How evident is the shape coexistence phenomenon in the lead region?

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Region of interest

Z

Mid shell

82

104  126

N

Pb  Hg  Po  Pt
The angular momentum projected mean field plus the Generator Coordinate Method generates different bands with very different deformation.
For nuclei near to closed shells, either for neutrons or for protons, it can be energetically favorable to have excitations of 2p-2h, 4p-4h … crossing the energy gap.

The np-nh excitations have a lower excitation energy than expected due to the correlation energy: pairing and deformed correlations.

Restricted to light and medium-heavy nuclei, at present.

In heavy nuclei the huge model space imposes some kind of truncation: symmetry dictated truncation.
Interacting Boson Model
(configuration mixing)

\[ \hat{H} = \hat{P}_N^\dagger \hat{H}_{\text{ECQF}}^N \hat{P}_N + \hat{P}_{N+2}^\dagger \left( \hat{H}_{\text{ECQF}}^{N+2} + \Delta_{N+2} \right) \hat{P}_{N+2} + \hat{V}_{\text{mix}}^{N,N+2} \]

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Pb and Hg isotopes

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Spherical

Prolate

Oblate

Pb and Hg isotopes

JEGR and K. Heyde, PRC 89, 014306 (2014)
Pt and Po isotopes

Excitation Energy (MeV)

Pt

Po

Flat behavior

JEGR and K. Heyde, NPA 825, 39 (2009),
JEGR, V. Hellemans, and K. Heyde, PRC 84, 014331 (2011).

JEGR and K. Heyde, PRC to appear.
Dynamic moment of inertia

\[ J^{(1)} = \frac{\hbar^2}{2} \left( \frac{dE}{d(J(J+1))} \right)^{-1} \approx \frac{\hbar^2(2J-1)}{2E_\gamma(J \rightarrow (J-2))} \]
How to fix the parameters (IBM)

Least squares fit to the experimental data, including excitation energies and absolute B(E2) transitions.

\[
\chi^2 = \frac{1}{N_{data} - N_{par}} \sum_{i=1}^{N_{data}} \frac{(X_i(data) - X_i(IBM))^2}{\sigma_i^2}
\]

<table>
<thead>
<tr>
<th>Error (keV)</th>
<th>States</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma = 0.1)</td>
<td>2_1^+</td>
</tr>
<tr>
<td>(\sigma = 1)</td>
<td>4_1^+, 0_2^+, 2_2^+</td>
</tr>
<tr>
<td>(\sigma = 10)</td>
<td>2_3^+, 3_1^+, 4_2^+, 6_1^+, 8_1^+</td>
</tr>
<tr>
<td>(\sigma = 100)</td>
<td>2_4^+, 3_1^+, 4_3^+, 6_2^+</td>
</tr>
</tbody>
</table>

+ all the known B(E2) transitions

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How the IBM results look like?

JEGR and K. Heyde, PRC 89, 014306 (2014).

Hg isotopes
Unperturbed energies (IBM-CM)

Hg

Pt

Po
Deformation

$$\beta = \frac{4 \pi \sqrt{B(E2; J \rightarrow J - 2)}}{3 Z e r_0^2 A^{2/3} \langle J 0 20 | J - 20 \rangle}$$

Pt

Po

Hg

Beta's from B(E2) values

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Summary and conclusions

• We have presented a detailed description of even-even Pt-Hg-Po isotopes using the interacting boson model including configuration mixing: excitation energies, BE2’s, deformation, radii, ...

• Two different behaviors are showed up: in Hg and Pb the presence of intruders is self evident while in the case of Pt and Po configuration mixing is somehow concealed.

• In Pt-Pb-Po-Hg two (or even three) configurations coexist, one slightly deformed (or spherical) and of gamma unstable character, corresponding to the regular states and a more deformed one of oblate (prolate) character corresponding to the intruder states.

• Shape coexistence all through the nuclear mass region, is a very general phenomenon, except in few cases where the spherical shell gaps indeed block the development of deformed states.
Thank you
Nucleons couple preferably in pairs with angular momentum either equal to 0 (S) or equal to 2 (D). Those pairs are then described by means of bosons: $s$ and $d$.

\[
s^\dagger, \quad d^\dagger_m (m = 0, \pm 1, \pm 2)
\]
\[
s, \quad d_m (m = 0, \pm 1, \pm 2)
\]

\[
\hat{H}_{ECQF} = \epsilon \hat{n}_d + \kappa \hat{Q} \cdot \hat{Q} + \kappa' \hat{L} \cdot \hat{L}
\]
Correlation energy (IBM-CM)

- **a) Hg**
- **b) Po**
- **c) Pt**

![Graph showing correlation energy for different elements](image)

**Legend:**
- IBM-CM
- [N]
- [N+2]
What is shape coexistence?

It appears in quantum systems where eigenstates with very different shapes coexist.

Therefore, it is implicit the existence of a geometric interpretation.

Molecules

Nuclei
Many regions to understand

Proton number $Z$

Neutron number $N$
Excitation energies (exp)

a) Hg
b) Po
c) Pt

E (MeV)

N

$0^+$  $2^+$  $4^+$  $6^+$  $8^+$
Wave functions (IBM-CM)

Pt

Hg

Po