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Study of Positive Parity Yrast Bands in ^{157,159}Gd Nuclei

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Abstract: High spin states of odd mass ^{157,159}Gd isotopes are studied using a framework of calculations known as Projected Shell Model (PSM). Some nuclear structure properties like yrast spectra, transition energies and banddiagrams are calculated. A good agreement between the calculated and the available experimental values for theyrast spectra in ^{157,159}Gd nuclei has been obtained. Transition energies for ^{157,159}Gd have also been calculated andcompared with the experimental data. From the comparison, it is clear that there is perfect match of these valuesat lower spins for both the nuclei while a small disagreement exists at higher spins for ^{157}Gd nucleus. Abovecomparison for the yrast and transition energies predicts the reliability and validity of the chosen framework.Further, from the band diagrams, it has been found that the lower spins arise from one quasi-particle (1-qp)states, whereas, multi quasi-particle states are responsible for the formation of yrast band at higher spin states.

Keywords: Projected shell model; yrast spectra; multi-quasi-particle configuration.

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1. Introduction

Nuclei falling in the mass A~150 region belong to the transitional region- a region where one can study the variation of shape from spherical to well deformed, within an isotopic mass chain i.e increasing neutron number (N) and same proton number (Z) or within a chain of isotones i.e same N and increasing Z. Various experimental and theoretical studies [1-5] on these nuclei show that these nuclei are very interesting to study because they exhibit a large variety of nuclear structure properties. These nuclei have been characterized by the interplay of collective motions and single particle excitations [6]. Nuclear deformations in this mass region show a gradual transition from a spherical shape in a closed shell to a prolate deformation with increased neutron number [7,8]. These studies have provided a wealth of experimental data on the structure of the heavy rare-earth nuclei in the mass region A≈150. These measurements, apart from other nuclear structure data, provide quantities which are generally used as testing grounds for nuclear structure models. Gadolinium isotopes, ^{157}Gd and ^{159}Gd, belong to such a region of deformed rare-earth nuclei with deformation parameter (ε) ~0.3 and are a member of the well known prolate deformed nuclei [2], hence present an interesting case for study. Hence, in the present work, we have undertaken the study of ^{157,159}Gd isotopes using a framework of calculation known as Projected Shell Model (PSM) [9]. The high spin states of above mentioned nuclei are studied, as substantial changes in nuclear structure are expected here. Rotational bands in all these isotopes have been extended to considerably higher spin states than known before. Some nuclear structure properties like yrast spectra, transition energies and band diagrams are calculated and compared with the experimental results and the paper is closed by concluding remarks.

2. Calculational details

The Hamiltonian used in the calculations is Pairing (monopole and quadrupole) plus quadrupole one. Also, here we have included active particles from three oscillator shells, N=3,4,5 for protons and N= 4,5,6 for neutrons. The quadrupole strength constant has been chosen to reproduce the quadrupole deformation parameter ε_2 which takes the values 0.340 for ^{157}Gd and 0.330 for ^{159}Gd. The monopole pairing force constants for neutrons (-sign) and protons (+sign) are usually taken as $(G_M=20.20 \mp 12.12\frac{N-Z}{A})\frac{1}{A}$ in the rare-earth calculations, the values being adjusted to roughly reproduce the known energy gaps.

3. Yrast spectra for ^{157,159}gd isotopes

The reliability of the PSM calculations depends very much on the reliability of the PSM wave function. To check its reliability it is important to calculate some observable quantities such as yrast spectra. Yrast spectra consist of lowest rotational energy states for a given angular momentum, no matter which band the angular moment states belong to. As is clear from figure 1, experimentally, yrast levels are available only upto spin 29/2 ħ for ^{157}Gd and upto spin 13/2 ħ for ^{159}Gd, but through the present PSM calculations we are able to reproduce the corresponding data upto the spin of 59/2 ħ. The comparison of experimental data with the calculated values shows a very good agreement in these two isotopes (^{157,159}Gd). Further, from the presented results, it may be noted that the band heads for these isotopes (5/2 ħ) are very well reproduced by the PSM calculations, thereby, confirming the reliability of this model.

