Hexadecapole bands in ^{114,116}Sn nuclei

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Introduction

Nuclear structure studies of Sn isotopes have been a central area of research due to their near-magic nature and rich variety of nuclear phenomena, including the observation of high-spin states, shape coexistence, and collective excitation. Among these, hexadecapole deformations, characterized by the β_4 deformation parameter, have attracted attention due to their role in shaping high-spin nuclear states. This article explores hexadecapole deformed bands in Sn isotopes using the Deformed Hartree-Fock (DHF) model and compares theoretical predictions with experimental data.

Theoretical Framework

The model used by us is based on a quantum many-body method which has been quite successful in explaining the structure of nuclei in the rare-earth region [1, 2] as well as lighter mass region [3]. It is based on deformed Hartree-Fock model for the intrinsic states and Angular Momentum Projection (J-projection, for short) for the physical states based on these intrinsic states.

An intrinsic wave function $\mid \Phi_K\rangle$ is a superposition of states of good angular momenta which are projected using the angular momentum projection operator:

$$P_K^{IM} = \frac{2I+1}{8\pi^2}\int d\Omega {D_{MK}^{I}}^{*}(\Omega)\, R(\Omega) \quad . \quad (1)$$

The angular-momentum-projected normalized states are given by

$$\Psi_K^{IM} = \frac{P_K^{IM} \mid \Phi\rangle}{\sqrt{\langle\Phi \mid P_K^{IK} \mid \Phi\rangle}} \quad . \quad (2)$$

The energy of the states are obtained from the Hamiltonian overlap given by,

$$\langle\Psi_{K_2}^{I} \mid H \mid \Psi_{K_1}^{I}\rangle = \frac{2I+1}{2}\frac{1}{(N_{K_1K_1}^{I}N_{K_2K_2}^{I})^{1/2}} \times \int d\theta \sin\theta d_{K_2K_1}^{I}(\theta)\langle\phi_{K_2}|He^{-i\theta J_y}|\phi_{K_1}\rangle (3)$$

with $N_{KK}^{I} = \langle\Phi \mid P_K^{IK} \mid \Phi\rangle$. N_{KK}^{I} represents the intensity of angular momentum I in a K configuration.

Reduced matrix element of a tensor operator T^L of polarity L, between projected states $\psi_{K1}^{J_1}$ and $\psi_{K2}^{J_2}$ is given by

$$\langle\psi_{K_1}^{J_1}||T^L||\psi_{K_2}^{J_2}\rangle = \frac{1}{2}\frac{(2J_2+1)(2J_1+1)^{1/2}}{(N_{K_1K_1}^{J_1}N_{K_2K_2}^{J_2})^{1/2}} \times \sum_{\mu\nu} C_{\mu\nu K_1}^{J_2 L J_1}\int_0^{\pi} d\beta\ sin(\beta) d_{\mu K_2}^{J_2}(\beta) \times\langle\phi_{K_1}|T_{\nu}^{L}e^{-i\beta J_y}|\phi_{K_2}\rangle \, (4)$$

Results and Discussions

The deformed HF orbits are calculated with a spherical core of ^{56}Ni, the model space spans the $1p_{3/2}$, $0f_{5/2}$, $1p_{1/2}$, $0g_{9/2}$, $0d_{5/2}$, $0g_{7/2}$,

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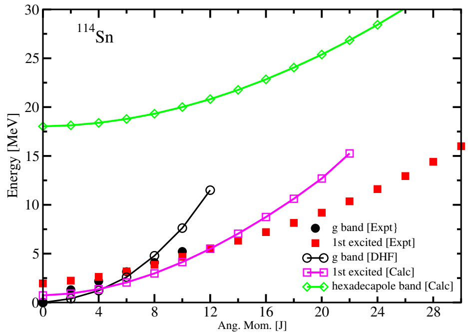

FIG. 1: The ground and excited bands in ^{114}Sn. Experimental data are taken from Ref. [4].

$0d_{3/2}$, $2s_{1/2}$ and $0h_{11/2}$ orbits both for protons neutrons with single particle energies 0.0, 0.78, 1.88, 4.44, 8.88, 11.47, 10.73, 12.21 and 13.69 MeV respectively. We use a surface delta interaction (with interaction strength ∼0.36 for $p-p$, $p-n$ and $n-n$ interactions) as the residual interaction among the active nucleons in these orbits.

Sn isotopes, specially with mass numbers $A \sim 110 - 130$ exhibit interesting shape dynamics as a function of angular momentum. Typically, Sn isotopes are expected to be spherical or near-spherical at low spins due to their closed proton shells ($Z = 50$). However, as the system gains angular momentum, the competition between pairing interactions, shell effects, and rotational alignment can lead to non-spherical shapes, including hexadecapole deformations.

The deformed HF model predicts that for certain Sn isotopes, rotational bands with significant β_4 deformations can emerge at high spins. These deformations result in specific patterns in the energy spectra, including changes in transition probabilities that are characteristic of hexadecapole shapes.

Fig. 1 shows the ground and excited bands in comparison with available experimental data [4]. Apart from the intruder excited band we predicted a hexadecapole deformed band with band-head energy about 18 MeV. The reduced E4 transition probabilities for the hexadecapole band is depicted in Table I. It clearly demonstrates the increased E4 collectivity of the excited hexadecapole band.

TABLE I: BE(4) values in $e^2 fm^8$ for ground and excited hexadecapole band.

$J^\pi \rightarrow (J\text{-}4)^\pi$	ground band	excited band
$4^+ \rightarrow 0^+$	1.41×10^3	1.13×10^5
$6^+ \rightarrow 2^+$	2.82×10^3	1.77×10^5
$8^+ \rightarrow 4^+$	5.07×10^3	2.03×10^5
$10^+ \rightarrow 6^+$	8.96×10^3	2.17×10^5
$12^+ \rightarrow 8^+$	13.88×10^3	2.25×10^5

We also calculated similar hexadecapole structure in ^{116}Sn. Details will be shown during the conference.

Summary

To, summarize, we have analyzed excited hexadecople structure in some Sn nuclei using the deformed Hartee-Fock and J-projection technique. In our theory we treat the quadrupole and hexadecapole deformation on equal-footing. Moreover, deformation is not something externally imposed. It follows dynamically from the HF theory. Of course, the intrinsic states are not the physical states, one needs J-projection from the intrinsic states to obtain the physical states. The hexadecapole deformation is difficult to measure in traditional nuclear electric transition measurements, as it is often overshadowed by the nuclear quadrupole deformation. But the heavy ion collision experiments are sensitive to the hexadecapole deformation of the colliding nuclei. This opens the door to gain new insight into nuclear structure.

References

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