrm{n}h^{-1}_{11/2}, \quad A \sim 130$

The Bohr Hamiltonian

$$H_{\mathrm{GBH}}(\beta,\gamma,\Omega) = T_{\mathrm{vib}} + T_{\mathrm{rot}} + V$$

$$\begin{aligned} T_{\mathrm{vib}}(\beta,\gamma) &= -\frac{1}{2\sqrt{wr}}\left\{\frac{1}{\beta^4}\left[\partial_\beta\left(\beta^4\sqrt{\frac{r}{w}}B_{\gamma\gamma}\right)\partial_\beta - \partial_\beta\left(\beta^3\sqrt{\frac{r}{w}}B_{\beta\gamma}\right)\partial_\gamma\right]+\right.\\ &\left.+\frac{1}{\beta\sin 3\gamma}\left[-\partial_\gamma\left(\sqrt{\frac{r}{w}}\sin 3\gamma B_{\beta\gamma}\right)\partial_\beta + \frac{1}{\beta}\partial_\gamma\left(\sqrt{\frac{r}{w}}\sin 3\gamma B_{\beta\beta}\right)\partial_\gamma\right]\right\} \\ T_{\mathrm{rot}}(\beta,\gamma,\Omega) &= \frac{1}{2}\sum_{k=1}^{3} I_k^2(\Omega)/J_k; \quad J_k(\beta,\gamma) = 4B_k(\beta,\gamma)\beta^2\sin^2(\gamma - 2\pi k/3) \end{aligned}$$

$$w = B_{\beta\beta}B_{\gamma\gamma} - B_{\beta\gamma}^2; \quad r = B_x B_y B_z$$

Simplest form of the kinetic energy

$$T_{\mathrm{kin}} = \frac{1}{2}B|\dot{\alpha}|^2 \quad \leftrightarrow B_{\beta\beta} = B_{\gamma\gamma} = B_k = B, \quad B_{\beta\gamma} = 0$$

Symmetry S and its consequences

$$S = P_5 C_{\rm pn}$$

Core part: P_5 (α-parity of the core)

FQ core

$$P_5 \alpha_\mu = -\alpha_\mu \quad \text{(laboratory coordinates)}$$
$$P_5(\beta, \gamma, \Omega) = (\beta, \gamma \pm \pi, \Omega)$$
$$P_5(\beta, \gamma, \Omega) = (\beta, \pi/3 - \gamma, R_x(\pi/2)\Omega)$$

DF core

$$P_5 \to R_x(\pi/2)$$

Proton-neutron part: $C_{\rm pn}$

$$C_{\rm pn}|(\mathrm{p}, i)(\mathrm{n}, k)\rangle = |(\mathrm{p}, k)(\mathrm{n}, i)\rangle$$
$$C_{\rm pn}|((\mathrm{p}, j)(\mathrm{n}, j))^L\rangle = (-1)^{L+1}|((\mathrm{p}, j)(\mathrm{n}, j))^L\rangle$$
$$S^2 = (P_5 C_{\rm pn})^2 = I$$

Inertial functions and potential energy of the P_5 symmetric Hamiltonian

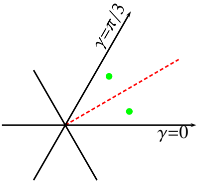
Conditions imposed by the P_5 symmetry

$$f(\beta, \pi/3-\gamma) = f(\beta,\gamma) \quad \text{for } f = B_{\beta\beta}, B_{\gamma\gamma}, B_x$$

$$B_{\beta\gamma}(\beta, \pi/3-\gamma) = -B_{\beta\gamma}(\beta,\gamma)$$

$$B_y(\beta, \pi/3-\gamma) = B_z(\beta,\gamma)$$

$$V(\beta, \pi/3-\gamma) = V(\beta,\gamma)$$



Symmetry S. Quadrupole operators, angular momenta. $H_{\mathrm{o-o}}$ Hamiltonian

