Non-adiabatic approach for odd-odd proton emitters

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Introduction

The structure of heavy nuclei near the proton drip line remains less explored yet interesting area of research from both experimental and theoretical perspectives. In many cases, even the ground state spin and parity of nuclei are not known. Many of these nuclei decay by emitting a proton where the proton is bound only by the coulomb barrier. It is well established [1–3] that decay from deformed nuclei proceeds from a single-particle Nilsson resonance of the unbound proton with respect to the core, generated by the Coulomb and centrifugal barriers. However it is important to consider the nonadiabatic effects, which take care of the rotational excitations of the daughter nucleus, through the Coriolis interaction in a particle-plus-rotor model approach. A proper treatment of the pairing residual interaction [1] provides a more complete and consistent description of proton emission in agreement with the experimental data.

The nonadiabatic effects which play crucial role in our calculations, are considered so far in the case of odd-even nuclei only and the odd-odd nuclei were studied [2] within the strong coupling limit. Odd-odd nuclei are more interesting due to the complications involved in the coupling of the proton as well as neutron with the core [4, 5]. However, this area is least explored [5] and hence the theoretical study of the structure of these nuclei has not been carried out extensively despite rich experimental data being available. In the present work we undertake the important task of formulating a proper theoretical framework comprising the Coriolis interaction, to study proton emission from odd-odd deformed nuclei. We also discuss our preliminary results in the case of ^{112}Cs.

Theoretical framework

We have used the two quasiparticle plus rotor model(TQPRM)[4,5] based on the mean field defined by Woods-Saxon potential along with a deformed spin-orbit term. The residual pairing interactions are considered within constant gap BCS approach, where the pairing gap of $12/\sqrt{A}$ MeV is used. The complete Hamiltonian can be expressed as a sum of intrinsic part and rotational part, where the former gives the single-particle energies, and latter consists of a sum of various terms as shown below:

$$H_{rot} = \frac{\hbar^2}{2\Im}(I^2 - I_z^2) + H_{cor} + H_{ppc} + H_{irrot},$$

where

$$\begin{aligned} H_{cor} &= -\frac{\hbar^2}{2\Im}(I^+J^- + I^-J^+)\,, \\ H_{ppc} &= \frac{\hbar^2}{2\Im}(j_p^+j_n^- + j_p^-j_n^+)\,, \\ H_{irrot} &= \frac{\hbar^2}{2\Im}\left[(j_p^2 - j_{p_z}^2) + (j_n^2 - j_{n_z}^2)\right]. \end{aligned}$$

The symbols used have their usual meaning. The variable moment of inertia (VMI) $\Im$, is defined as $\Im(I) = \Im_0\sqrt{1 + b\ I(I+1)}$, b is the VMI parameter, and the constant $\Im_0$ is evaluate by using the energy of first 2^+-state in the neighbouring even-even nucleus. The total

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Hamiltonian is then, diagonalised to obtained mixing coefficients of the parent nucleus wavefunction. The overlap of the parent wavefunction with the final state (coupled state of of daughter and emitted proton) wavefunction gives, the partial decay width as given below:

$$\Gamma^{I,I_d}_{l_p j_p} = \frac{\hbar^2 k}{\mu} \left| \sum_{K_n,K_p} \alpha^{I,M}_{K_T,K_n,K_p} \, \beta^{I_d,M_d}_{K_n} u_{K_p} \right.$$
$$\left. \times \sqrt{\frac{(2I_d+1)}{(2I+1)}} \langle I_d, K_n, j_p, K_p | I, K_T \rangle N^{K_p}_{l_p j_p} \right|^2 ,$$

where α and β are mixing coefficients of parent and daughter nuclear wave functions respectively, $N^{K_p}_{l_p j_p} = \frac{\phi^p_{j_p,K_p}(r)}{G_{l_p}+iF_{l_p}}$ represents asymptotic normalization along with F and G as regular and irregular Coulomb wave functions, u_{K_p} is the spectroscopic factor calculated from BCS approach and hence $u^2_{K_p}$ represents the probability of unoccupancy of proton level in daughter nucleus, $\phi^p_{j_p,K_p}(r)$ is radial wavefunction of emitted proton. Total decay width is obtained by summing all partial decay widths over all possible l_p and j_p combinations.

Result and Discussion

We studied the case of ^{112}Cs nucleus for which adiabatic calculations were already reported [2]. As a first check to our code, we have reproduced all adiabatic calculations. We have obtained VMI parameter as 0.1, and $\Im_0$ is evaluated by taking E^{2+} of 469.7 KeV from the ^{110}Xe core. The energy levels close to the Fermi energy contribute actively in level mixing. As same set of levels appear near Fermi surface for both proton and neutron coincidently, we have considered following same levels 3/2[422], 5/2[413], 3/2[411], 1/2[420] for mixing. The spin of ground state for the daughter nucleus is fixed by looking into minimum of energy for the combination of various spins and parity, under nonadiabatic quasiparticle approach. Least energy state is examined at $\beta_2 = 0.20$ (as suggested by Moller and Nix), comes out to be $3/2^+$ for the daughter nucleus ^{111}Xe.

We have done preliminary calculations for the probable ground state spin $I^\pi = 3^+$ of ^{112}Cs. Half-lives are calculated for adiabatic and non-adiabatic cases with two attenuation parameters at quadrupole deformation 0.20 and 0.22. We did calculations first for zero hexadecapole deformation and then with 0.067 as given by Moller and Nix. Blanks are left in table for the half-lives which exceed the unit of ms. Good agreement with experimental value can be seen from the table for both adiabatic and nonadiabatic calculations. We propose to further refine the calculations by introducing effect of residual interaction, which we have neglected so far.

In conclusion, we have extended the nonadiabatic approach to calculate half-lives of the odd-odd deformed proton emitters. We could reproduce the proton decay half-life of ^{112}Cs without assuming any single decaying state.

TABLE I: Calculated half-live values for ^{112}Cs in case of proton emission from $I^\pi = 3^+$ state. The experimental value is 0.5 ± 0.1ms.

	$\beta_2 = 0.20$		$\beta_2 = 0.22$	
	$\beta_4 = 0$	$\beta_4 = .067$	$\beta_4 = 0$	$\beta_4 = .067$
Adiabatic	0.459	0.475	0.529	0.541
Nonadiabatic				
$\rho = 0.5$	0.583	0.597	0.478	0.855
$\rho = 0.7$	0.683	0.889	–	–

Acknowledgments

Authors thank the CSIR, DST(Govt. of India) and FCT (Portugal) for financial support.

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