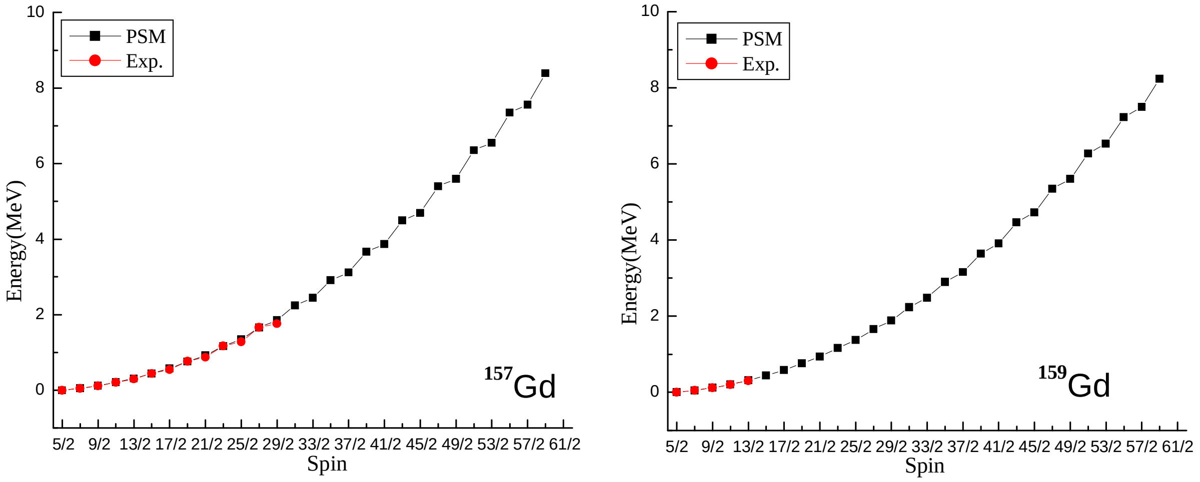

Figure 1: Comparison of calculated (PSM) yrast spectra with the Experimental (Expt.) data for ^{157}Gd and ^{159}Gd isotopes. Experimental values are taken from references [10] and [11] respectively.

4. Transition energies for ^{157,159}gd isotopes

Fig. 2 gives the variation in energies with respect to spin for ^{157,159}Gd isotopes. It is evident from the figure that for ^{157}Gd nucleus, the variations shown by calculated transition energies with spin is following the same trend as that of experimental values at low spins (that is, upto spin 15/2 ħ), thereafter, there is a disagreement between the experimental and theoretical changes. However, for ^{159}Gd isotope, experimental energy variation is same as shown by PSM calculations.

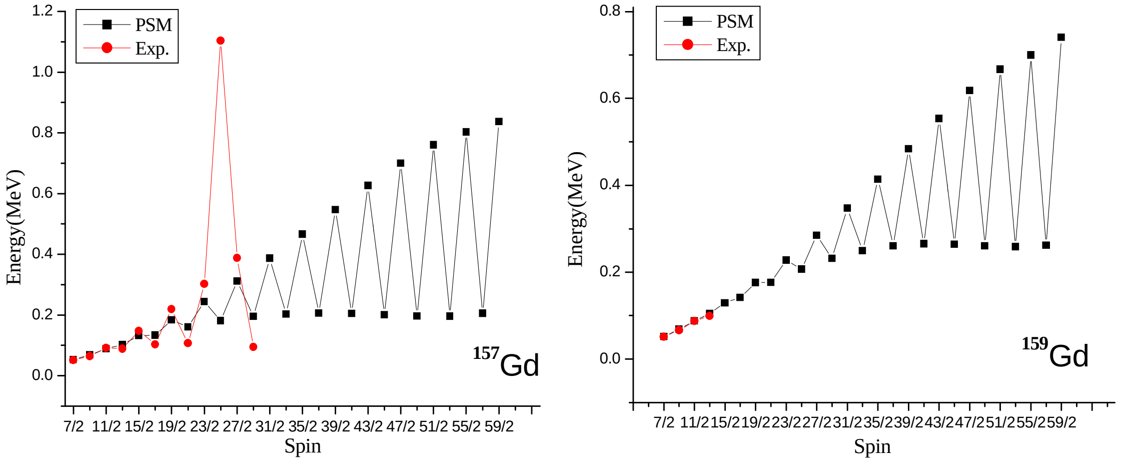

Figure 2: Comparison of calculated (PSM) and Experimental (Expt.) transition energy E(I)-E(I-1) versus spin I for ^{157}Gd and ^{159}Gd isotopes.

