Quartet structure of N=Z nuclei in an IBM formalism: ^{28}Si as a nucleus at the U(5)-$\overline{\mathrm{SU}(3)}$ phase-transitional point

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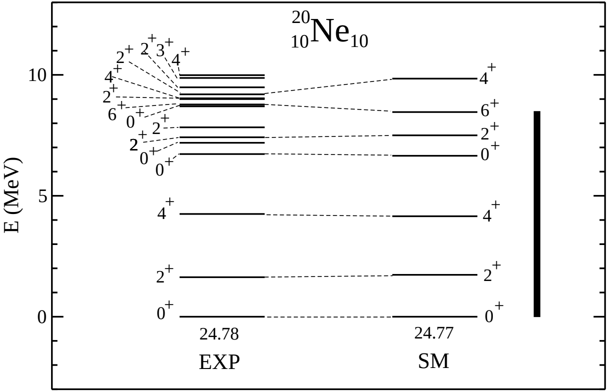
Outline

- Quartetting and proton-neutron pairing ($\Rightarrow$ Sandulescu's talk)
- Quartet structure of even-even N=Z nuclei:
  - a study of ^{24}Mg
- Bosonic approach to quartetting in even-even N=Z nuclei:
  - a study of ^{28}Si
- Conclusions

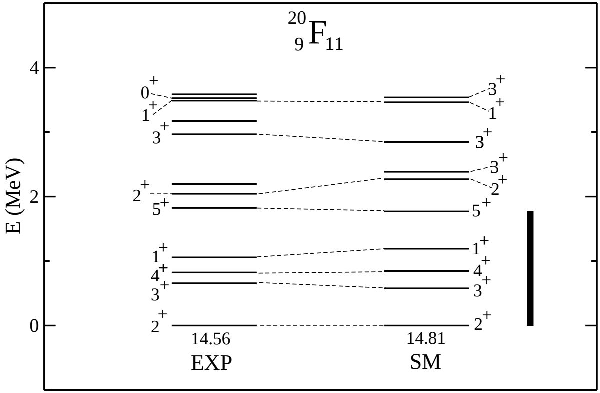
Quartets

$$Q^{+}_{\alpha,JM,TT_z} = \sum_{i_1 j_1 J_1 T_1} \sum_{i_2 j_2 J_2 T_2} C^{(\alpha)}_{i_1 j_1 J_1 T_1, i_2 j_2 J_2 T_2} \times \left[[a^{+}_{i_1} a^{+}_{j_1}]^{J_1 T_1} [a^{+}_{i_2} a^{+}_{j_2}]^{J_2 T_2} \right]^{JT}_{MT_z}$$

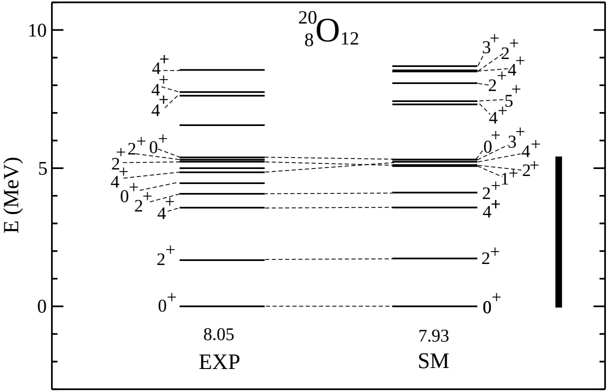
^{20}Ne: T=0 quartets



^{20}F: T=1 quartets



^{20}O: T=2 quartets



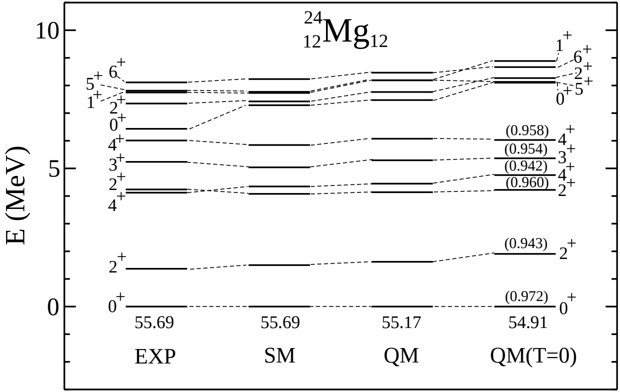
^{24}Mg in a formalism of quartets

$^{24}_{12}\mathrm{Mg}_{12}$ = 4 protons + 4 neutrons outside the ^{16}O core = 2 quartets

