

Particle-hole excitations in nucleon-pair configurations

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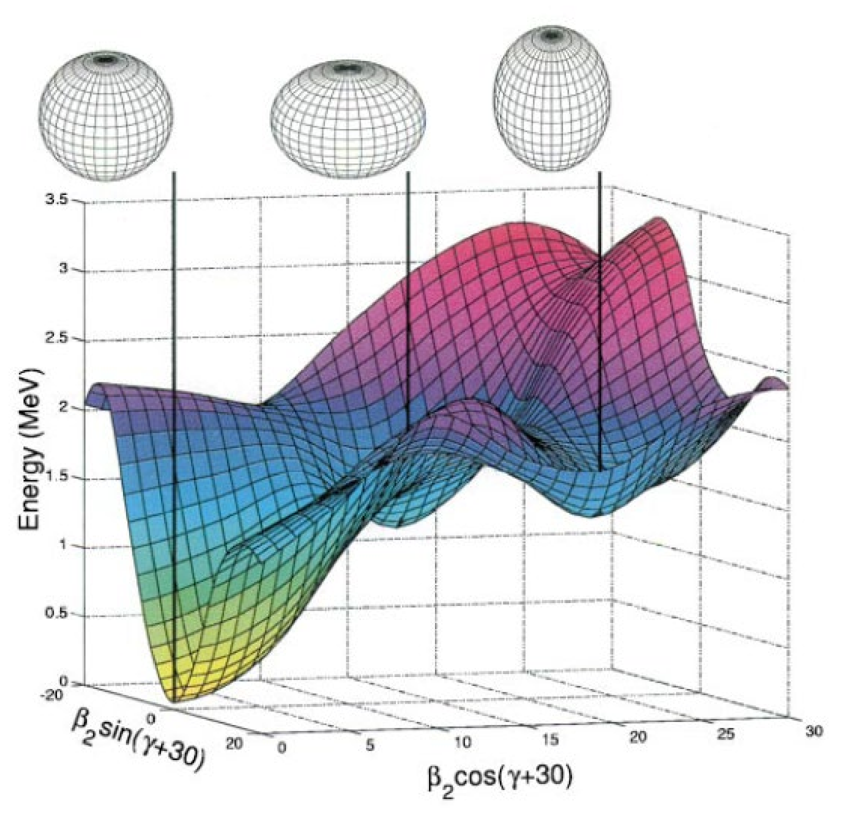
- Introduction about NPA with ph. excitations
- Cal. for Sn-100
- inversion-island nuclei
- N=126 isotones