Quadrupole operators and angular momenta

$$P_5 Q P_5^+ = -Q$$
$$P_5 R P_5^+ = R$$
$$C_{\mathrm{pn}}\, q_{\mathrm{p,n}}\, C_{\mathrm{pn}}^+ = -q_{\mathrm{n,p}}$$
$$C_{\mathrm{pn}}\, j_{\mathrm{p,n}}\, C_{\mathrm{pn}}^+ = j_{\mathrm{n,p}}$$

Odd-odd nucleus Hamiltonian $\quad H_{\mathrm{o-o}} = H_{\mathrm{core}} - \chi Q q_{\mathrm{p}} - \chi Q q_{\mathrm{n}} - \chi' q_{\mathrm{p}} q_{\mathrm{n}}$

H_{core} is P_5–symmetric $\longrightarrow$ $S H_{\mathrm{o-o}} S^+ = H_{\mathrm{o-o}}$

New additional label $s = \pm 1$ for eigenstates of $H_{\mathrm{o-o}}$

E2 & M1 transition operators

E2

$$T(E2) = \kappa Q + e_\mathrm{p} q_\mathrm{p} + e_\mathrm{n} q_\mathrm{n}$$

$$SQS^+ = -Q \qquad \longrightarrow \langle J, s | T(E2) | J', s \rangle \approx 0$$

$e_\mathrm{p} q_\mathrm{p}, e_\mathrm{n} q_\mathrm{n}$ — small

M1

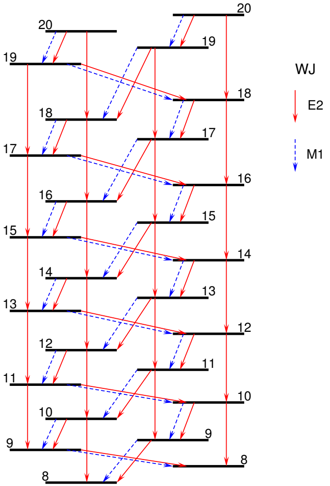
$$T(M1) = \sqrt{\frac{3}{4\pi}} \mu_N (g_R R_\mathrm{core} + g_\mathrm{p} j_\mathrm{p} + g_\mathrm{n} j_\mathrm{n})$$

$$P_5 R_\mathrm{core} P_5^+ = R_\mathrm{core}$$

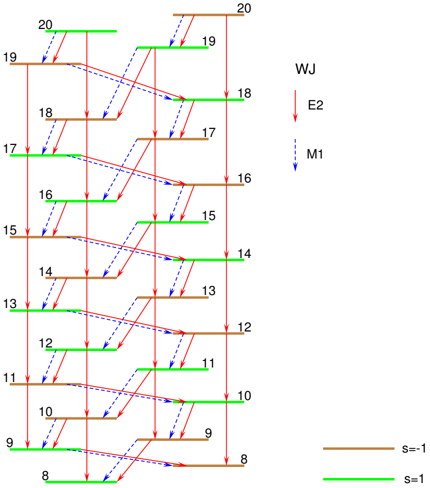
$$\left.\begin{array}{l} g_R - (g_\mathrm{p} + g_\mathrm{n})/2 = 0 \\ \text{some other properties} \end{array}\right\} \longrightarrow \langle J, s | T(M1) | J', s \rangle = 0, \quad J \neq J'$$

Example (reasonable values): $g_R = 0.44$, $g_\mathrm{p} = 1.22$, $g_\mathrm{n} = -0.21$