We want to represent its states as linear superpositions of

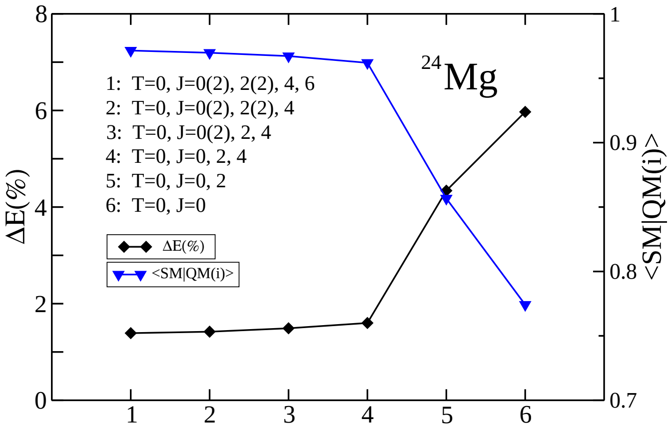
$$[Q^{+}_{\alpha J_1 T_1} Q^{+}_{\beta J_2 T_2}]^{J,T=0}_{M,T_z=0}|0\rangle$$

^{24}Mg: the spectrum



M.S. and N. Sandulescu, PRL 115, 112501 (2015)

^{24}Mg: the ground state



Bosonic approach to quartetting in even-even N=Z nuclei

- We assume two basic building-blocks:

$$Q^{+}_{J=0,T=0} \equiv S^{+} \qquad Q^{+}_{J=2,T=0} \equiv D^{+}$$

- We replace them with two elementary bosons:

$$S^{+} \Longrightarrow s^{+}$$

$$D^{+} \Longrightarrow d^{+}$$

- We construct the most general one- plus two-body Hamiltonian

$$H_B = \epsilon_s \widehat{n}_s + \epsilon_d \widehat{n}_d + \sum_{\lambda_1\lambda_2\lambda_1'\lambda_2'\Lambda} V^{(\Lambda)}_{\lambda_1\lambda_2\lambda_1'\lambda_2'} [[b^{+}_{\lambda_1} b^{+}_{\lambda_2}]^{(\Lambda)} [\tilde{b}_{\lambda_1'} \tilde{b}_{\lambda_2'}]^{(\Lambda)}]^{(0)}$$

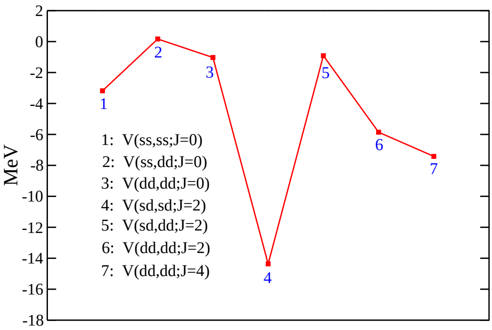
- It is: $H_B \equiv H_B^{(IBM)}$ but $N_B \equiv \frac{N_B^{(IBM)}}{2}$
- Previous use of this formalism:
  J. Dukelsky et al, Phys. Lett. 115B, 359 (1982)