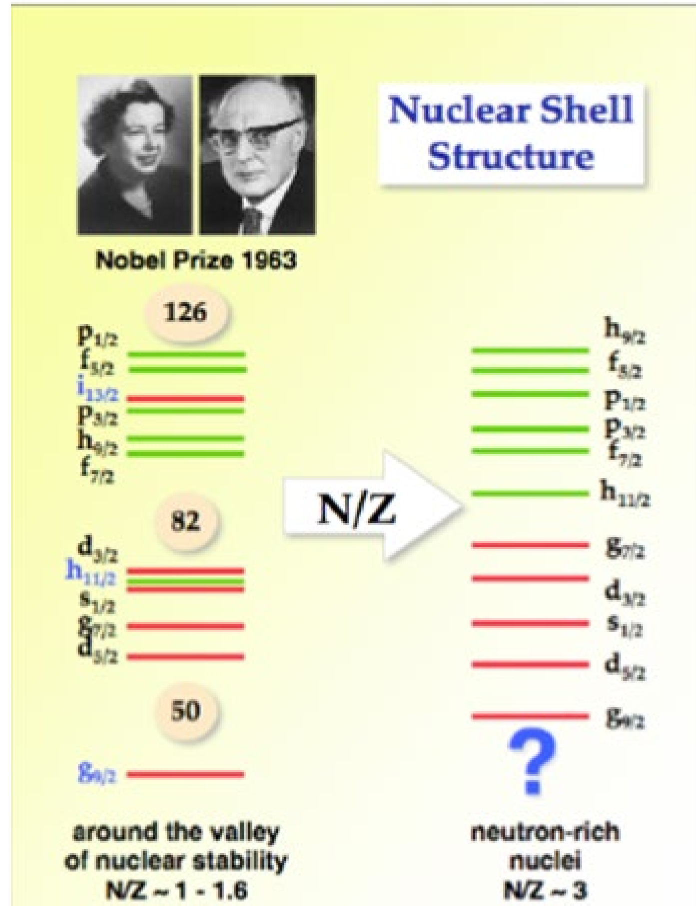
WHY multiple major shells

Shape coexistence

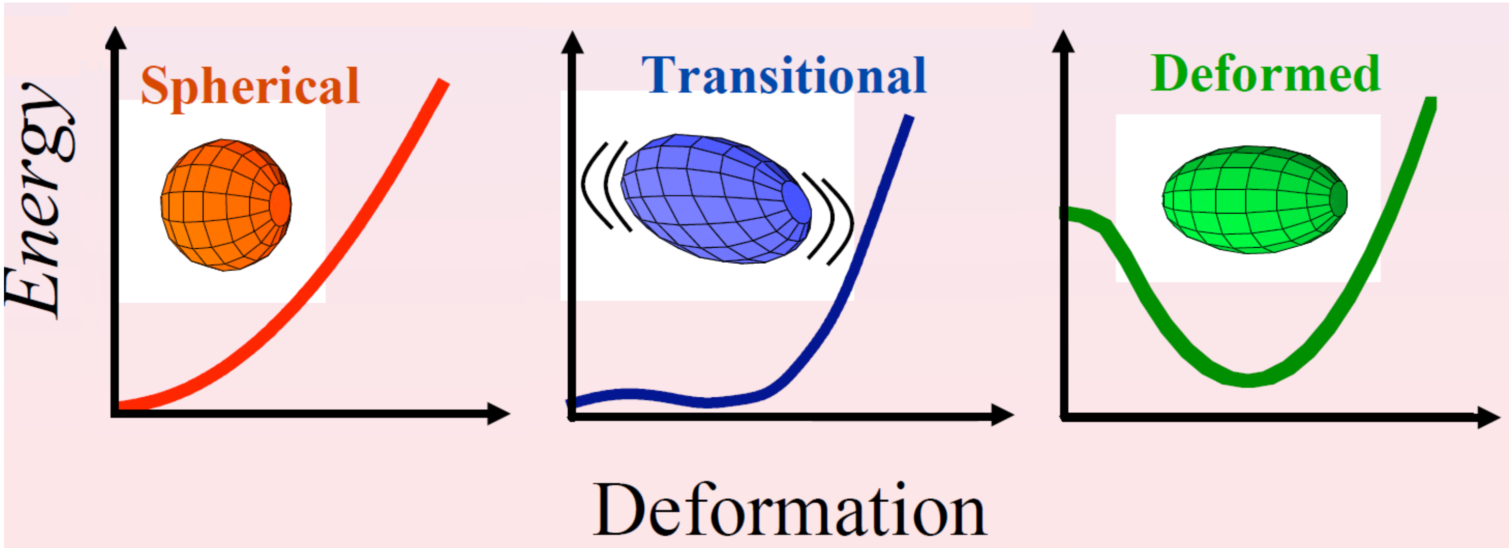


A. N. Andreyev et al., Nature 405, 430 (2000).

Shell evolution



WHY pair truncation



To describe Shape Coexistence:

HUGE space when using spherical s.p. basis

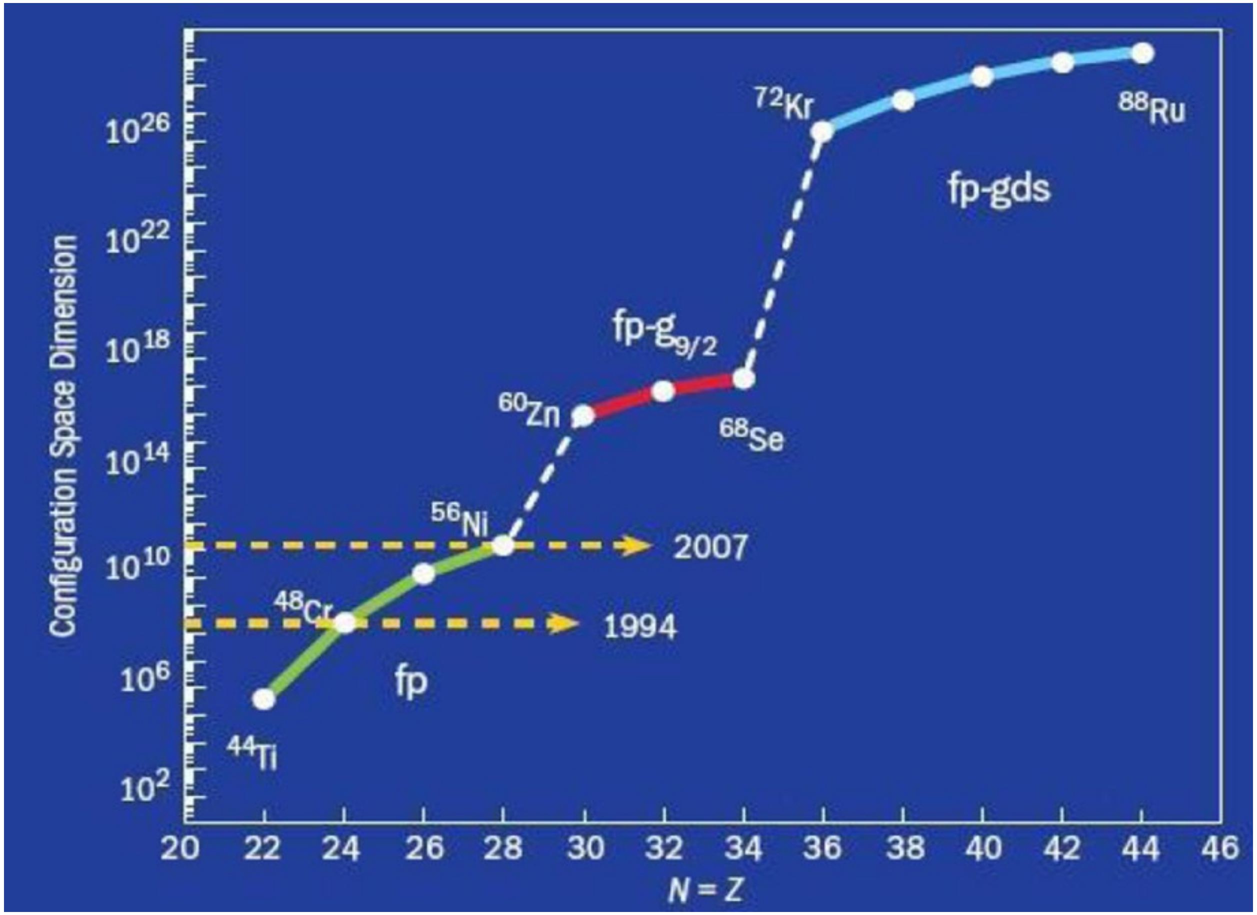
Deformed nuclei: Deformed DFT + angular momentum projection 

