Microscopic description of triaxially deformed proton emitters

Swati Modi*
Department of Physics, Indian Institute of Technology Roorkee, Uttarakhand - 247667, India.

To improve our understanding of the nuclei and nuclear interaction, it is necessary to study a variety of nuclei. There are more proton rich nuclei experimentally known than the neutron rich nuclei. It is comparatively easy to synthesise proton rich nuclei, e.g. in fusion-evaporation reactions, because of their isospin.

In a theoretical perspective, explaining the properties of exotic systems are quite challenging because our knowledge about the basic ingredients of nuclear interaction is still rudimentary. We undertake such a challenging investigation pertaining to proton emitting nuclei with the aid of available data. Apart from building a robust nuclear model, this task is motivated by other crucial implications of proton emitters in nucleosynthesis and in astrophysics. Proton rich nuclei in the mass region $60 < A < 110$ take part in the stellar nucleosynthesis during explosive hydrogen burning in a very hot and dense stellar environment through the rapid proton (rp) capture process. The rp-process follows the path of nuclei near to $N = Z$, which is quite nearer to proton drip line and in a few cases it gives rise to the type 1 x-ray bursts. The proton emitters exhibit many interesting structural and decay properties like large quadrupole and triaxial deformations and decay by direct emission of charged particles with large Q values.

Various theoretical approaches have been introduced to investigate the proton emitters. In a macroscopic approach, the models based on WKB method are widely used. In this approach, the proton emission is treated semiclassically as a tunneling through the Coulomb barrier created by the electrostatic interaction between the proton and the core.

*Electronic address: swatimodi2@gmail.com

Detailed information, including the configuration of the proton emitting nuclei, is obtained through microscopic studies. In the microscopic approach for deformed proton emitters, we calculate the decay width from the overlap of parent (particle+rotor) and daughter (rotor) wave functions. In this regard, with the inclusion of Coriolis interaction the nonadiabatic quasiparticle approach is quite successful to unveil the structure and decay properties of proton emitters. For the particle+rotor system, the conventional particle-rotor model (PRM) assumes a moment of inertia rendering the method with a semiclassical component.

An important aspect of this thesis work is the formulation of a fully microscopic nonadiabatic approach. We have developed a microscopic approach for rotation-particle coupling in triaxial nuclei without the explicit use of the moment of inertia. We have termed this approach as modified particle-rotor model (MPRM) [1]. In this approach, the matrix elements (ME) of the rotational Hamiltonian of an odd-A nucleus is written in terms of the ME of the rotor states through angular momentum couplings.

Our formalism can be explained better in three parts, viz., 1) Mean field of nucleons, 2) Rotation-particle coupling and 3) Decay width for proton emission. The nuclear mean field is chosen to be of Woods-Saxon type with triaxial deformation. The rotation-particle coupling is treated microscopically by coupling the triaxial rotor states of the even-even core with the states of the valence particle in order to obtain the matrix elements of the odd-A system. The decay width is derived in terms of the overlap between the initial (parent nucleus) and final (daughter and proton) states wave functions.

We bring out the advantages of MPRM over the conventional PRM with a fixed or variable moment of inertia. One clear evidence favoring our approach is the rotation alignment phenomenon which we discuss for the β-stable nuclei. We have successfully explained the ground and side bands in the nuclei ^{137}Pr, ^{137}Pm and ^{139}Eu and their corresponding cores ^{136}Ce, ^{136}Nd and ^{138}Sm with our MPRM. In the cases of ^{137}Pm and ^{139}Eu, the relative energy difference between two bands arising from the same configuration [2] is obtained. After validating MPRM for β-stable nuclei we proceed to study structural and decay properties of exotic nuclei where the data is scarce.

The primary focus of our work is to extend the MPRM to study the role of triaxial deformation in the proton emitting nuclei. We consider the decay of odd-A nuclei where the initial state (parent) wave functions are calculated through the MPRM and the final state wave functions correspond to that of the proton (Coulomb wave functions, asymptotically) and the even-even rotor (Wigner matrix). The decay width of proton emission is calculated through the overlap of the initial and final state wave functions.

We have applied our formalism to study rotational spectra and proton emission from the nuclei ^{109}I, ^{141}Ho, ^{145}Tm and ^{147}Tm [3] and discuss the role of triaxial deformation. Without assuming an exact single-particle state from which the decay could happen, we could explain the experimentally observed half-lives in all these nuclei. For the considered nuclei, the ground state spin and parity have been confirmed or reassigned with the aid of the measured proton emission half-lives. With this approach, we can unambiguously determine the configuration of nuclei where the spectroscopic data could be explained in many ways.

In the case of ^{109}I, we get a good agreement with experimental data for both the positive and negative parity bands using the same set of deformation parameters. We have observed that the positive parity band has a strong contribution from $1g_{7/2}$ and $2d_{5/2}$ states. The configuration for negative parity band is predominantly $1h_{11/2}$. In ^{109}I, the comparison of calculated proton emission half-life with data enables us to conclude unambiguously that the proton is emitted from the $3/2^+$ state originating from the admixture of $1g_{7/2}$ and $2d_{5/2}$ states [4]. Similar analysis has been carried out for the proton emitters ^{141}Ho, ^{145}Tm and ^{147}Tm.

We conclude that we have developed a microscopic nonadiabatic quasiparticle approach (MPRM) for the rotation-particle coupling in triaxially deformed odd-A nuclei. The rotation-particle coupling is carried out by expressing the matrix elements of the odd-A nucleus in terms of the measured energies of the rotor. After validating the MPRM for nuclei close to stability region, the extension to drip line is carried out. We have studied triaxial proton emitters and described their rotational spectra and decay width. MPRM is an excellent approach to study triaxiality in nuclei. We could successfully explain the spectra of the parent and daughter, and also the decay width, in a unified way which enables us to establish the configuration of the rotational bands and the decaying state. MPRM is quite suitable to study the low-lying states of the exotic nuclei where the data is scarce.

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