Signature effects in two quasi-particle rotational bands of odd-odd deformed nuclei

Sushil Kumar[1,2*]
[1]Department of Physics, Maharishi Markandeshwar University, Mullana-133207, INDIA
*email: sushil.rathi179@gmail.com

Introduction

The two quasi-particle (2qp) excitations in odd-odd deformed nuclei exhibit varieties of high spin features such as back bending, band crossing, band termination, signature splitting and signature inversion etc. The signature effects exhibited by these bands have attracted a considerable attention from theoretical as well as from experimental aspects, which lead to the emergence of different possible explanations for these effects [1-4]. In present thesis, we adopted axially symmetric Two Quasi-Particle plus Rotor Model (TQPRM) [4] to investigate the role of Coriolis and particle-particle mixing in explaining signature effects observed in 2qp rotational bands of odd-odd deformed nuclei.

Objectives

The prime objectives of present study are as follows

(i) To explain the signature effects observed in various 2qp rotational bands of eight odd-odd deformed nuclides namely, ^{152}Eu, ^{154,156}Tb, ^{162,164}Ho, ^{164}Tm and ^{180,182}Ta through TQPRM calculations.

(ii) To resolve various critical issues such as, violation of GM rules, ambiguous spin, configuration assignments and conflict in the placement of tentative energy levels.

(iii) The prediction of some unobserved energy levels for the future experimental studies and estimation of Newby shift energies of various 2qp rotational bands appeared in the basis space of present TQPRM calculations.

Results and Discussion

Primary emphasis of present thesis work is to enlighten the phenomenon of signature inversion exhibited by $\pi h_{11/2} \otimes \nu i_{13/2}$ rotational band observed in three different nuclides namely ^{152}Eu and ^{154,156}Tb [5-7] through TQPRM calculations. On the basis of good agreement among experimental and TQPRM results, we successfully reproduced the magnitude of signature splitting and explicit point of signature inversion in ^{152}Eu and ^{156}Tb nuclides [8], which could not be attained in the earlier calculations [9]. Additionally, we also resolved some critical issues such as, violation of GM rule for 08 GM doublets appeared in the basis space of earlier calculations [9] for ^{152}Eu and ^{156}Tb nuclides. The conflict among different research groups [5,7] regarding the spin assignment of $\pi h_{11/2} \otimes \nu i_{13/2}$ band observed in ^{156}Tb nuclide is also resolved.

In case of ^{154}Tb nuclide, our model calculations successfully reproduce the phase as well as magnitude of signature splitting throughout the observed spin range with an explicit signature inversion at I=17$\hbar$. We also confirmed the tentative nature of spin, parity and configuration assignment to $\pi h_{11/2} \otimes \nu i_{13/2}$ band [8]. On the basis of present TQPRM calculations, we suggest that, the rotational bands observed in ^{152}Eu and ^{154,156}Tb nuclides are based on the $K^\pi=4^-(\uparrow\uparrow)$: $5/2[532]_\pi \otimes 3/2[651]_\nu$ Nilsson configuration.

Our second emphasis is to investigate the signature effects observed in various GM doublets lying in the range of $63 \leq Z \leq 71$ and $152 \leq A \leq 170$. To effectively carry out the above said investigation, we compiled a list of total 101 GM doublets observed in 18 different nuclides lying in above said range. Although there was an earlier compilation of the GM doublets [10], but we completed previous list with addition of experimental data of 17 newly observed GM doublets. It is also found that some of the earlier known GM doublets have also been extended up to higher spins in recent experimental studies.

From our analysis of recent experimental data pertaining to GM doublets, we observed that, there are total 12 GM doublets which have more than five experimentally observed energy levels. Among these 12 GM doublets only 08 GM doublets shows signature splitting and sometimes

[2]Present Address: Department of Physics, Akal University, Talwandi Sabo, Bathinda

signature inversion. Further a careful inspection of experimental data pertains to 08 GM doublets revels a special feature i.e. low-K member of GM doublets exhibit signature splitting throughout observed spin range whereas high-K members show pronounced staggering at higher spin only.

In order to understand the above said feature of low-K and high-K members of GM doublets, we performed TQPRM calculations of total five GM doublets. These doublets are observed in ^{162}Ho, ^{164}Ho and ^{164}Tm nuclides and are based on two different configurations namely, $7/2[523]_\pi \otimes 5/2[642]_\nu$ and $7/2[523]_\pi \otimes 5/2[523]_\nu$ [11-13]. Our model calculations successfully reproduced the magnitude as well as phase of signature splitting in these GM doublets. On the basis of present TQPRM calculations, we suggested that, the signature splitting of low-K members which are based on the $7/2[523]_\pi \otimes 5/2[642]_\nu$ configuration, are mainly influenced by Coriolis coupling (ΔK=1). But in case of high-K members, the Coriolis (ΔK=1) as well as particle-particle couplings (ΔK=0) plays a major role in explaining the observed signature splitting [14-16].