Spherical nuclei: Spherical s.p. basis

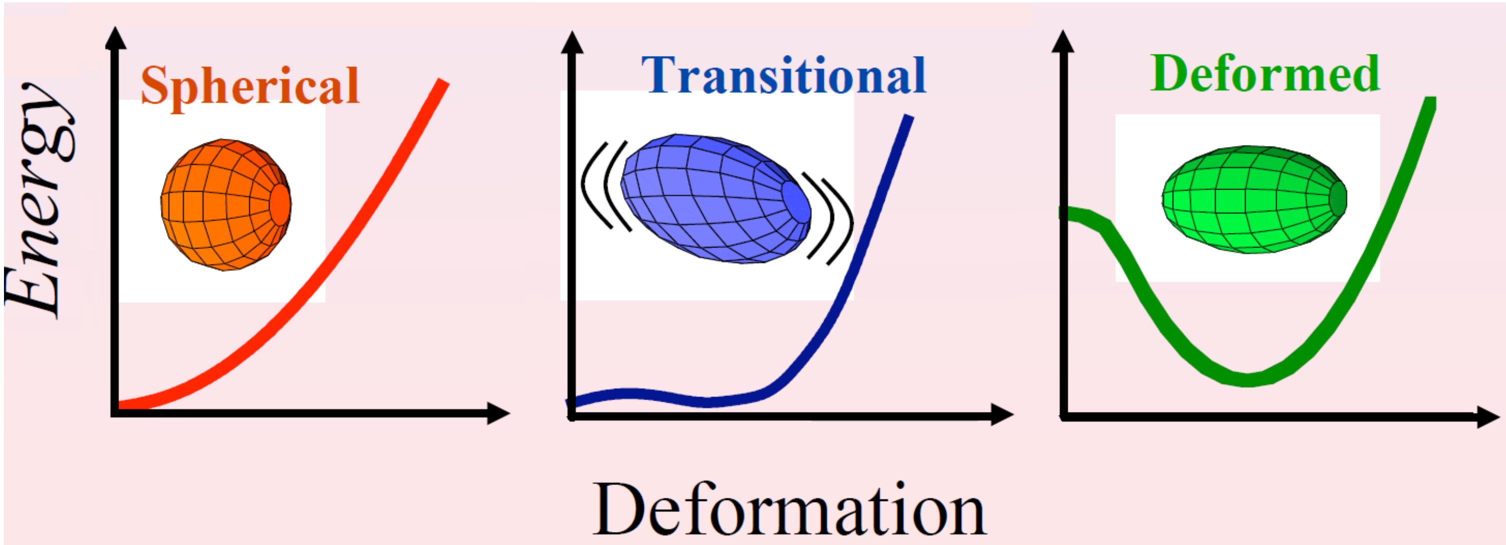
Transitional nuclei: Spherical s.p. basis

WHY pair truncation

Examples of Shell-Model dimension



WHY pair truncation



To describe Shape Coexistence:

HUGE space when using spherical s.p. basis

Deformed nuclei: Deformed DFT + angular momentum projection

Spherical nuclei: Spherical s.p. basis

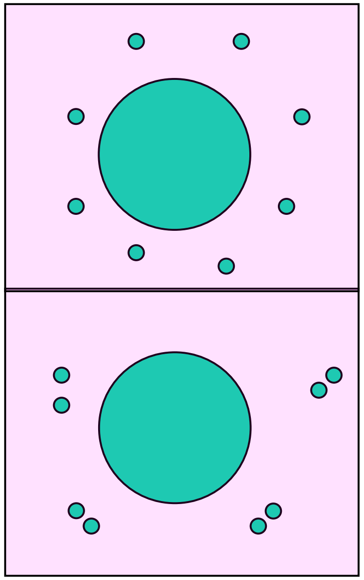
Transitional nuclei: Spherical s.p. basis

+ truncation !

Nucleon-pair approximation

Shell-model basis (m-scheme):

$$\left|\phi\right\rangle = a^{+}_{j_1 m_1} a^{+}_{j_2 m_2} \cdots a^{+}_{j_n m_n} \left|0\right\rangle$$



nucleon pair:

$$A^{(r)+} = \sum_{j_1 j_2} y(j_1 j_2 r) A^{(r)+}(j_1 j_2), \quad A^{(r)+}(j_1 j_2) = (a^{+}_{j_1} \times a^{+}_{j_2})^{(r)}$$

pair basis (J-scheme):

$$\left|\varphi\right\rangle = \left(\cdots \left(\left(A^{(r_1)+} \times A^{(r_2)+} \right)^{(J_2)} \times A^{(r_3)+} \right)^{(J_3)} \cdots \times A^{(r_N)+} \right)^{(J_N)}_{M_N} \left|0\right\rangle$$

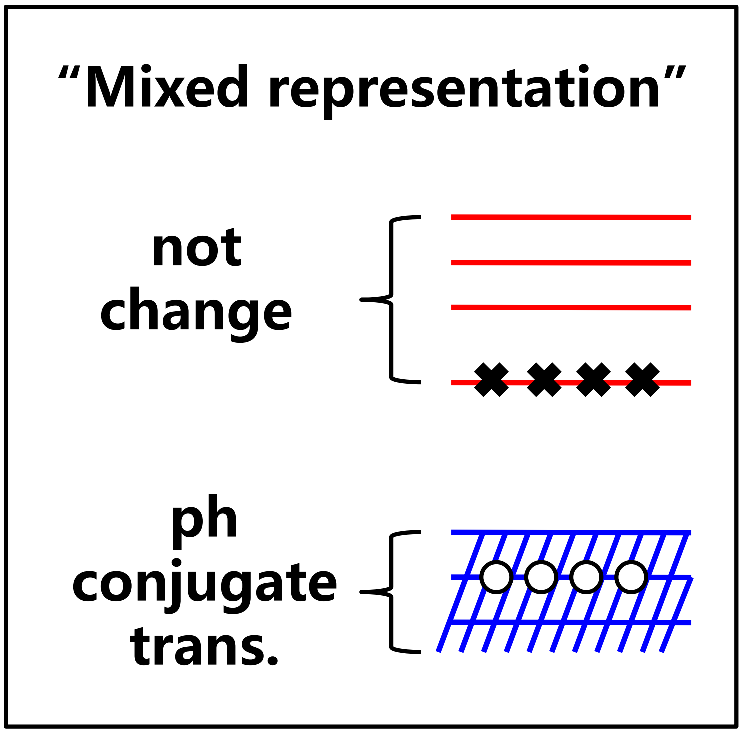
J. Q. Chen, Nucl. Phys. A 626, 686 (1997).