Selection rules

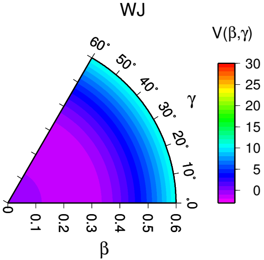


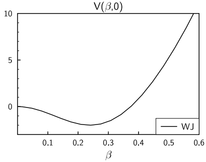
Selection rules

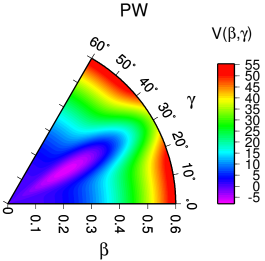


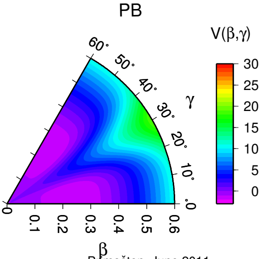
Examples of the S symmetric Hamiltonians

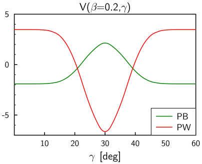
Wilets-Jean, Potential Well, Potential Barrier. Simple kinetic energy



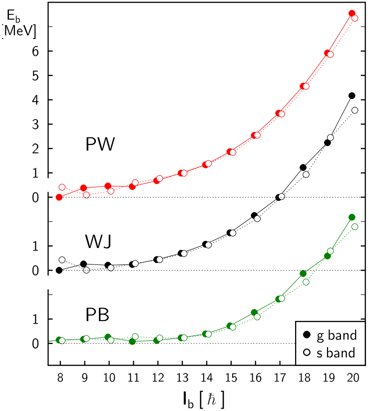




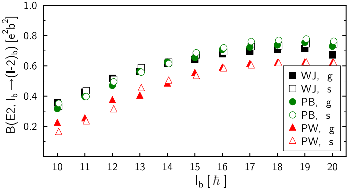




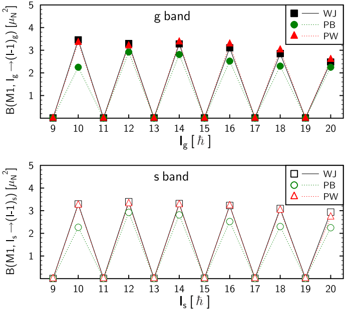
Results for the S symmetric cases



$\Delta I = 2$ E2 transitions



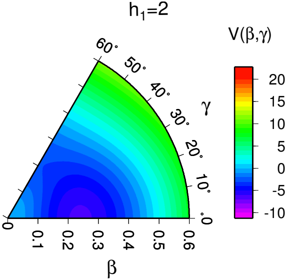
M1 transitions

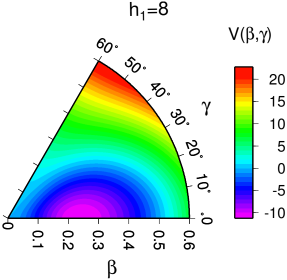


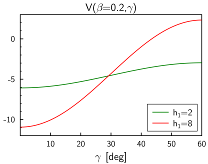
Deviations from the S symmetry

Non-symmetric core (potential or/and kinetic energy)
Different one-particle spaces for proton and neutron

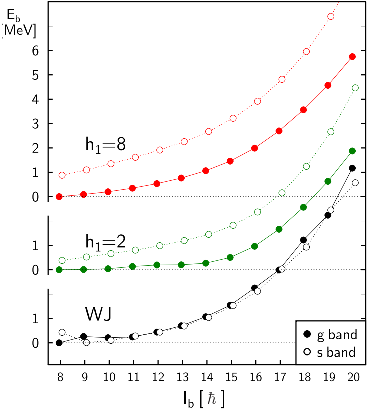
Example: non-symmetric potential energy



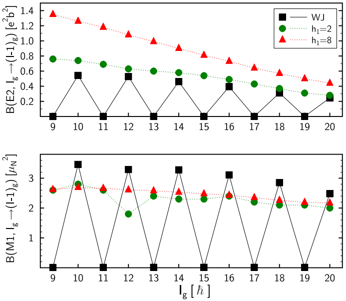




Deviations from the S symmetry cont.

