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Advances in the microscopic study of the Interacting Boson Model

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Interacting boson model (IBM)

- **Ingredients:** collective pairs of valence nucleons
- **shell-model derivation. Valid for** near vibrational nuclei

**Refs:**
- T. Otsuka, A. Arima, F. Iachello (1978)
- ...

Otsuka-Arima-Iachello (OAI) mapping

**Microscopic basis**

- **S pair** ($J^P=0^+$)
- **D pair** ($J^P=2^+$)

- **Nucleon**
- **Boson**

- **s boson** ($J^P=0^+$)
- **d boson** ($J^P=2^+$)

**SD nucleon space**

**sd boson space**

Q. Can we derive IBM Hamiltonian in some unified way?
Long-standing problem

Features of Nuclear Deformations Produced by the Alignment of Individual Particles or Pairs

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“IBM may not be sufficient to describe some properties of strongly deformed nuclei because of the SD truncation.”

Many debates over the validity of the IBM. Concrete answer still missing.

- Nilsson-BCS model (T. Otsuka et al., 1982; D. Bes et al., 1982)
- Renormalization of G pair or inclusion of g boson (e.g., T. Otsuka, Ginocchio, 1985; T. Otsuka, M. Sugita, 1988)
- Conventional boson mapping (e.g., M. R. Zirnbauer, 1984)
- J projection on the intrinsic wave function (N. Yoshinaga et al., 1984)
- ... Many others
This talk

A unified way of deriving IBM Hamiltonian for all known cases of basic low-lying collective states:

- Vibrational (weakly deformed) nuclei [1,2]
- Rotational (strongly deformed) nuclei [3]
- Triaxial (or γ-soft) nuclei [4]
- ... (Other relevant cases)

Relevant publications:

Principal idea

- A given mean-field model (Skyrme, Gogny, RMF, etc) can be a good starting point for computing spectra of the intrinsic state of interest.

- We construct an IBM(-2) Hamiltonian by mapping the mean-field solution onto the interacting-boson state.
Basic case: mapping energy surface

An IBM-2 Hamiltonian is determined by the equality $E_{\text{HFB}} \approx E_{\text{IBM}}$; energy levels and wave functions with good spin, particle number, parity, etc.
Fermion-boson mapping for deformed nuclei

- A basic rotational property should be also reproduced by bosons. We consider rotational response (= energy shift due to infinitesimal rotation of nucleon intrinsic state).
- The missing piece is the rotational LL term in the IBM, giving correct moment of inertia.

- Intuitive picture -
“Essential” boson Hamiltonian

\[ \hat{H}^B = \epsilon(\hat{n}_d\pi + \hat{n}_d\nu) + \kappa \hat{Q}_\pi \cdot \hat{Q}_\nu + \kappa' \hat{L} \cdot \hat{L} \]

Step 1) “Basic part”: mapping of the PES. Valid for near-spherical and \( \gamma \)-unstable cases

\[ \langle \phi^F | \hat{H}^F | \phi^F \rangle \sim \langle \phi^B | \hat{H}^B | \phi^B \rangle \]

Step 2) LL term: rotational response (cranking) at a mean-field minimum. “Basic part” is kept unchanged. Necessary for strongly deformed nuclei.

\[ \delta \langle \phi^F | \hat{H}^F e^{-i\hat{J}_y\delta \theta} | \phi^F \rangle \sim \delta \langle \phi^B | \hat{H}^B e^{-i\hat{J}_y\delta \theta} | \phi^B \rangle \]

angle \( \delta \theta \ll 1 \)
Proof of principle

* Skyrme SkM* Mapped IBM

- Spherical-Deformed transition in Sm; Rotational band is reproduced nicely.
- Good description of γ-soft nucleus $^{134}$Ba
Is a triaxial nucleus $\gamma$ rigid or unstable?

Majority of observed soft nuclei are halfway. Empirical models cannot explain it. Microscopic realization?

- Rigid triaxial rotor model (Davydov & Filippov, 1958)
- $\gamma$-unstable rotor model (Wilets & Jean, 1956)
- Equivalence between W-J and $O(6)$ in IBM (Ginocchio & Kirson, 1980)
The “harmonic” structure of quasi-γ band is reproduced only if the IBM-2 Hamiltonian is comprised of up to three-body boson terms.
Robustness

- Independently of EDFs, neither W-J nor D-F picture is realized in presumably all triaxial nuclei. New symmetry/phase?
- In the IBM, 3B term must be included.
Shape coexistence in Hg

- IBM-2 with config. mixing (0p-0h + 2p-2h) using Duval-Barrett’s technique
- Spherical-Prolate-Oblate transition
- Reasonable spectroscopic and intrinsic properties
Microscopic description of octupole shape-phase transitions in light actinide and rare-earth nuclei

K. Nomura, D. Vretenar, T. Nikšić, and Bing-Nan Lu

- Calc. by sdf-IBM mapped from RMF DD-PC1
- Most pronounced octupole deformation at $^{226}\text{Th}$, being a transition point.
Summary

New formulation of the IBM has been developed. Bridge the gap between IBM and nuclear mean-field model.

- Physical observables in lab frame
- Valid for (in principle) any situation:
  - 3-B term: necessary for a triaxial minimum
- Real prediction for heavy unknown nuclei
- Remaining issues: mixed symmetry (in progress), super deformation, ... etc.
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L. Guo (Tokyo, now in Beijing)
D. Vretenar (Zagreb)
L. M. Robledo (Madrid)
R. Rodríguez-Guzmán (Rice U)

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Thank you for your attention!

ありがとうございます！