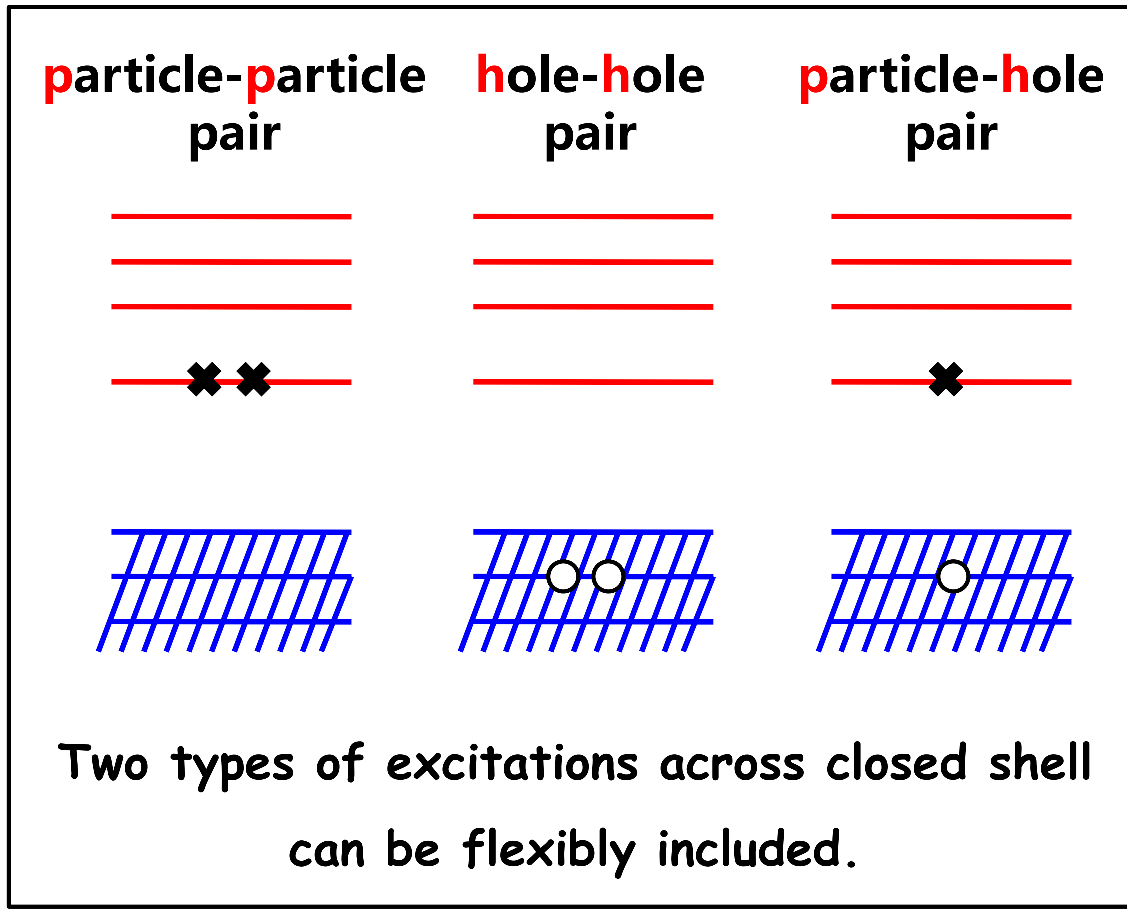
Y. M. Zhao et al., Phys. Rev. C 62, 014304 (2000).

PHYSICAL REVIEW C **97**, 024303 (2018)

Nucleon-pair approximation with particle-hole excitations

Y. Y. Cheng,[1,2] Y. M. Zhao,[2,3,*] and A. Arima[4,2]





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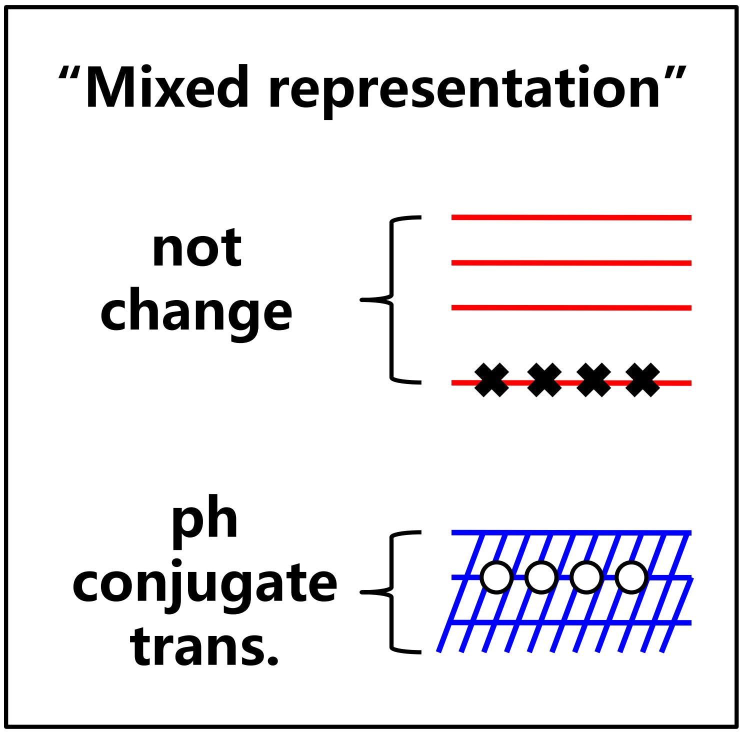


$$A^{e\dagger} \equiv A^{J_e\dagger}_{m_e} = \sum_{ab} y(abe)(a^\dagger \times b^\dagger)^{J_e}_{m_e}$$

pair structures:

particle-particle $\begin{pmatrix} A_{n\times n} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} \end{pmatrix}$

hole-hole $\begin{pmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & B_{m\times m} \end{pmatrix}$

particle-hole $\begin{pmatrix} \mathbf{0} & C_{n\times m} \\ \mathbf{0} & \mathbf{0} \end{pmatrix}$

Hamiltonian in mixed representation

particle: $$H = \sum_j \varepsilon_j N_j + \sum_{j_1 \le j_2} \sum_{j_3 \le j_4} \sum_{JM} \sum_{TM_T} \frac{V_{JT}(j_1 j_2 j_3 j_4)}{\sqrt{(1+\delta_{j_1 j_2})(1+\delta_{j_3 j_4})}} \boxed{A^{JT\dagger}_{MM_T}(j_1 j_2) A^{JT}_{MM_T}(j_3 j_4)}$$

mixed:

$$\boxed{\begin{array}{ccc} (A_1^{t\dagger} \times \tilde{A}_2^t)^{(0)} & (Q_1^t \times Q_2^t)^{(0)} & (\tilde{A}_1^t \times A_2^{t\dagger})^{(0)} \\ (\tilde{A}^t \times Q^t)^{(0)} & (Q^t \times \tilde{A}^t)^{(0)} & (\tilde{A}_1^t \times \tilde{A}_2^t)^{(0)} \\ (A_1^{t\dagger} \times A_2^{t\dagger})^{(0)} & (A^{t\dagger} \times Q^t)^{(0)} & (Q^t \times A^{t\dagger})^{(0)} \end{array}}$$

