Signatures of octupole shape phase transitions in radioactive nuclei

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Self-consistent mean field within DFT

\[ {}^{90}\text{Th} (N=132-142) \]

from Relativistic Hartree-Bogoliubov calc. with DD-PC1 EDF + separable pairing force

... universal description of intrinsic properties of arbitrary nuclei
... calculation of \textit{spectra} requires inclusion of dynamical correlations

\textbf{Interacting-boson Hamiltonian}
Microscopic description of octupole shape-phase transitions in light actinide and rare-earth nuclei

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$^{88}$Ra ($N=130-140$)
$^{62}\text{Sm} (N=84-94)$

$^{56}\text{Ba} (N=84-94)$
Microscopic PES is mapped onto the expectation value of the IBM Hamiltonian in the \( J=0^+ \) (s), \( 2^+ \) (d), and \( 3^- \) (f) boson condensate state.

\[
\hat{H} = \epsilon_d \hat{n}_d + \kappa_2 \hat{Q}^x \cdot \hat{Q}^x + \kappa_2' \hat{L} \cdot \hat{L} + \epsilon_f \hat{n}_f + \kappa_3 : \hat{V}_{sdf}^\dagger \cdot \hat{V}_{sdf} : 
\]

\[
|N, \beta_2, \beta_3\rangle = \frac{1}{\sqrt{N!}} (\lambda^\dagger)^N |0\rangle \quad \lambda^\dagger = s^\dagger + \beta_2 d_0^\dagger + \beta_3 f_0^\dagger
\]
$^{226}$Th: rigid octupole deformation

![Diagram showing the excitation energy (MeV) for $^{226}$Th with both experimental (Expt.) and theoretical (Th.) results. The diagram includes levels with quantum numbers for different states.]
Excitation energies of positive-parity states

(a) $^{90}$Th (b) $^{88}$Ra (c) $^{62}$Sm (d) $^{56}$Ba
Excitation energies of negative-parity states

(a) $^{90}$Th

(b) $^{88}$Ra

(c) $^{62}$Sm

(d) $^{56}$Ba

Excitation energy (MeV) vs. Mass number
E3 and E1 systematics
Signatures of QPT
Signatures of QPT

\[ \delta E(J) = E(J^-) - \frac{E((J+1)^+) + E((J-1)^+)}{2} \]
Signature splitting

\[ S(J) = \frac{[E(J + 1) - E(J)] - [E(J) - E(J - 1)]}{E(2^+_1)} \]

... similar with Gogny EDF
Octupole correlations in odd-A nuclei

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Signatures of octupole correlations in neutron-rich odd-mass barium isotopes

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.. **Interacting boson-fermion model** (IBFM) Hamiltonian constructed from DFT

\[
\hat{H}_{\text{IBFM}} = \hat{H}_{\text{IBM}} + \hat{H}_F + \hat{H}_{BF}
\]

Input from DFT:

(i) Potential energy surface for even-even core
(ii) Spherical single-particle energies and occupation probabilities of odd particle
... octupole (one-f boson) bands in both even-even and odd-A nuclei...
... large E3 transitions to g.s. in $^{145}$Ba (to be confirmed experimentally)
Conclusions

• Quadrupole & **octupole** shape phase transitions occur in medium and heavy nuclei;

• **DFT-based IBM.** Detailed, **computationally feasible**, and systematic description of **observables** relevant to octupole deformation;

• ... Spectroscopy in **other mass regions, other properties** (e.g., parity doublet, Schiff moment).

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