Proton emission and triaxialilty in ^{147}Tm

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Introduction

To improve our understanding of the nuclear interaction and to explore the related applications, it is important to study structure and decay properties of variety of nuclei. The nuclei at proton drip-line mostly decay by proton emission which is a very interesting example of quantum mechanical tunneling through the Coulomb barrier. The associated half-lives range from nanoseconds to seconds. In many cases, the rotational spectra are also measured in coincidence with the proton emission. Hence a rich information about the structure and decay is available for these exotic nuclei far from stability.

We theoretically investigate the structure and decay properties of triaxially deformed proton emitting nuclei within a microscopic nonadiabatic quasiparticle approach utilizing the experimental core energies. This is a fully quantum mechanical approach where we need not assume a (semi-classical) moment of inertia. We have termed this approach as modified particle-rotor model (MPRM)[1].

Formalism

Hamiltonian for the triaxially deformed particle-plus-rotor system is given by

$$H = H_{\rm av} + H_{\rm pair} + H_{\rm rot}, \tag{1}$$

where eigenvalue of $H_{\rm av} + H_{\rm pair}$ corresponds to quasiparticle energy ϵ_q. The Hamiltonian for a triaxial rotor is given by $H_{\rm rot} = \sum_{k=1,2,3} \frac{\hbar^2 R_k^2}{2\mathcal{I}_k}$, with angular momentum R and moment of inertia $\mathcal{I}$. The wavefunction of this system at position $\vec{r}$ and orientation ω can be written by [2]

$$\Psi_{IM}(\vec{r},\omega) = \sum_{ljR\tau} \frac{\phi^I_{ljR\tau}(r)}{r} |ljR\tau, IM\rangle, \tag{2}$$

where I is the total angular momentum of the particle-plus-rotor system with M and K its projections on z-axis (laboratory frame) and third axis (body-fixed frame), respectively. l and j are the orbital and total angular momenta of the particle.

The matrix elements of the rotor Hamiltonian in K representation can be written as

$$\begin{aligned}\langle lj\Omega_{p'}K', IM|H_{\rm rot}|lj\Omega_p K, IM\rangle = \\ \sum_{RK_{R'}K_R} A^{IK'}_{j\Omega_{p'}RK_{R'}} \sum_i c^{Ri}_{K_{R'}} E_{TRi} c^{Ri}_{K_R} A^{IK}_{j\Omega_p RK_R}, \\ = W^{K'K}_{j\Omega_{p'}\Omega_p}. \end{aligned} \tag{3}$$

Here, Ω is the projection of j and K_R is the projection of R. Amplitude A is used to transform the matrix elements from R representation to K representation. The quantity E_{TRi} represents the total energy of rotor. For a given value of R, i labels the different eigenstates with $c^{Ri}_{K_R}$ specifying the contribution of each K_R. The matrix elements for the total Hamiltonian H (1) can be written in terms of the coupling matrix W (3) as

$$\begin{aligned}\langle q'K', IM|H|qK, IM\rangle = \epsilon_q\ \delta_{K'K}\delta_{q'q} \\ + \sum_{lj\Omega_{p'}\Omega_p} W^{K'K}_{j\Omega_{p'}\Omega_p} \times \int dr f_{uv} \phi^{IK'*}_{lj\Omega_{p'}}(r)\phi^{IK}_{lj\Omega_p}(r). \end{aligned} \tag{4}$$

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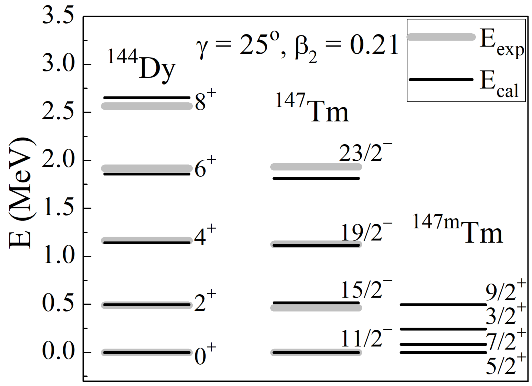

FIG. 1: Rotational spectra of ^{144}Dy and ^{147}Tm calculated by using modified particle-rotor model. The grey lines correspond to the experimental spectra for ^{144}Dy [4] and ^{147}Tm [5].

Here, f_{uv} is the factor to transform the matrix elements from particle states to quasiparticle states. Single-particle occupation and unoccupation probabilities are given by v and u, respectively.

With the wavefunction of the particle-plus-rotor system calculated from Eq. (4), the decay width for the triaxial odd-A nucleus can be calculated from the relation given in Ref. [3].

Results

We have calculated the structure and decay properties of triaxially deformed proton emitter ^{147}Tm with MPRM. Both the ground and isomeric states of ^{147}Tm are proton emitting states [6]. The experimental data of its core ^{146}Er is not available. We use the data of next nearest core ^{144}Dy in the particle-plus-rotor calculations with MPRM. In Fig. 1, the rotational spectra of negative parity ground and positive parity isomeric states of ^{147}Tm with rotor ^{144}Dy are presented. The better agreement of the calculated results with the experimental data are obtained at triaxial deformation $\gamma = 25°$ and quadrupole deformation $\beta_2 = 0.21$. The signature partner of negative parity ground state band is also observed and we have reproduced this band with our MPRM. A gamma transition of 587 keV is observed in Argonne National Laboratory [6] between the two isomeric states of ^{147}Tm by using the recoil decay tagging method. The angular momentum of those isomeric states are not reliably assigned. We have successfully reproduced the decay width of ground state proton emission from $11/2^-$ state with MPRM. The calculated decay width from both the isomeric states $3/2^+$ and $5/2^+$ corresponds to the observed data for the lower triaxiality ($\gamma \lesssim 30°$). For $\gamma \gtrsim 30°$, decay width calculated for $3/2^+$ state goes away form the experimental data. From Fig. 1, it can be observed that $5/2^+$ is the lowest energy state and also the energy difference between the $5/2^+$ and $9/2^+$ states corresponds to the observed gamma.

Conclusion

With MPRM we could successfully reproduced the rotational spectra of proton emitting parent ^{147}Tm with its core ^{144}Dy. The angular momentum states $11/2^-$ and $5/2^+$ can be assigned unambiguously as the proton emitting ground and isomeric states, respectively for the triaxial nucleus ^{147}Tm.

Acknowledgments

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