(I) Calculation for Sn-100

1. Space

   holes : 28-50 major shell , particles : 50-82 major shell

   up to 4-particle-4-hole

2. Shell-model Hamiltonian

$$H = H_{\rm SM} + \beta\left(H_{\rm CM} - \frac{3}{2}\hbar\omega\right), \qquad H_{\rm CM} = \frac{\tilde{P}^2}{2mA} + \frac{1}{2}mA\omega^2\tilde{R}^2.$$

$$H_{\rm SM} = \sum_j \varepsilon_j N_j + \sum_{j_1\leqslant j_2}\sum_{j_3\leqslant j_4}\sum_{JM}\sum_{TM_T} \frac{V_{JT}(j_1 j_2 j_3 j_4)}{\sqrt{(1+\delta_{j_1 j_2})(1+\delta_{j_3 j_4})}} A^{JT\dagger}_{MM_T}(j_1 j_2) A^{JT}_{MM_T}(j_3 j_4)$$

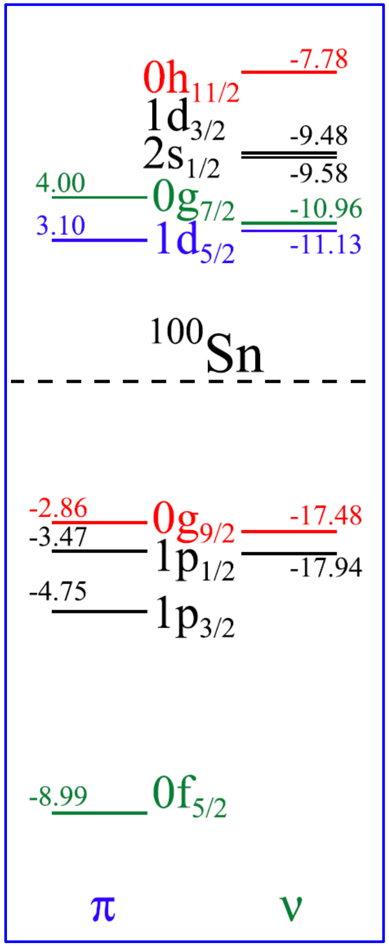
TBME : CD-Bonn + $V_{\text{low-k}}$ (given by Prof. T.T.S.Kuo)

$$\beta\hbar\omega / A = 10\text{MeV}$$

(I) Calculation for Sn-100

SPE

$$\varepsilon'_j = \varepsilon_j + \frac{1}{(2j+1)} \sum_{j_h} (1+\delta_{j j_h}) \times \sum_J (2J+1) \langle j_h j J T | V_{\text{low}-k} | j_h j J T \rangle$$



taken from 'Faestermann et al., Prog. Part. Nucl. Phys. 69, 85 (2013)'

(I) Calculation for Sn-100

3. Pair truncation

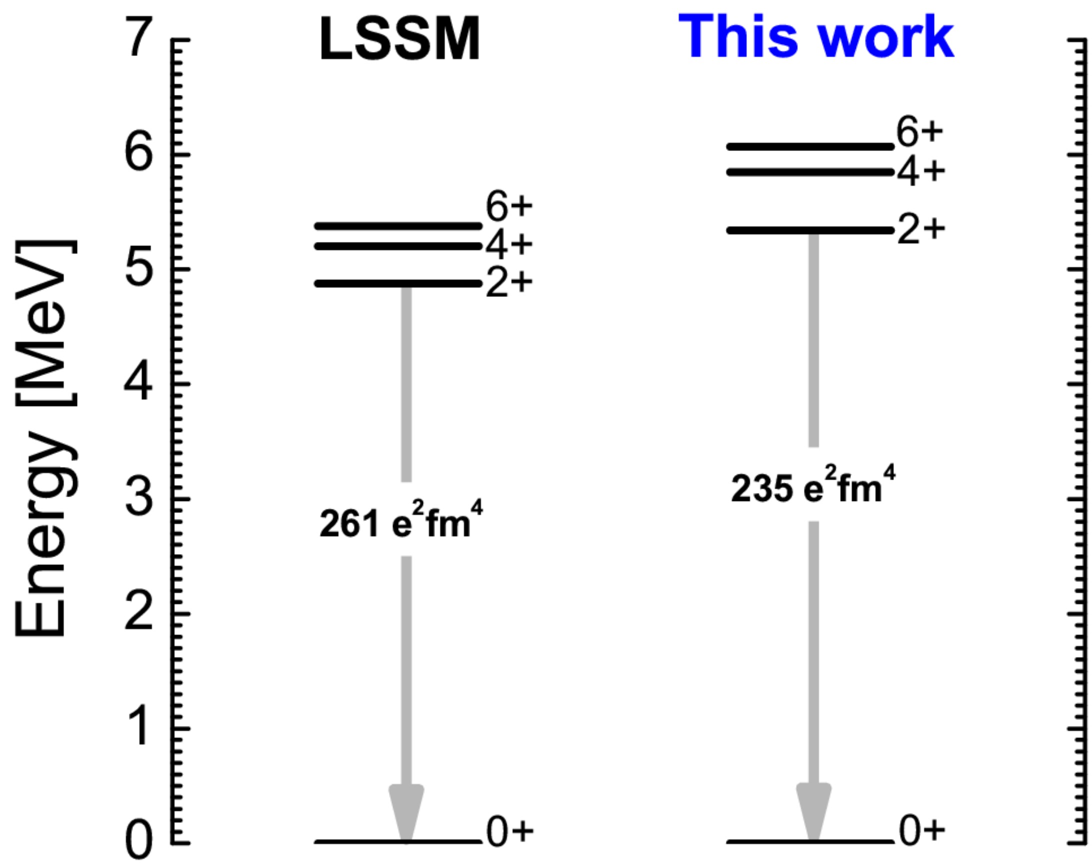
   SD pairs of both pp and hh types

   & ph pairs with spin-2, 4, 6 (positive-parity phonons)

   structure coefficients corresponding to

   2p-, 2h-, 1p1h-wavefunctions with respect to Sn-100

(I) Calculation for Sn-100



LSSM [Faestermann et al., Prog. Part. Nucl. Phys. 69, 85 (2013)]

holes in $0g_{9/2}$, particles in $0g_{7/2}1d_{5/2}1d_{3/2}2s_{1/2}$, up to 4p4h

CD-Bonn + G-matrix

(II) Calculation for inversion-island nuclei

$$H = \sum_j \varepsilon_j N_j + \sum_{j_1 \le j_2} \sum_{j_3 \le j_4} \sum_{JM} \sum_{TM_T} \frac{V_{JT}(j_1 j_2 j_3 j_4)}{\sqrt{(1+\delta_{j_1 j_2})(1+\delta_{j_3 j_4})}} A^{JT\dagger}_{MM_T}(j_1 j_2) A^{JT}_{MM_T}(j_3 j_4)$$

sdpf-M interactions of Utsuno et al.

