Study of quasiparticle structure of odd-mass ^{165,167}Tb nuclei

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Introduction

The nuclear shell effects investigation away from the valley of stability towards the drip lines is one of the most important topics in nuclear structure physics. Due to this reason, the study of neutron rich nuclei has gained significant interest as these nuclei are more accessible with the advancement of the experimental facilities using rare exotic ion beams. As a result, phenomena like the quenching of shell closure [1–5] and the occurrence of new magic numbers are observed in these nuclei [6–8]. The neutron-rich transitional nuclei lying in the rare-earth region with $A \approx 160$ have been quite extensively studied in the last few decades as these nuclei are characterized by the interplay of collective motions and single-particle excitations. These nuclei have been proved to be fascinating due to the variety of structures resulting from the active proton orbitals and the softness of nuclei with respect to deformation. Much of the interest lies in the fact that these nuclei dwell within a highly transitional area of deformed space and thus can provide a fertile ground to investigate quasiparticle structures, alignments and some other properties associated with the band termination.

A large amount of work has been done over the last few decades on the odd-*Z*, odd-*A* rare-earth nuclei around the mass 160. The $N = 90$ isotone chain has been found to be extensively studied groups of nuclei in the rare-earth region as these nuclei possess transitional nature in deformation space. While, the $N \leq 88$ nuclei are weakly deformed as a result of the $N = 82$ shell gap, the $N \geq 92$ isotopes behave as well-deformed quantum rotors. In order to explain the structure of these nuclei, an attempt has been made in the present work to find the structure of odd-mass ^{165,167}Tb (Z = 65) nuclei in the PSM and the present PSM calculations have been found to explain the experimental observation quite successfully in ^{165,167}Tb nuclei.

The Theory of the Applied Model

In the present work, we have studied both the isotopes within the quantum mechanical framework of calculations known as Projected Shell Model (PSM). This model is basically the modification of nuclear shell model. Various nuclear structure properties of ^{165,167}Tb nuclei have been obtained by using this model. In this section, we present the basic input parameters used in the PSM calculations. The detailed theory of PSM is available in a review article [9]. The total Hamiltonian used in the present work is

$$\hat{H} = \hat{H}_o - \frac{\chi}{2}\sum_{\mu} \hat{Q}^{\dagger}_{\mu}\hat{Q}_{\mu} - G_M \hat{P}^{\dagger}\hat{P} - G_Q \sum_{\mu} \hat{P}^{\dagger}_{\mu}\hat{P}_{\mu}$$

Where the first term $\hat{H}_o$ is the spherical single-particle Hamiltonian which contains a proper spin-orbit force. The second term in the above equation is the quadrupole-quadrupole (QQ) interaction and χ represents its strength whose value is adjusted via self-consistent conditions with a given quadrupole deformation ε_2, and the last two terms are the monopole and quadrupole pairing interactions, respectively. The monopole pairing force constant G_M is adjusted to give the known energy gaps. In the present calculations, the monopole pairing strength is described as

$$G_M = \left(G_1 \mp G_2 \frac{N-Z}{A} \right) \frac{1}{A} (\text{MeV})$$

Where − (+) is for neutron (proton) while in this work, G_1 and G_2 are chosen as 21.20 and 12.70 MeV, respectively ^{165,167}Tb isotopes under study. The strength parameter G_Q for quadrupole pairing is assumed to be proportional to G_M and for present calculations, it is taken as 0.20. The present calculations are performed by considering three major shells (N= 3, 4 and 5) for protons and (N= 4, 5 and 6) for neutrons.

Results and Discussions

To investigate the nature of yrast band obtained in the present PSM study, several representative multi-*qp* bands, like projected 1- and 3-*qp* configurations, are plotted against the spin values in a diagram known as band diagram (see Figs. 1(a)-(b)). In the present study, the yrast levels and their composition i.e., band structures from multi-quasi-particle configurations for ^{165,167}Tb nuclei have been investigated.

