Nonadiabatic quasiparticle approach for neutron-rich nuclei

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Introduction

In the neutron-rich region with $A \sim 100$ and $Z \sim 40$, the shape transition from spherical to large quadrupole and triaxial deformation has long been of a major interest [1]. The properties of these nuclei also play a vital role in the calculations pertaining to astrophysical nucleosynthesis throgh the r-process. In the case of Tc isotopes in neutron-rich region, the proton Fermi level changes as the neutron number increases. The Fermi level for lighter isotopes ^{97,99}Tc is close to $1/2^+$ and $3/2^+$ states of $g_{9/2}$ orbital with a small deformation. However, for more neutron rich isotopes $^{107-111}$Tc, Fermi level approaches the $5/2^+$ state with larger deformation. Thus in an isotopic chain, as neutron number increases, the coupling scheme changes from weak to strong and hence the ground state band with their signature partners can be observed. The rigid triaxial rotor plus particle model calculations [1] suggest that the triaxiality also increases with the neutron number. In the present work, microscopic rotation-particle coupling model [2] is utilised to investigate ^{111}Tc with its non-rigid rotor ^{110}Mo. The effect of triaxial deformation γ on the structural properties of these neutron-rich nuclei is highlighted.

Formalism

The wave function of an odd-A nucleus is given by

$$\Psi_{IM}(\vec{r},\omega) = \sum_{ljR\tau} \frac{\phi^I_{ljR\tau}(r)}{r} |ljR\tau, IM\rangle, \quad (1)$$

where the quantum numbers (I, M, K) correspond to the particle-plus-rotor system, (l, j, Ω) are related to the particle and (R, K_R, M_R) correspond to rotor [2]. $\phi^I_{ljR\tau}(r)$ and $|ljR\tau, IM\rangle$ are the radial and angular parts of the wave function, respectively.

The total Hamiltonian reads

$$H = H_{\rm avg} + H_{\rm pair} + H_{\rm rot} \ , \quad (2)$$

where $H_{\rm avg}$ corresponds to the intrinsic energy of the odd particle. The pairing interaction is given by $H_{\rm pair}$, and $H_{\rm rot}$ is the rotor Hamiltonian. The matrix element of $H_{\rm rot}$ can be written in K-representation by utilizing the experimental rotor energies E_{TRi} and the calculated wave functions $c^{Ri}_{K_R}$ as [2]

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

Here, the rotor wave functions and the unobserved rotor energies are calculated through variable moment of inertia (VMI) method [2]. The amplitude $A^{IK}_{j\Omega_p,RK_R}$ correspond to the transformation of the wave function from R-representation to K-representation and vice versa. The matrix element of the total Hamiltonian H can be written as

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

where q defines the particle state and ϵ_q is the quasiparticle energy. The quantity f_{uv} is used to transform the matrix element from single-particle states to quasiparticle states. Here we have employed the universal set of parameters [3] for the mean field potential of Woods-Saxon form.

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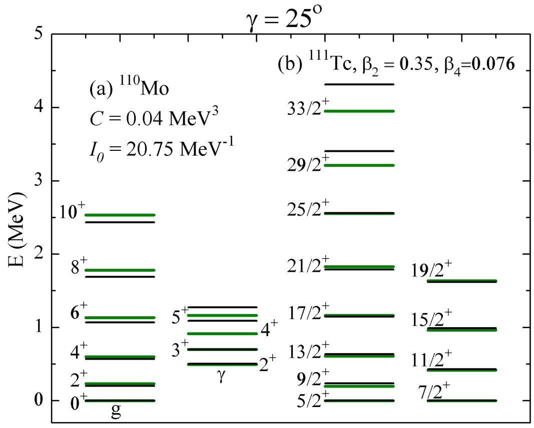

FIG. 1: Rotational spectra of ^{110}Mo and ^{111}Tc calculated within the microscopic nonadiabatic quasiparticle approach. The green lines correspond to the experimental spectra for ^{110}Mo [5] and ^{111}Tc [1].

Results

The neutron rich nucleus ^{111}Tc and its rotor ^{110}Mo are studied with microscopic nonadiabatic quasiparticle approach. In the rotor ^{110}Mo, experimental finding of second 2^+ state lower than the first 4^+ state suggests the enhanced axial asymmetry or γ deformation [5]. With the Grodzins formula the quadrupole deformation for ^{110}Mo nucleus is calculated as 0.31 [6]. A considerable γ deformation is also assured from the newly observed gamma band at a lower energy. The best agreement between our model and data is achieved at the value of triaxial deformation, $\gamma = 25°$. The experimental data and calculated results for ^{110}Mo are presented in Fig. 1(a). The corresponding VMI parameters are $C = 0.04$ MeV^3 and $\mathcal{I}_0 = 20.27$ MeV^{-1}. Since the configurations of the ground and gamma bands are same, the energy difference between their band-heads are reproduced well by our calculations.

With the rotation particle coupling, the energy spectra of the particle-plus-rotor system ^{111}Tc is calculated and the corresponding results are presented in Fig. 1(b). The low lying states of ground state band built on $5/2^+$ are successfully reproduced at $\beta_2 = 0.35$, $\beta_4 = 0.076$ and $\gamma = 25°$. The high angular momentum states are not in a good agreement with the data [1] which indicates shape change of the nucleus with rotation. The side band of ^{111}Tc built on $7/2^+$ is also presented in Fig. 1(b) which depicts good correspondence with the data. Both the ground state band and side band of ^{111}Tc have predominant contributions from the $2d_{5/2}$ and $1g_{9/2}$ orbitals.

Conclusion

With the microscopic nonadiabatic quasiparticle approach we could successfully reproduce the ground state band and side band of neutron rich nucleus ^{111}Tc with its core ^{110}Mo at $\gamma = 25°$. The quadrupole deformation $\beta_2 = 0.35$ turns out to be for ^{111}Tc. Orbitals $2d_{5/2}$ and $1g_{9/2}$ have maximum contribution in the configuration of ground and side bands of ^{111}Tc.

Acknowledgments

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