# Study of excitation energy spectra of $^{153}$Gd

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## 1. Introduction

The Gd isotopes with neutron number around N=90 lie at the lower limit of the deformed region. In this region, a sudden change occurs from vibrational to the rotational character [1]. The $^{153}$Gd isotope lies in the heart of this region. To investigate the nuclear structure of this isotope, various spectroscopic studies have been done in the past [2-4]. The most extended level scheme with some new rotational sequences has been established by Brown et al. [5]. They have extended the ground state negative parity neutron $f_{7/2}$[521]3/2$^-$ band up to I=25/2$^-$ and 15/2$^-$ for α=+1/2 and α=-1/2 signature partners, respectively. They have also confirmed the assigned configurations for negative parity bands. They have identified that the lowest I=9/2$^-$ state is not a member of the ground state band but is part of the partially decoupled $h_{9/2}$ band. Among the positive parity bands, the neutron $i_{13/2}$[660]1/2$^+$ band is the lowest in energy and large signature splitting is seen in this band due to the low-K orbital. The first crossing for the α=-1/2 signature partner of this band takes place at ħω=0.37 MeV. All the energies of bands are measured relative to the I=3/2$^-$ state of the neutron $f_{7/2}$[521]3/2$^-$ band. The nuclear structure of this isotope is interesting to study as its low spin excitation energy spectra has been reconfirmed by Ross et al. [6] and some new levels have also been observed in their study. Therefore, the Projected Shell Model (PSM) has been employed to investigate the nuclear structure properties of this isotope [7].

## 2. The Model

In PSM, deformed single-particle states are obtained by the deformed Nilsson model in which pairing correlations are included by BCS calculations. The Nilsson+BCS defined a set of deformed quasiparticles (qp) basis. Major harmonic oscillator shells N=3,4 and 5 for protons and N=4,5 and 6 for neutrons are used in the present calculations.

The Hamiltonian used in the present calculation is

$$\hat{H} = \hat{H}_0 - \frac{1}{2}\chi \sum_{\mu} \hat{Q}^{\dagger}_{2\mu}\hat{Q}_{2\mu} - G_M\hat{P}^{\dagger}\hat{P} - G_Q\sum_{\mu}\hat{P}^{\dagger}_{2\mu}\hat{P}_{2\mu} \, ,$$

The monopole pairing interaction $G_M$ is taken as

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

where $G_1$ and $G_2$ are taken as 19.60 and 13.13, and $G_Q = \gamma G_M$, where $\gamma$ is the proportionality constant and is taken as 0.16 for present calculation.

## 3. Results and Discussion

The PSM calculations have been performed by taking quadrupole deformation parameter ($\varepsilon_2$)=0.30 and hexadecapole deformation parameter ($\varepsilon_4$)=-0.026. In Fig. 1(a), calculated energy levels are compared with available experimental data for negative parity bands. The bands labelled as 1, 2, 11 and 12 in ref. [5] are nicely reproduced by the present calculations. Band head spins and configurations are consistent with the observed ones. The bands 11 and 12 are predicted theoretically up to I=47/2$^-$ and 49/2$^-$ which were experimentally known up to I=15/2$^-$ and 25/2$^-$, respectively. For the band 1, the absolute difference between experimentally observed band head energy and the theoretically calculated value is only 0.01 MeV. Fig. 1(b) shows the comparison of calculated energy levels with experimental data for positive parity neutron $i_{13/2}$[660]1/2$^+$ band. The observed staggering and energies are reproduced nicely by the calculated results. The experimentally observed band head energy of neutron $i_{13/2}$[660]1/2$^+$ band relative to the I=3/2$^-$ state of the $f_{7/2}$[521]3/2$^-$ neutron band is 0.095 MeV which is theoretically reproduced as 0.103 MeV. The absolute difference between the two is 0.008 MeV. The signature splitting in this band is reproduced well by the present calculations. The excitation energies of α=-1/2 signature partner band of positive parity band is predicted up to I=51/2$^+$.

In Fig. 2, the alignment plot of yrast positive parity band is displayed. From this figure, it is seen that a smooth gain in alignment observed in this band at ħω=0.37 MeV is reproduced by the calculated results at ħω=0.33 MeV at I=41/2$^+$. This smooth gain in alignment is due to mixing of 1-qp neutron i$_{13/2}$[660]1/2$^+$ and i$_{13/2}$[651]3/2$^+$ bands with 3-qp bands arising from the coupling of 1-qp i$_{13/2}$[651]3/2$^+$ neutron band with 5/2 and 7/2 components of proton h$_{11/2}$ orbital.