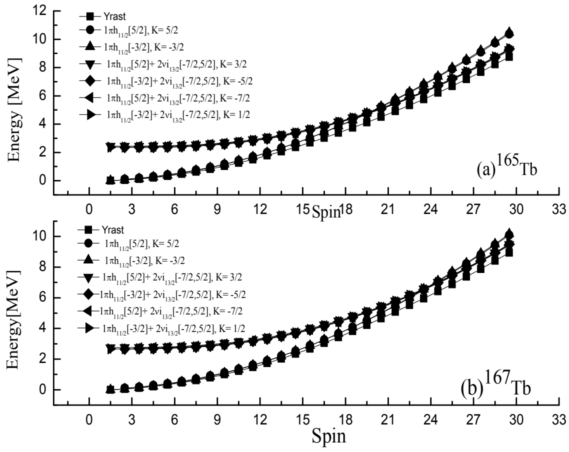

Fig. 1 Band diagrams of (a) ^{165}Tb, (b) ^{167}Tb

For ^{165}Tb isotope , it is clear from fig. 1(a) that the yrast band up to spin 39/2$^-$ is arising due to a mixture of two 1-*qp* bands with configurations: $1\pi h_{11/2}[5/2]$, K = 5/2 and $1\pi h_{11/2}$ [-3/2], K= -3/2. After this spin value 39/2$^-$, a mixture of four 3-*qp* bands: $1\pi h_{11/2}[5/2]$ + $2\nu i_{13/2}$[5/2,-7/2], K=3/2, $1\pi h_{11/2}$ [-3/2]+ $2\nu i_{13/2}$[-7/2,5/2], K= 1/2, $1\pi h_{11/2}$ [-3/2]+ $2\nu i_{13/2}$ [-7/2,5/2], K= -5/2 and $1\pi h_{11/2}$ [5/2]+ $2\nu i_{13/2}$ [-7/2,5/2], K= -7/2 cross the above mentioned two 1-*qp* bands, thereby, contributing to yrast spectra upto the last calculated spin value. For, ^{167}Tb , it is clear from fig. 1(b) that the yrast band up to spin 47/2$^-$ is arising due to a mixture of two 1-*qp* bands with configurations: $1\pi h_{11/2}[5/2]$, K = 5/2 and $1\pi h_{11/2}$ [-3/2], K= -3/2. After this spin value 39/2$^-$, a mixture of four 3-*qp* bands: $1\pi h_{11/2}[5/2]$ + $2\nu i_{13/2}$[5/2,-7/2], K=3/2, $1\pi h_{11/2}$ [-3/2]+ $2\nu i_{13/2}$[-7/2,5/2], K= 1/2, $1\pi h_{11/2}$ [-3/2]+ $2\nu i_{13/2}$ [-7/2,5/2], K= -5/2 and $1\pi h_{11/2}$ [5/2]+ $2\nu i_{13/2}$ [-7/2,5/2], K= -7/2 cross the above mentioned two 1-*qp* bands, thereby, contributing to yrast spectra upto the last calculated spin value. Furthermore, Figs. 2(a) and 2(b) present the yrast spectra of ^{165,167}Tb. The experimental data has been well reproduced with an overall good agreement by the calculated values of energy for ^{165,167}Tb.

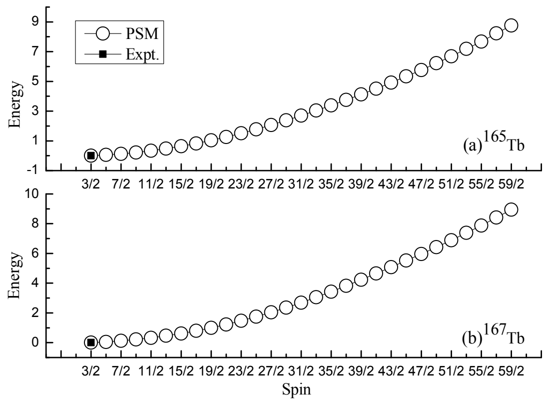

Fig. 2 Comparison of the Experimental and PSM yrast spectra for (a) ^{165}Tb, (b) ^{167}Tb

Summary

The neutron rich ^{165,167}Tb nuclei have been studied within a theoretical microscopic technique-Projected Shell Model. The composition of the yrast levels from various multi-quasi-particle configurations for these nuclei has been well described. Further, the comparison between yrast levels with the available experimental data has also been made and a good level of agreement has been obtained.

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