proton: 0d1s

neutron: particle-hole excitations across N=20 shell,

$0d1s$—$0f_{7/2}1p_{3/2}$

(II) Calculation for inversion-island nuclei

Mg-32: $R_{4/2}$=2.62

To fix structure coefficents

$$\frac{\delta}{\delta y_i} E_{g.s.} = 0$$

i.e., fixed in the full NPA space

(II) 2p2h results

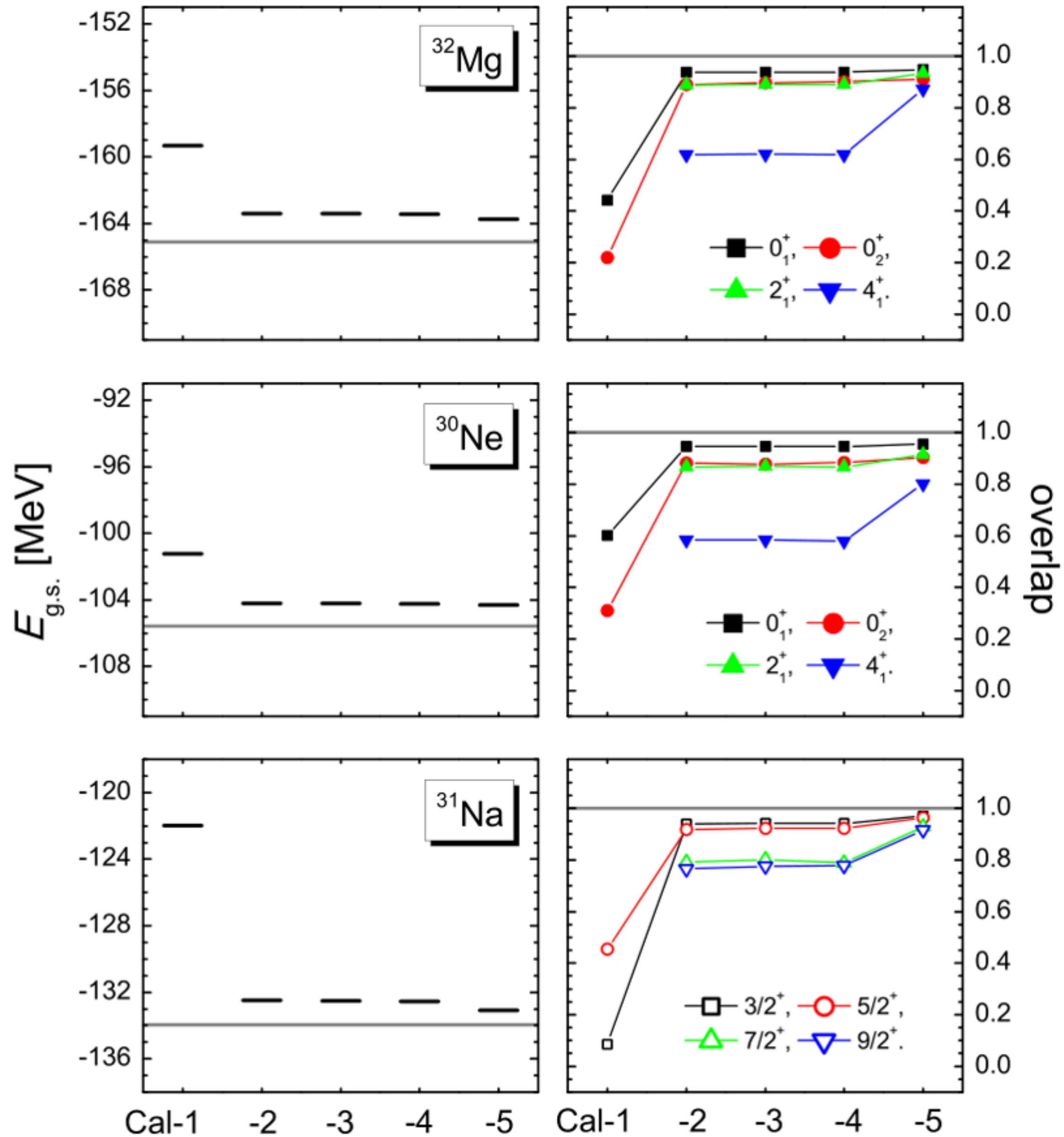
Cal-1: pp and hh *S* pairs

Cal-2: pp and hh *SD* pairs

Cal-3: Cal-2+ph *F* pair

