Study of evolution of energetically favored collectivity and hindered isomeric states in the $A \approx 90$ region

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NIDHI GOEL

Under the supervision of

Dr. Somnath Nag

DEPARTMENT OF PHYSICS
INDIAN INSTITUTE OF TECHNOLOGY
BANARAS HINDU UNIVERSITY
VARANASI - 221005

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Chapter 7

Conclusions and Future Perspectives

7.1 Summary of contributions and conclusions

The present thesis probes into the structural aspects of nuclei in $A \approx 90$. The motivation behind the present work comes from the existence similar valence Fermi space in $A \approx 90$ as that of $A \approx 150$, and 200, where hindered decays and collectivity based on different rotation mechanism have already been reported. A justified comparison of the nuclei in these different mass regions with similar nucleonic occupancy across similar high- and low-j orbitals should help in successful prediction of nuclear phenomena.

The thesis addresses the hindered transitions and favored collectivity in ^{92}Nb and ^{93}Nb. These nuclei were populated using heavy-ion fusion reactions. The nuclei were studied with INGA spectrometer using reactions ^{80}Se(^{18}O, $p5n/p4n$)$^{92-93}$Nb, Detailed level schemes with spin-parity assignment of the levels were produced for above mentioned nuclei. The overall new findings along with the verification of the earlier results have been summarized below.

The half-life of the long-lived 9^- state at 2087.3 keV in odd-odd ^{92}Nb was measured to be 35.8(24) ns for the first time. The 9^- state $E2$ decays to the lower-lying 7^- state, controlling the isomeric nature due to low gamma decay energy with a $B(E2)$ value of 26.3(17) $e^2 fm^4$. The 9^- isomer also $M2/E3$ decays to the 7^+ ground state via a strong gamma feeding. As stated in the introduction section, $M2/E3$ isomers in $A \approx 210$ and 150 highlights the effect of valence space around the magic closure and the existence of isomeric states dominated by particle-phonon coupling. Hence, the similarity in the Fermi space with that of $A \approx 90$ has resulted in existence of similar type of isomeric state in ^{92}Nb.

The shell model calculations using a ^{78}Ni core, referred to as Set1, provided a reasonable agreement with the experimental level scheme. However, potential improvements using core excitation may be required to address the discrepancies in negative parity levels. A more stubborn mechanism was further applied to refine the calculated results which includes 3p-3h proton and 1p-1h neutron excitation below ^{78}Ni, referred to as Set2. The inclusion of proton core excitation either from $\pi(f_{7/2})$ below Z=28, neutron core excitation from $\nu(g_{9/2})$ below N=50 affected the negative-parity levels. To be precise, the location and nucleonic configuration for the 7_2^- level has been influenced.

The present work also provides a testing ground for the average effective charges proposed by Brown *et al.* which could effectively predict the half-lives of $13/2^-$ and 11^- isomeric states in ^{91}Nb and ^{92}Nb, respectively. The shell model calculated $B(E2)$ values for 9_1^- isomeric level to the 7_1^- level using both sets overestimated the $B(E2)$ values and supported a nanosecond isomer only when the measured gap was used. The large-scale shell model calculations from both sets supported a four-quasiparticle isomeric configuration for the 9^- state involving three protons from $g_{9/2}$ and $p_{1/2}$ orbitals and one neutron from $d_{5/2}$ and highlighted the dependence of isomeric lifetime on the wavefunction of 7^- state to which isomeric 9^- state $E2$ decays.

The isomeric state with nano second order of lifetime may not be quite promising in terms of nuclear astrophysical studies. However, the search for isomers which can be potential astromers should continue in order to build up a better understanding of the nucleosynthesis phenomenon.