In case of $K^\pi = 1^-$: $7/2[523]_\pi \otimes 5/2[642]_\nu$ GM partner observed in ^{164}Tm nuclide, the change in phase of oscillations before and after the point of inversion, which could not be explained in the earlier calculations [13] is also successfully reproduced [14,16]. We suggest that Newby shifted $K^\pi = 0^-$: $7/2[523]_\pi \otimes 7/2[633]_\nu$ band is responsible for above said change in phase of oscillations [14,16].

Finally, the rotational structure of some 2qp rotational bands observed in tantalum nuclides namely ^{180}Ta [17,18] and ^{182}Ta [19] have been explored. Among all these 2qp rotational bands observed in both the above said nuclides, there are only four rotational bands namely, $K^\pi=1^+$: $7/2[404]_\pi \otimes 9/2[624]_\nu$ and $K^\pi=0^-$:$9/2[514]_\pi \otimes 9/2[624]_\nu$ observed in ^{180}Ta [17,18] and $K^\pi= 0^-$: $7/2[404]_\pi \otimes 7/2[503]_\nu$, $K^\pi=1^-$: $5/2[402]_\pi \otimes 3/2[512]_\nu$ observed in ^{182}Ta [19] shows pronounced signature splitting and hence examined through present TQPRM approach. On the basis of good agreement among experimental and theoretical results, we successfully explained observed signature splitting in above said 2qp rotational bands [20,21]. Additionally, the ambiguity regarding placement of 12^+ level [17,18] observed in the $K^\pi=1^+$: $7/2[404]_\pi \otimes 9/2[624]_\nu$ rotational band of ^{180}Ta is also resolved. The Newby shift energies of some rotational bands of ^{180}Ta and ^{182}Ta nuclides are also estimated. On the basis of present calculations [20,21], we confirmed the tentative spin, parity and configuration assignments to $K^\pi=0^-$:$7/2[404]_\pi \otimes 7/2[503]_\nu$ and $K^\pi=1^+$: $7/2[404]_\pi \otimes 9/2[624]_\nu$ rotational bands of ^{182}Ta nuclide.

In summary, the signature effects observed in eight odd-odd deformed nuclides are explored using TQPRM approach and some critical issues regarding violation of GM rules, tentative spin and configuration assignment are also addressed.

Acknowledgements

I would like to thank my supervisor Dr. Sukhjeet Singh Dhindsa, Akal University, Talwandi Sabo, for his immense support and Prof. A.K. Jain, IIT Roorkee for his invaluable suggestions. The financial support from MM University, Mullana, DST Govt. of India and IAEA, Austria is gratefully acknowledged.

References

[1] Bengtsson *et al.*, Nucl. Phys. A **415**, 189(1984).
[2] Lee *et al.*, Prog. Part. Nucl. Phys. **38**, 251(1997).
[3] Hamamoto *et al*, Phys. Letts. B **235**, 221(1990).
[4] Jain *et al.,* Phys. Rev. C **40**, 432(1989).
[5] Bengtsson *et al*., Nucl. Phys. A **389**, 158(1982).
[6] Pinston *et al*., Nucl. Phys. A **361**, 464(1981).
[7] Hartely *et al*., Phys. Rev. C **59**, 1171(1999).
[8] S. Kumar *et al.*, Eur. Phys. J. A **53**, 76(2017).
[9] Goel *et al*., Pramana J. Phys. **46**, 51(1996).
[10] Jain *et al.,* Rev. Mod. Phys. **70**, 843(1998).
[11] Liang *et al*., Phys. Rev. C **72**, 7301(2005).
[12] Hojman *et al*., Eur. Phys. J. A **21**, 383(2004).
[13] Reviol *et al*., Phys. Rev. C **59**, 1351(1999).
[14] S. Kumar, *et al.*, Eur. Phys. J. P. **131**, 224(2016).
[15] S. Kumar *et al.*, *Proceedings of the DAE Symp. on Nucl. Phys*. **60**, 240(2015).
[16] S. Kumar *et al.*, *Proceedings of the DAE Symp. on Nucl. Phys*. **60**, 242(2015).
[17] Saitoh *et al*., Nucl. Phys. A **660**, 121(1999).
[18] Dracoulis *et al*., Phys. Rev. C **58**, 1444(1998).
[19] Cruyce *et al*., Phys. Rev. C **20**, 504(1979).
[20] S. Kumar *et al.*, *Proceedings of the DAE Symp. on Nucl. Phys*. **58**, 138 (2013).
[21] S. Kumar *et al*., Pramana J. Phys. **87**, 14(2016).