5. Band diagrams

A band diagram is obtained by plotting different energy bands with respect to spin. It is an indispensable tool for the analysis of data as it enables us to extract valuable physical information. Various bands have been plotted against spins for odd mass ^{157,159}Gd isotopes in Fig. 3 (a) and 3(b). It is evident from these figures that there exists a mixing of bands at higher spins, which in itself is an indication that a shape-rearrangement occurs at these spins. For ^{157}Gd, the yrast band upto spin 45/2 ħ arises from one quasi-particle band having configuration $1\nu i_{13/2,\ [5/2]}$ with band head 5/2. After that there is a superposition of this band with another one quasi-particle band with configuration $1\nu i_{13/2,[-3/2]}$ and band head -3/2 and this trend continues upto 51/2 ħ. At this spin, a combination of two three quasi-particle bands with configurations $1\nu i_{13/2,[5/2]}+2\pi h_{11/2,[5/2,-7/2]}$ having band head -7/2 and $1\nu i_{13/2,[-3/2]}+2\pi h_{11/2,[-7/2,1/2]}$ with band head -5/2 respectively is also superimposing on this combination of bands and this is forming the yrast band upto the last calculated spin. For ^{159}Gd, upto spin 45/2ħ, the yrast band is generated by a one quasi-particle band with configuration $1\nu i_{13/2,[\ 5/2]}$ and band head 5/2, then upto spin 51/2 ħ, another band $1\nu i_{13/2,[-3/2]}$ having band head -3/2 is getting mixed with it and this combination is thus accounting for the yrast band. Finally at 51/2 ħ, this combination is crossed by a three quasi- particle band with configuration $1\nu i_{13/2,[5/2]}+2\pi h_{11/2,[5/2,-7/2]}$ having band head 7/2 thus creating the yrast band till the last calculated spin.

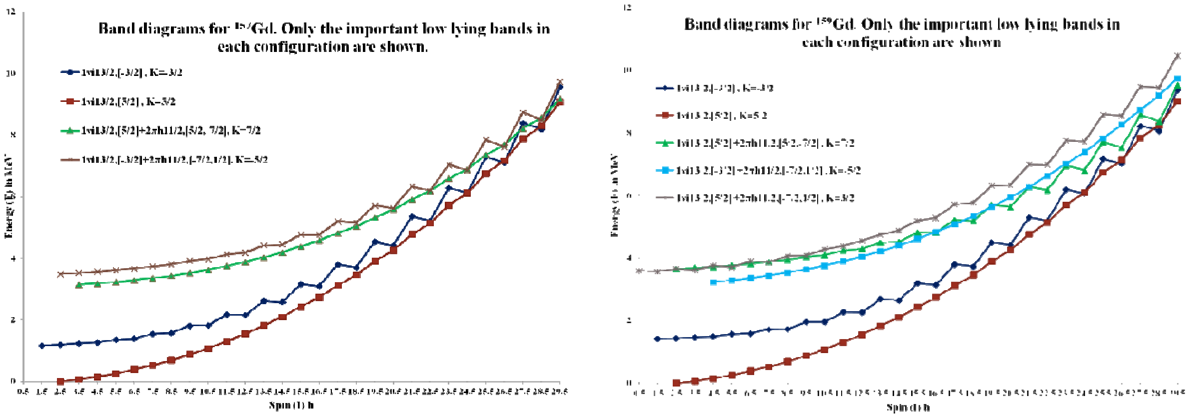

Figure 3: Band diagrams for ^{157}Gd and ^{159}Gd isotopes. Only the important lowest lying bands in each configuration are shown.

6. Conclusions

(1) Calculated yrast spectra show qualitative agreement with the observed yrast spectra for ^{157,159}Gd isotopes, thereby predicting the reliability of PSM.

(2) Band heads of above mentioned isotopes have been successfully reproduced by calculations which turn out to be 5/2ħ for ^{157,159}Gd nuclei.

(3) Calculated transition energies show almost a similar trend as predicted by experiments for ^{157}Gd nuclei, with a little exception for higher spins, where there is a slight mismatch between the experimental and the calculated results. However, for ^{159}Gd isotope. the calculated values are found to be in very good agreement with the experimental ones

(4) It is evident from the band diagrams of the above mentioned nuclei that the yrast states do not arise from a single band, but rather, they arise from 1quasi-particle (qp) or 3 quasi-particle (3qp) bands, i.e the low lying yrast states arise from a single band, whereas, the higher spin states arise from a superposition of bands which indicates a shape-co-existence in ^{157,159}Gd nuclei at higher spins.

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