Parameters of H_B from a mapping procedure

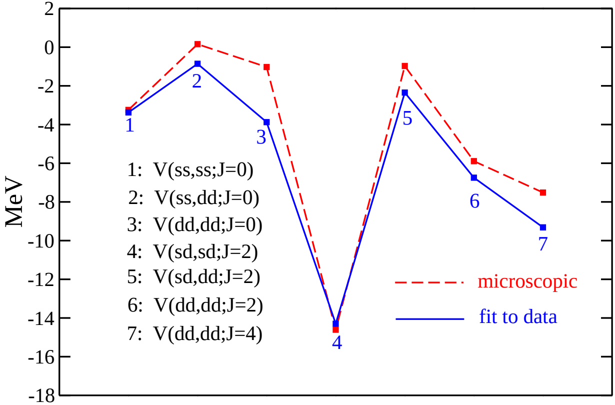
- H_B (one- plus two-body, hermitian) is generated from $H_F(USDB)$
  - Single-boson energies ϵ_s and ϵ_d:

$$\epsilon_s = \langle Q_{J=0,T=0}|H_F|Q_{J=0,T=0}\rangle$$
$$\epsilon_d = \langle Q_{J=2,T=0}|H_F|Q_{J=2,T=0}\rangle$$

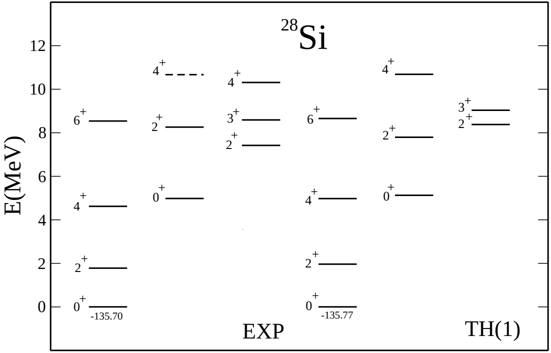
  - Two-body matrix elements:



Parameters of H_B: microscopic vs phenomenological



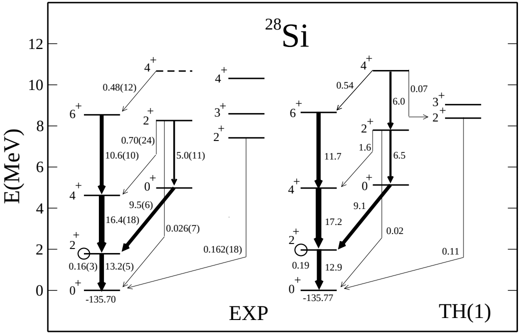
^{28}Si: spectrum



(EXP: R.K. Sheline et al., Phys. Lett. B 119, 263 (1982))

^{28}Si: spectrum and E2 transitions

$$T^{(E2)}_{\mu} = e_B([d^\dagger_\mu s + s^\dagger \tilde{d}_\mu]^2 + \chi[d^\dagger \tilde{d}]^2_\mu)$$



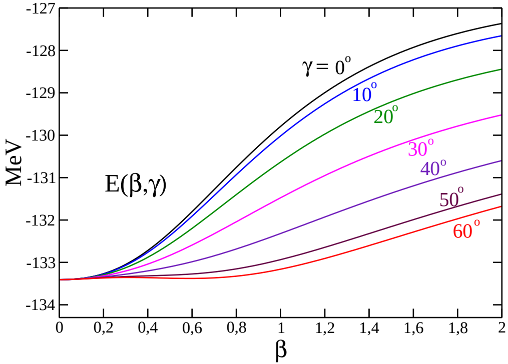
M.S. and N. Sandulescu, to be published

^{28}Si: geometric structure

$$|N;\beta,\gamma\rangle = \frac{1}{\sqrt{N!(1+\beta^2)^N}}(B^\dagger)^N|0\rangle$$

$$B^\dagger = s^\dagger + \beta[\cos\gamma\ d_0^\dagger + \frac{1}{\sqrt{2}}\sin\gamma\ (d_{+2}^\dagger + d_{-2}^\dagger)]$$