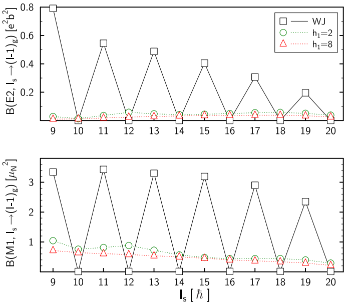


$\Delta I = 1$ in-band transitions



Deviations from the S symmetry cont.

Inter-band transitions



Microscopic cores

$$^{128}\mathrm{Xe} + p \otimes n^{-1} \longrightarrow {}^{128}\mathrm{Cs}$$
$$^{128}\mathrm{Ba} + p \otimes n^{-1} \longrightarrow {}^{128}\mathrm{La}$$

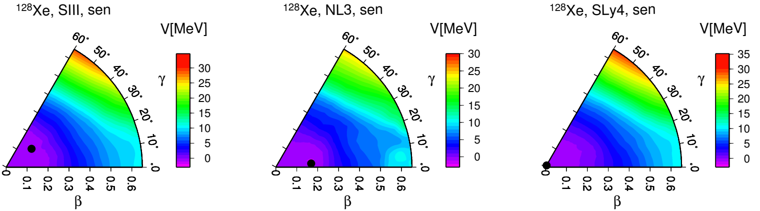
Mean field:
Skyrme SIII and SLy4
RMF NL3

Pairing: seniority force

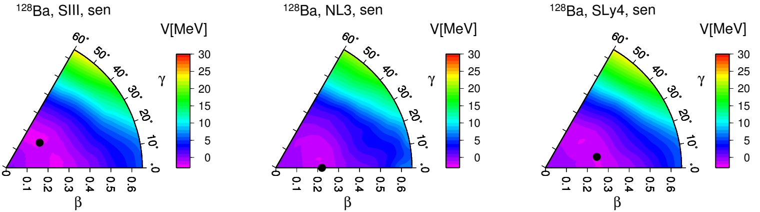
Kinetic energy — ATDHFB type formulas

Microscopic cores, potential energy

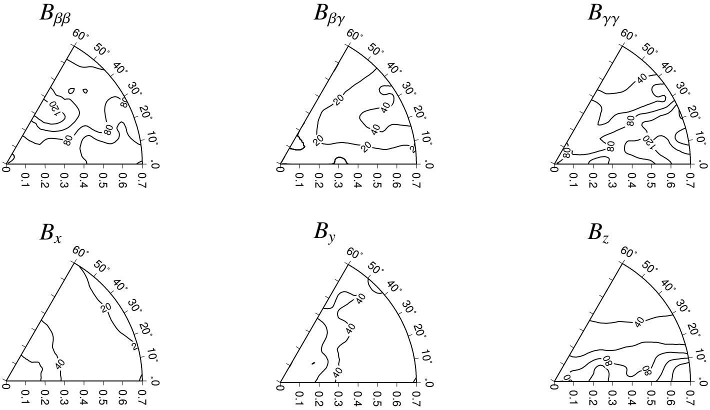
^{128}Xe



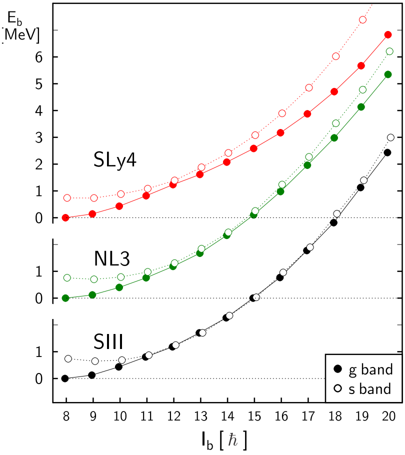
^{128}Ba



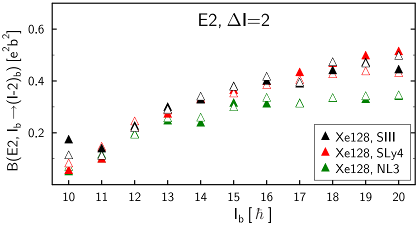
Inertial functions, ^{128}Xe, Skyrme III