Low-spin isomers with comparatively longer lifetimes may be promising candidates for nucleosynthesis based study, whereas medium or high-spin isomers, mostly being the pure states, can provide a testing ground for formulating nucleon-nucleon interaction strength by the theoretical groups. Along a similar line of discussion, ^{93}Nb is the neighboring nucleus where the existence of a high-spin isomeric state was already estimated in earlier literature. Within the constraints of our methodologies and available data, we could not confirm the existence of the reported isomer. On the other hand, we tried to make sure that the isomer does not exist within the scope of the level scheme under consideration.

The dipole band based on enhanced $M1$ transitions was verified and re-investigated through the lifetime measurement of the corresponding levels using DSAM. The constancy in the measured reduced transition probabilities as a function of angular momentum indicates the absence of a magnetic rotational band. Though, the dipole band is characterized by the enhanced magnetic nature. Extensive calculations were performed in the framework of CNS to show that the dipole band evolves with triaxial shape which is contrary to the earlier prediction of collective oblate shape.

In addition, the previously reported level scheme of ^{93}Nb has been rearranged owing to the observation of several high-energy γ transitions decaying from single-particle excited states to the aligned or anti-aligned states in the ground state band. Such transitions are the outcome of neutron and proton core-excited configurations. Lifetimes were also measured for some of the $E2$ transitions in the ground state band.

The evolution of collectivity at high-spin through enhanced magnetic transitions in ^{93}Nb, akin to ^{89}Zr and ^{90}Y has motivated us to probe ^{92}Nb, which was already explored for the existence of low-spin isomers. The level scheme of ^{92}Nb has been extended by the placement of twenty-nine new transitions and replacing a few already reported transitions. A couple of already observed dipole bands have been placed and connected to the ground band. Further, a new dipole band has been placed. In particular, band 1 has been shown to feed on low-spin levels. Spins and parities assignment has been done through measurement of ADO ratios and polarization asymmetries of γ rays. Feasible configurations of band 1 and the newly observed band 2 are discussed within the framework of both the shell model calculations and CNS model. According to the CNS calculations, the lowest-energy configuration which can explain band 1 and band 2 are built with four protons in $\mathrm{g}_{9/2}$ orbital and two neutrons excited across the N = 50 shell gap to gd shells, i.e., [34;12]. Detailed calculations show that the configuration [34;12] represents the triaxial shape for most of the observed spin range with $\gamma \approx$ -20°, $\varepsilon_2 \approx 0.15$. On the other hand, the shell model results predict a configuration based on completely filled $g_{9/2}$ neutron orbitals for both band1 and band2, respectively. This may be attributed to the lack of pairing interaction in the CNS model.

Thus, observation of dipole bands in nuclei neighboring to semi-magic core in $A \approx 90$ may be considered as the result of a similar Fermi level distribution as observed in $A \approx 150$ where evolution of similar collective bands was reported, especially in ^{142}Gd. However, a difference between these two mass regions is the absence of the $E2$ crossovers in $A \approx 90$ nuclei. The enhancement of $M1$ transition rates may be due to tilted axis rotation.

7.2 Future perspectives

- The $A \approx 90$ region is enriched with nuclei which may have many more unreported isomers. The mass region will be probed for the existence of low and high-spin isomers in neighbouring nuclei.

- The existence of a dipole band at medium and high-spin regimes has been reported in various nuclei in this mass region. However, lifetime measurements have been done in the case of only a few nuclei, which ascertain the constancy of $B(M1)$ over the spin range of the dipole band. Hence, lifetime measurement based experiments may be planned for other nuclei where such bands are already observed in order to build up a comprehensive understanding.

- It is speculated that enhanced $M1$ character in such bands is an outcome of tilted axis rotation. A detailed theoretical approach may be pursued to study such a phenomenon.

- The high-spin rotational bands have been extensively studied using the cranked Nilsson Strutinsky model which is a macroscopic model and independent of pairing. Such analysis in the concerned nuclei included in this thesis has helped to remove discrepancies from previously reported results. Such model calculations may be performed for other nuclei which can be helpful in preparing a detailed map of nuclei undergoing rotation about the longest, intermediate and shortest principal axis.