$$E(N,\beta,\gamma) = \langle N;\beta,\gamma|H_B|N;\beta,\gamma\rangle$$



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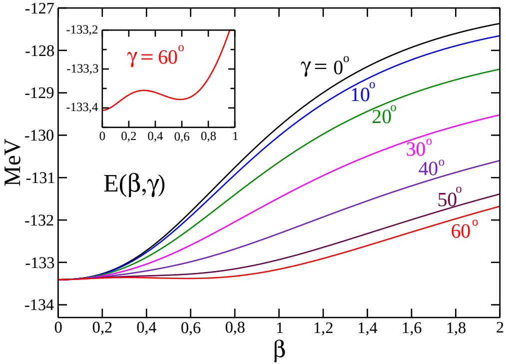
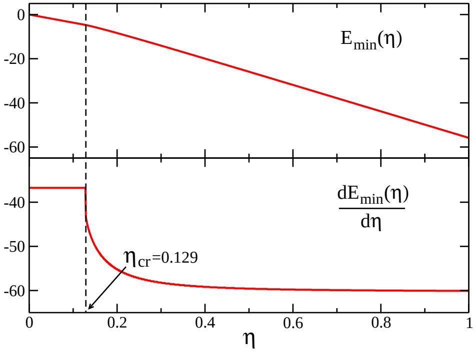


A schematic U(5)-$\overline{\mathrm{SU}(3)}$ Hamiltonian

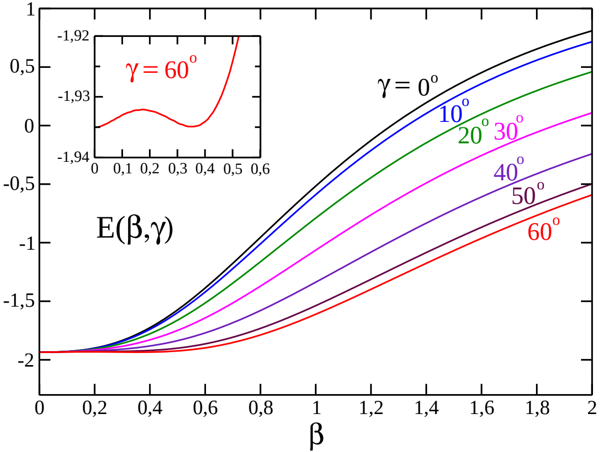
$$H_B^{(T)} = (1-\eta)\hat{n}_d - \eta(Q^\dagger \cdot Q^\dagger)$$

$$Q^\dagger = [d^\dagger s + s^\dagger \tilde{d}]^{(2)} + \chi[d^\dagger \tilde{d}]^{(2)}, \qquad \chi = +\frac{\sqrt{7}}{2}$$

First-order phase transition at $\eta = \eta_{cr}$

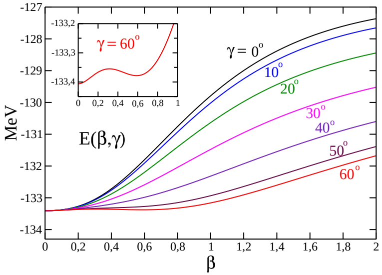


Potential energy surface at $\eta = \eta_{cr}$

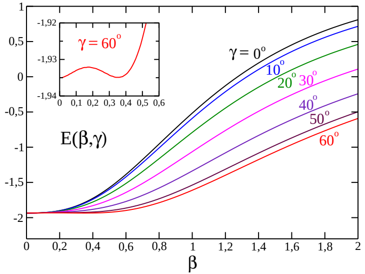


Comparison of potential energy surfaces

H_B



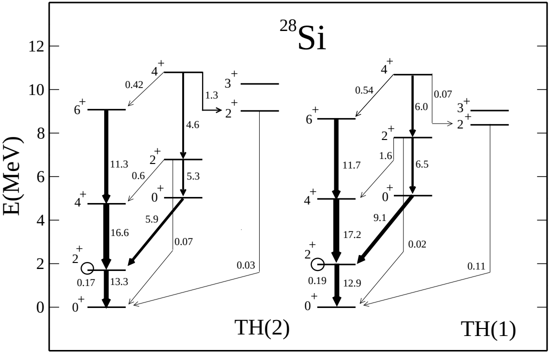
$H_B(\mathrm{U}(5)\text{-}\overline{\mathrm{SU}(3)})$ at $\eta = \eta_{cr}$