Odd-odd nucleus with ^{128}Xe core



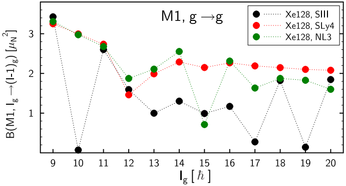
E2 in-band transitions

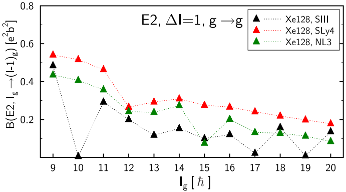


Odd-odd nucleus with ^{128}Xe core cont.

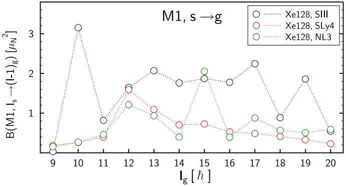
$\Delta I = 1$ M1 and E2 transitions

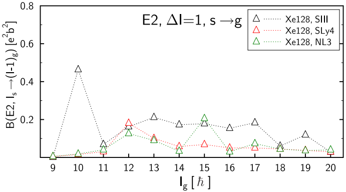
In-band



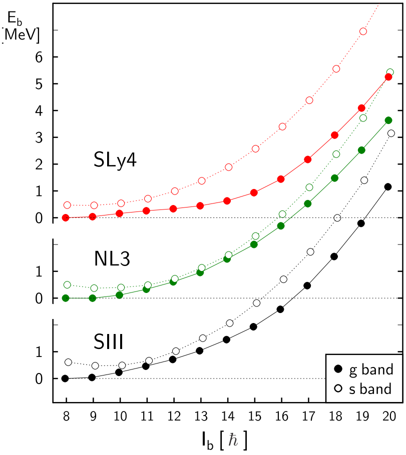


Inter-band

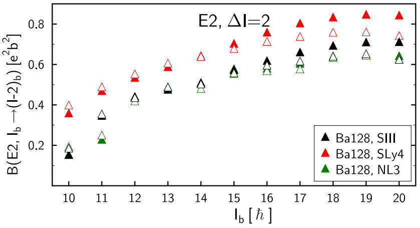




Odd-odd nucleus with ^{128}Ba core



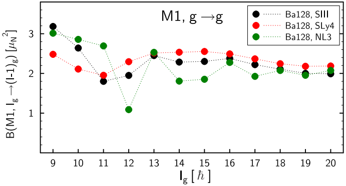
E2 in-band transitions

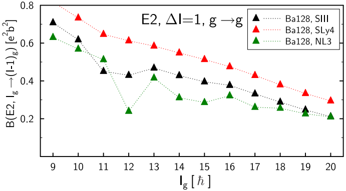


Odd-odd nucleus with ^{128}Ba core cont.

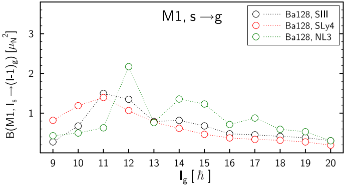
$\Delta I = 1$ M1 and E2 transitions

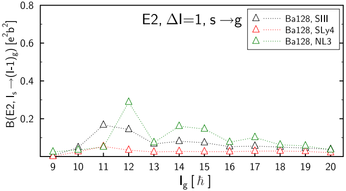
In-band





Inter-band





Conclusions

- Existence of the partner bands do not require rigid deformation of the core
- The S symmetry — useful in model studies, not much probable to exist in real nuclei
- It is possible to obtain partner bands with microscopic cores