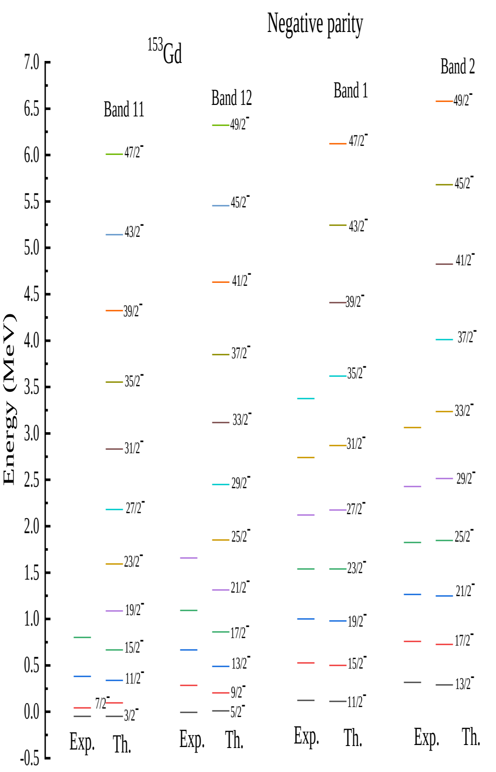

**Fig. 1(a)** Comparison of calculated energy levels with available experimental data [5] for negative parity bands of $^{153}$Gd.

## 4. Conclusions

The excitation spectra and staggering in positive parity band of $^{153}$Gd is well reproduced by the present calculations. The smooth gain in alignment observed in this band at ħω=0.37 MeV is reproduced by the calculated results at ħω=0.33 MeV at I=41/2$^+$. This smooth gain in alignment is due to mixing of 1-qp neutron i$_{13/2}$[660]1/2$^+$ and i$_{13/2}$[651]3/2$^+$ bands with 3-qp band arising from the coupling of 1-qp neutron i$_{13/2}$[651]3/2$^+$ band with 5/2 and 7/2 components of proton h$_{11/2}$ orbital.

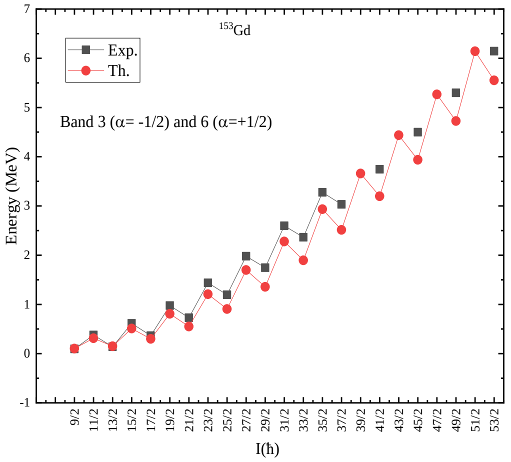

**Fig. 1(b)** Comparison of calculated energies available experimental data [5] for positive parity bands of $^{153}$Gd.

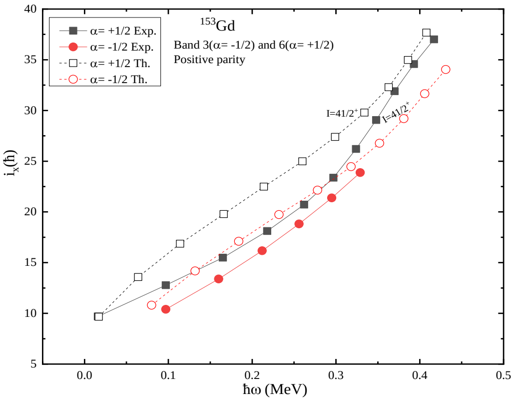

**Fig. 2** Comparison of calculated alignments with experimental data [5] for positive parity bands of $^{153}$Gd.

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## References

[1] R.F. Casten et al., Phys. Rev. Lett. **47**, 1433(1981).
[2] I. Rezanka et al., Nucl. Phys. A **179**, 51 (1972).
[3] J. Rekstad et al., Nucl.Phys. A **371**, 364 (1981)
[4] G. Lovhoiden et al., Nucl. Phys.A **494**, 157 (1989).
[5] T.B. Brown et al., Phys. Rev. C **66**, 064320 (2002)
[6] T.J. Ross et al., Phys. Rev. C **90**, 044323 (2014).
[7] K. Hara and Y. Sun Int. J. Mod. Phys. E**4**, 637 (1995).