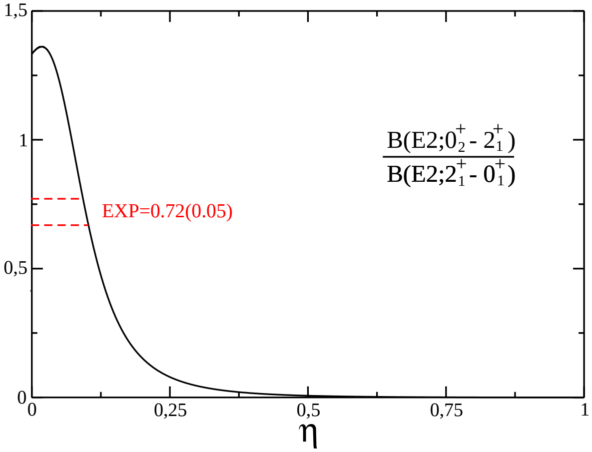
Comparison of theoretical spectra

TH(1): H_B

TH(2): $H_B(\mathrm{U(5)}\text{-}\overline{\mathrm{SU(3)}})$ at $\eta = \eta_{cr}$



$B(E2;0_2^+ - 2_1^+)/B(E2;2_1^+ - 0_1^+)$



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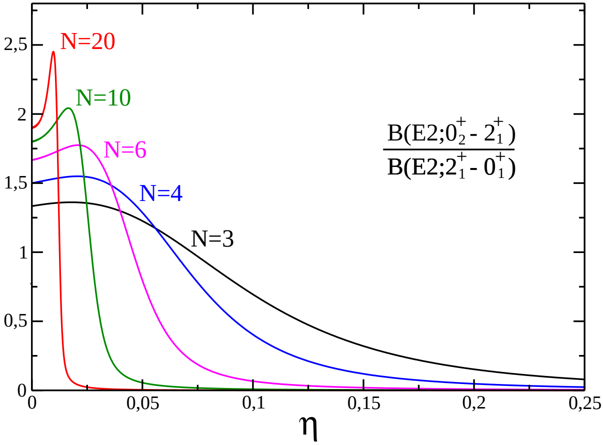
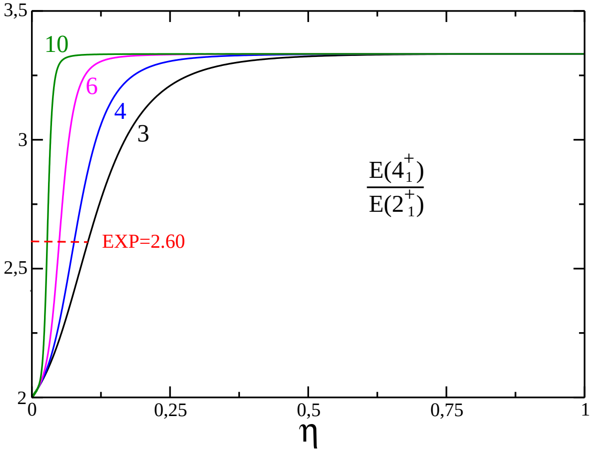


$E(4_1^+)/E(2_1^+)$

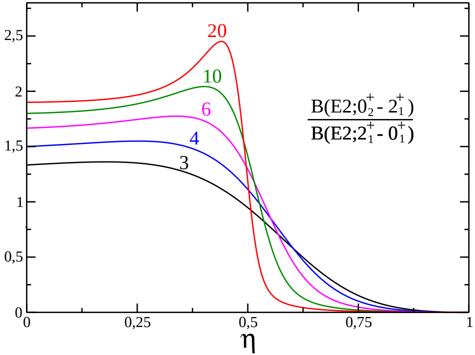


Conclusions

- We have presented a general approach to describe N=Z nuclei in an IBM formalism where s and d bosons represent $T = 0, J = 0$ and $T = 0, J = 2$ quartets.
- We have provided a microscopic justification for this model.
- We have shown an application for ^{28}Si.
- An analysis of the potential energy surface has placed ^{28}Si at the U(5)-$\overline{\mathrm{SU}(3)}$ phase-transitional point.
- Precursors of a phase transition in ^{28}Si have been evidenced.

$B(E2; 0_2^+ - 2_1^+)/B(E2; 2_1^+ - 0_1^+)$

$$H_B^{(T)} = (1-\eta)\widehat{n}_d - \frac{\eta}{4N}(Q^\dagger \cdot Q^\dagger)$$



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