Cal-4: Cal-2+*D'* pair

Cal-5: Cal-2+*G* pair



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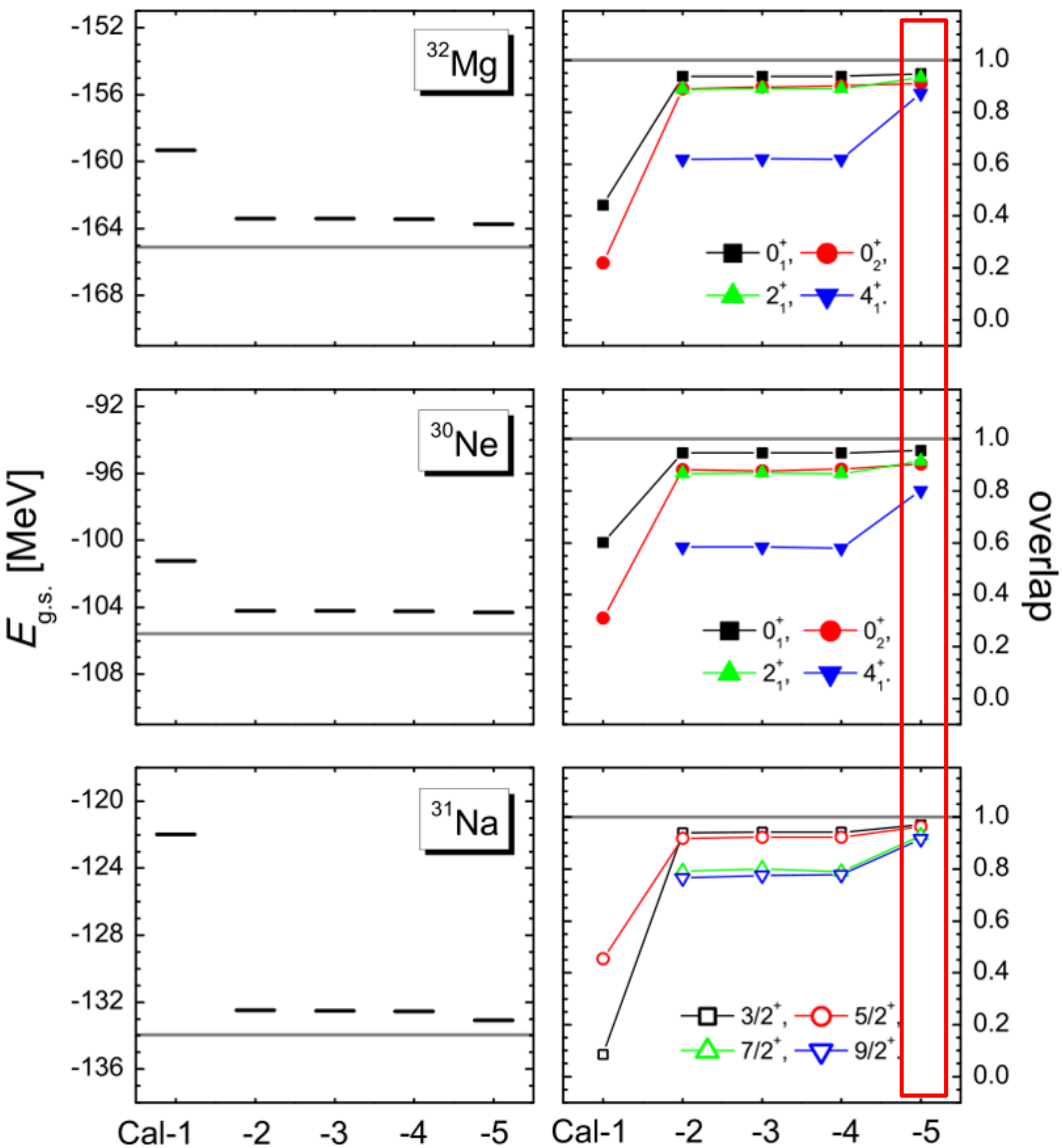


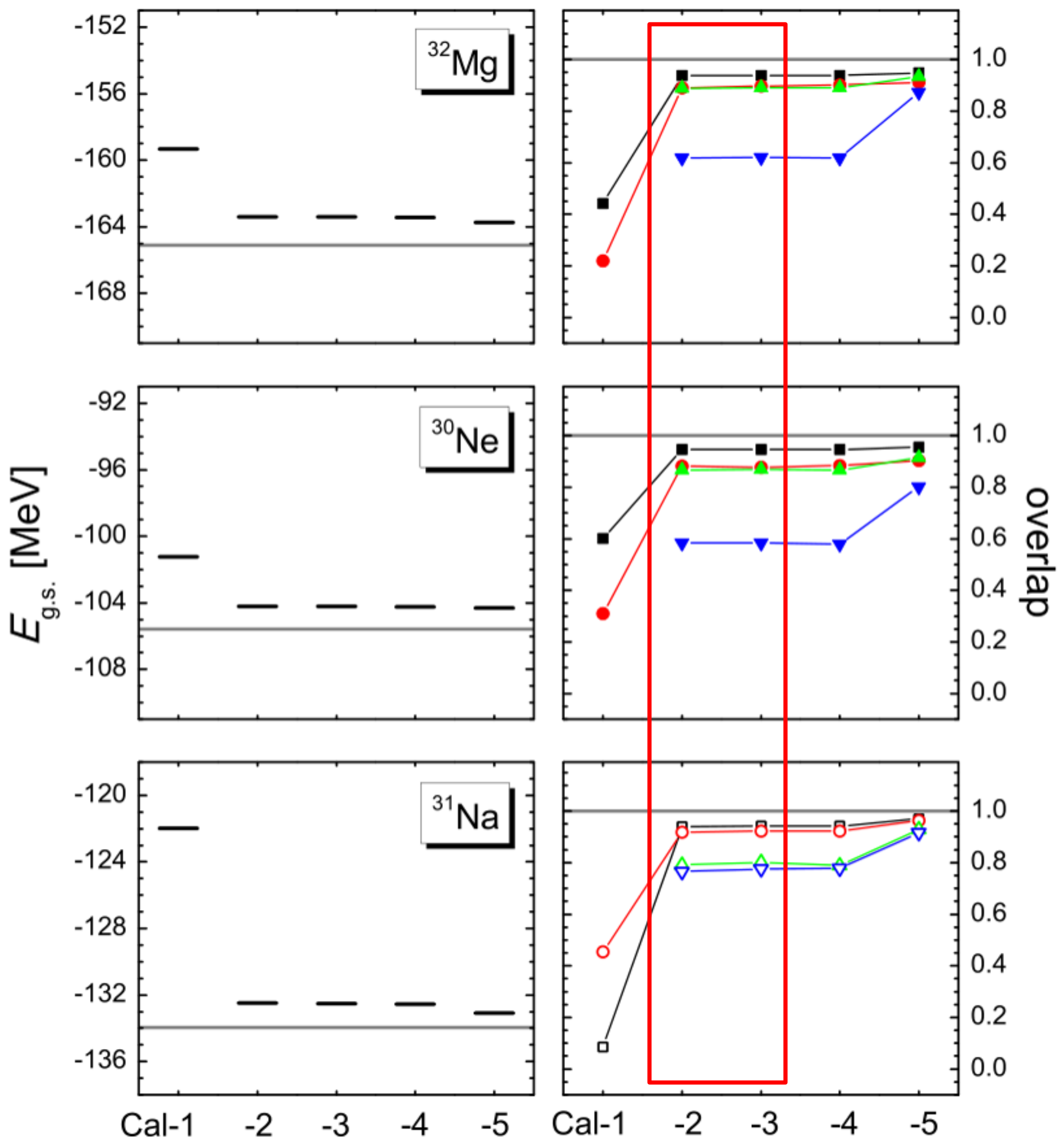
0^+_1, 2^+_1, 4^+_1, $3/2^+_1$, $5/2^+_1$, $7/2^+_1$, $9/2^+_1$

particle-hole config. dominant

0^+_2

shape-coexisting state; consistent with the result of two-neutron transfer reaction for Mg-32 (PRL 105, 252501)

