Role of Octupole-Octupole Interaction in High-Spin Nuclear States

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Introduction

The study of nuclear structure at high angular momenta is important to understand the nuclear interaction and many-body quantal effects that govern atomic nuclei. The importance of the quadrupole-quadrupole interaction to describe the low-spin properties of atomic nuclei is well established. Most of the in-band transitions in deformed nuclei have $E2$ character which signifies the importance of the quadrupole-quadrupole interaction for these nuclei. The importance of the higher order multipole components of the nucleon-nucleon interaction has also been investigated [1, 2]. In particular, it is known that in some regions of the Segre chart, the single-states that differ by $l = 3$ are close in energy and can be mixed by octupole-octupole interaction. The resulting octupole mean-field lowers the energy of the $-ive$ parity states and in some regions strong $E1$ transitions between the two parity states are observed. The purpose of the present work is to investigate the importance of the octuople- octupole interaction using the microscopic approach of the triaxial projected shell model (TPSM) approach.

TPSM approach with Octupole-Octupole interaction

The TPSM has become a powerful framework for describing the triaxial shapes and associated high-spin phenomena in atomic nuclei [3, 4]. In the original version, the TPSM Hamiltonian includes terms of quadrupole-quadrupole and pairing interactions, apart from the single-particle Nilsson potential, and is designed to describe the quadrupole properties of atomic nuclei. However, the transitions between the two parity states turn out to be quite weak, and in order to describe the strong $E1$ transitions observed in some nuclei, it is essential to include the octupole-octupole interaction term in the TPSM framework.

In this work, we extend the TPSM model by incorporating the octupole-octupole interaction term in the Hamiltonian. In this initial study, the basis states have reflection symmetry and parity is preserved by the mean-field Nilsson potential. This approach can be viewed as a perturbation contribution of the octupole-octuople interaction term on the basic quadrupole mean-field. The extended model Hamiltonian with the inclusion of octupole-octupole interaction is represented by:

$$\begin{aligned}\hat{H} &= \hat{H}_0 - \frac{\chi}{2}\sum_\mu \hat{Q}^\dagger_\mu . \hat{Q}_\mu - G_M \hat{P}^\dagger . \hat{P} \\ &\quad - G_Q \sum_\mu \hat{P}^\dagger_\mu . \hat{P}_\mu + \frac{\chi_3}{2}\sum_\mu \hat{Q}^\dagger_{3\mu} \hat{Q}_{3\mu}. \qquad (1)\end{aligned}$$

The octupole-octupole coupling strength (χ_3) has been fixed using the hydrodynamical estimate [1].

Results and Discussion

The extended TPSM approach has been used to perform the numerical calculations for both +ive and -ive parity states in ^{100}Ru. It is pertinent to mention here that the TPSM Hamiltonian is diagonalized in the angular-momentum projected basis with parity as a good quantum number and, therefore, in the present work, octupole interaction is considered as a perturbation and not at the mean field level. In this work, three major oscillator shells for neutron (N= 3,4,5) and three for protons (N= 2,3,4) have been employed with the quasiparticle(qp) excitations from two major oscillator shells. To generate +ive parity states, the qp

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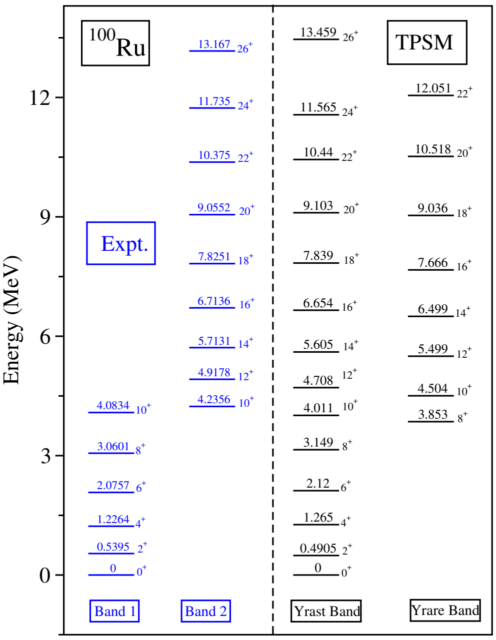

FIG. 1: (Color online) TPSM positive parity projected energies after configuration mixing for ^{100}Ru.

excitations are considered from the last oscillator shell, and for the -ive parity states, the qp excitations are included from the last two oscillator shells which have different parities [4].

TABLE I: The measured lifetimes of dipole transitions of the ^{100}Ru levels for Band 2 and Band 3 along with the values from the TPSM calculations. TPSM1 (TPSM2) is without (with) octupole interaction.

$J_\pi^i \rightarrow J_\pi^f$	B(E1) ($\times 10^{-4}$ e^{2}fm^2)		
	Expt.	TPSM1	TPSM2
Band 2			
$14^+ \rightarrow 13^-$	1.44(40)	0.67	0.72
$16^+ \rightarrow 15^-$	2.49(63)	0.58	0.69
$18^+ \rightarrow 17^-$	8.29(258)	0.14	0.23
Band 3			
$13^- \rightarrow 12^+$	1.59(28)	0.20	0.31
$15^- \rightarrow 14^+$	2.85(66)	0.27	0.54
$17^- \rightarrow 16^+$	5.88(187)	0.31	0.73

In ^{100}Ru nucleus, alternating parity rotational bands (Band 2 and Band 3) with $\Delta I = 1\hbar$ are observed [5]. TPSM reproduces the experimental energies quite well as illustrated in Fig. (1). In order to validate the octupole collectivity in ^{100}Ru, we have calculated $B(E1)$ transitions. TPSM calculated $B(E1)$ transitions with and without octupole-octupole interaction in the Hamiltonian are presented in Table I. It is evident from the results that the transitions without the inclusion of octupole-octupole interaction terms are quite weak as compared to the experimental values observed for some states. The inclusion of the octupole-octupole interaction enhances the magnitude of the transitions, but it is noted that they remain weak compared to the observed transitions. It is known that octupole correlations can either arise from the vibrational mode or it can originate from the octupole deformed mean-field. The perturbative treatment of the octupole correlations in the present work can be regarded as considering the vibrational mode. It is quite evident from the present investigation that this is inadequate to describe the observed features in ^{100}Ru. It can, therefore, be stated that to describe the observed properties, in particular, the strong $B(E1)$ transitions in ^{100}Ru, the octupole deformed mean-field or reflection symmetry needs to be broken in the TPSM approach.

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