Exotic phenomena in triaxial odd–odd nuclei

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An atomic nucleus is an excellent laboratory to probe the laws of nature. It is a many-body system comprising of protons and neutrons held tightly by the strong interaction, the form of which is still elusive. The advents of more powerful experimental facilities have challenged our understanding of the nucleus at all resolutions. As a result, the so-called "common properties" of all nuclei are no more accurate. Instead, these are understood as the properties of the stable nuclei. Moving away from the stability region, several unique, complex, and fascinating phenomena stimulate our quest for understanding.

In the shell closure regions, most of the nuclei are spherical. But moving away from the shell closures, different kinds of deformation start playing crucial roles. The energy spectra of nuclei play a key role in understanding the role of deformation. The existence of spherical symmetry breaking [1], known as axial deformation, is well established through the studies of rotational bands. The axial symmetry breaking, *i.e.*, the triaxial deformation, is manifested through several phenomena, like the wobbling motion and chiral symmetry breaking. Many proton emitters, for example, ^{108,109}I, ^{140,141}Ho, also display the presence of triaxial deformation. In the present work, we study the role of triaxial deformation in odd–odd nuclei, which render the proton emission phenomenon and chiral symmetry breaking.

Several theoretical models — macroscopic as well as microscopic — have been developed to calculate the decay width of the proton emission from the spherical and deformed nuclei. The nonadiabatic quasiparticle approach, which is the state-of-the-art approach for the proton emission study has been very successful in explaining the measurements from the deformed odd-A and odd–odd nuclei along with the triaxial odd-A nuclei. To the best of our knowledge, there is no microscopic approach to study proton emitters, which can take into account the triaxiality in odd–odd nuclei. In this work, we develop [2, 3] the first such microscopic approach for odd–odd nuclei, which considers the residual neutron–proton interaction in reliable ways apart from the triaxiality.

To explore the exotic nuclei, the present work is dedicated to develop a theoretical approach named the nonadiabatic quasiparticle approach [2] to study the triaxial odd–odd nuclei. The nucleus is treated as a system of even–even core coupled to the valence proton and neutron. We incorporate the experimental data of the core, which, in turn, leads to freedom from several freely adjustable parameters, unlike the conventional particle rotor model [1]. Furthermore, the matrix elements of the Hamiltonian of the system are calculated with angular momentum coupling algebra rather than expressing them with a moment of inertia that brings in a semiclassical approximation. With such tools, the derivations are more robust and easily extendable to microscopic approach.

The valence proton and neutron are treated in a mean-field potential in the form of triaxial Woods–Saxon potential with spin–orbit and Coulomb interaction. We consider the residual pairing interaction within the BCS approach. In the odd–odd system, the lowest-lying levels are highly sensitive to the interaction between valence proton and neutron. The phenomenological nucleon–nucleon interaction has several terms with tunable parameters. These parameters are tuned for a particular mass region utilizing the available data. However, in the proton drip-line region of our

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interest, the data are very scarce. Therefore, we need to incorporate the residual neutron–proton interaction in reliable forms having the least number of tunable parameters. Consequently, we incorporate such interaction in two forms, namely, 1) central (zero-range) potential form and 2) constant potential form.

To validate the formalism developed, first we apply it to study the nuclei close to β-stability region, where enough data are available. We apply our approach to investigate the two positive parity $\Delta I = 1$ bands and a negative parity $\Delta I = 2$ band in ^{138}Pm [2]. The data are well reproduced in expected manners with both the forms of interaction, and hence validates our formalism.

After successfully applying the developed approach in β-stability region, we investigate the structure and decay properties of the exotic nuclei in the proton drip-line region. We study the recently observed proton emitter ^{108}I [4], which enables studies of possible paths in the end-cycle of the astrophysical *rp* process. Based on the agreement with the measured half-life, the ground state spin and parity are assigned to be 1^+, analyzing the important role of residual neutron-proton interaction. Another proton emitter ^{140}Ho, whose nearby nuclei are found to be triaxial, is also explored.

The fine structure in proton emission is an even more powerful tool to get insight into the properties of these exotic nuclei. We explore the fine structure in ^{144}Tm, which is an odd–odd nucleus, and its neighboring nuclei are suggested to be triaxially deformed. Based on the agreement of results with the measured half-life and branching ratio, the ^{144}Tm is found to be highly triaxial with $\gamma \approx 30°$. Reproducing the present data allows us to unambiguously assign the ground state spin and parity of ^{144}Tm to be 9^+ [6].

We explore another exotic phenomenon in triaxial odd–odd nuclei, that is, the chiral symmetry identifiable through the nearly degenerate same parity bands. We present the first theoretical description of chiral bands in ^{138}Pm [3]. The chiral bands in nearby nucleus ^{136}Pm are also investigated through azimuthal plots and K-plots for the first time. These bands in both nuclei are found to be of vibrational nature. We further investigate the nuclei in the $A \approx 130$ region exhibiting chirality [5]. We find ^{128}Cs, ^{130}Cs, and ^{130}La of special interest. The static chirality has not been observed in ^{128}Cs in disagreement with earlier studies. Based on our investigation through several properties, ^{130}Cs qualifies for a better example of chirality than ^{128}Cs.

The scheme of calculations presented emphasizes the importance of a proper treatment of nonadiabatic effects in several scenarios. The neighboring nuclei of ^{108}I deciding the path of the *rp* process might also have mixed configuration states, and hence may require a nonadiabatic treatment. Furthermore, as learned from the investigation of ^{128}Cs, inappropriate treatment of mixing of several configurations might lead to misleading conclusions. This thesis work has led to a more inclusive and robust tool for studying the structure and some decay properties of nuclei including those away from the stable nuclei. This tool can explain several existing data and can guide the future experiments regarding the rotational spectra, electromagnetic transitions and proton emission.

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