(II) 2p2h results



Cal-1: pp and hh *S* pairs

Cal-2: pp and hh *SD* pairs

Cal-3: Cal-2+ph *F* pair

Cal-4: Cal-2+*D'* pair

Cal-5: Cal-2+*G* pair

(III) Calculation for N=126 isotones

1. Space

   proton: 82-126

   neutron holes : 82-126, particles: 126-184

   up to 2particle-2hole

2. Shell-model Hamiltonian

$$H = H_{\mathrm{SM}} + \beta\left(H_{\mathrm{CM}} - \frac{3}{2}\hbar\omega\right), \qquad H_{\mathrm{CM}} = \frac{\tilde{P}^2}{2mA} + \frac{1}{2}mA\omega^2\tilde{R}^2.$$

$$H_{\mathrm{SM}} = \sum_j \varepsilon_j N_j + \sum_{j_1 \leqslant j_2} \sum_{j_3 \leqslant j_4} \sum_{JM} \sum_{TM_T} \frac{V_{JT}(j_1 j_2 j_3 j_4)}{\sqrt{(1+\delta_{j_1 j_2})(1+\delta_{j_3 j_4})}} A^{JT\dagger}_{MM_T}(j_1 j_2) A^{JT}_{MM_T}(j_3 j_4)$$

TBME : Bonn-B + $V_{\text{low-k}}$ (given by Prof. T.T.S.Kuo)

(III) Calculation for N=126 isotones

3. Pair truncation

proton: SDGIK and F- pairs;

defined in the generalized-seniority v<=2 subspace

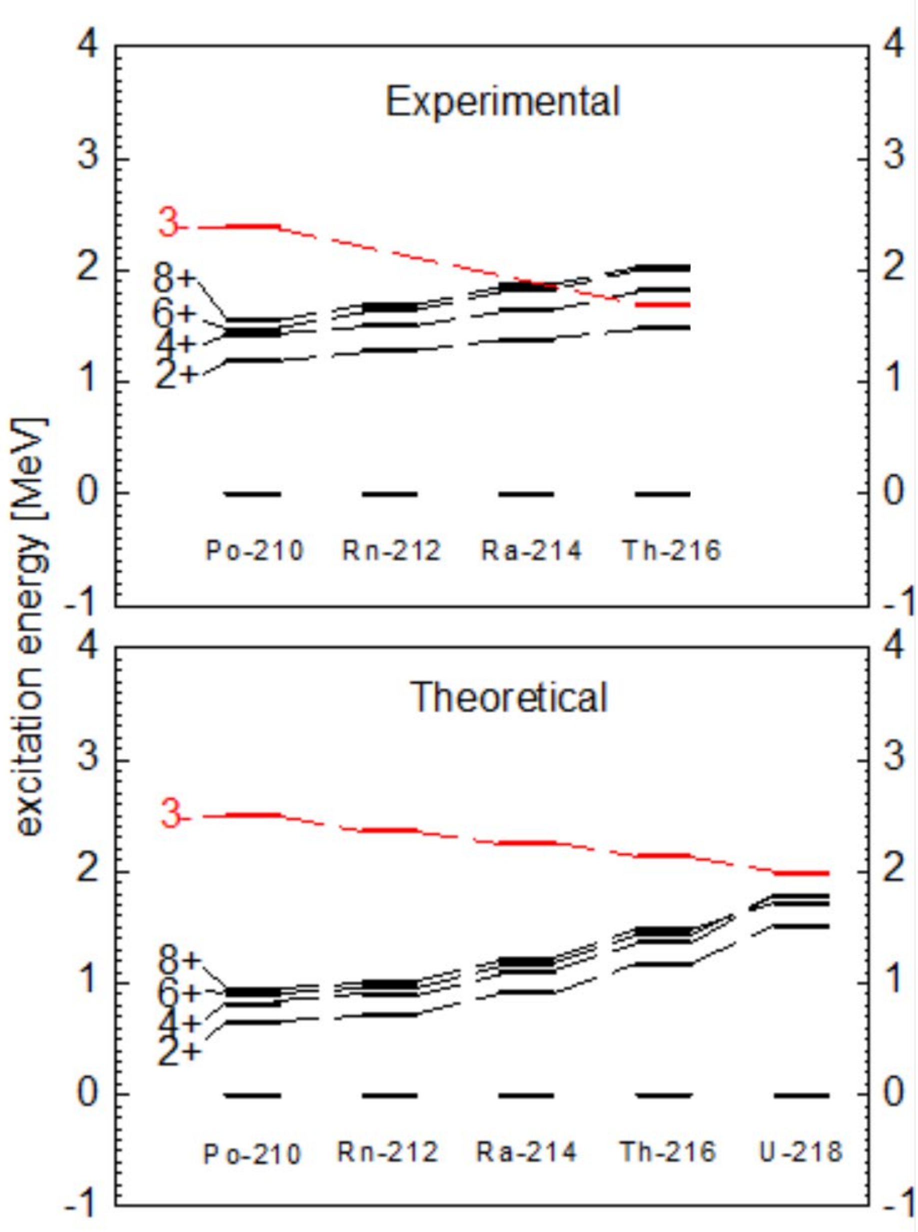
neutron: SD pairs of both pp and hh types

& 3- ph pair (octupole phonon);

structure coefficients corresponding to

2p-, 2h-, 1p1h-wavefunctions with respect to Pb-208

(II) Calculation for N=126 isotones



Thanks