K-Selection rule violating E2 and M1 transition from K=6^+ isomers to the ground band of $^{172, 174, 176}$Hf

B. B. Sahu[1*], Z. Naik[2], and C. R. Praharaj[3†]
[1] KIIT Deemed to be University, Bhubaneswar-751 024, INDIA
[2] School of Physics, Sambalpur University, Jyotivihar, Sambalpur-768 019, INDIA
[3] Institute of Physics, Sachivalaya Marg, Bhubaneswar-751 005, INDIA
*bbsahufpy@kiit.ac.in
†crp@iopb.res.in

Introduction

The well-deformed hafnium (Hf, Z = 72) isotopes contain multiquasiparticle K- isomers, with half-lives ranging from nanoseconds to years [1]. A number of strongly deformed bands have also been observed in Hf nuclei [2, 3]. Besides deformation and the associated rotational bands long lived K isomers are important features of the rare-earth and other heavy nuclei [4,5]. Here we study the rotational bands and K isomers of some neutron-rich Hf nuclei and their properties using deformed Hartree-Fock and J projection theories. Bands built on the K isomers have also been calculated.

Theoretical Framework

To this end, we have adopted in this work the Deformed Hartree-Fock (DHF) model to get the deformed single-particle states and the deformed multi-nucleon configurations. Ground and K-isomeric intrinsic states are constructed, and for each intrinsicstate (configuration), states of good angular momenta are obtained by Angular Momentum Projection. A deformed shape such as one described by slater determinant of deformed orbits $|\Phi_K>$ is localized in angle and, by the uncertainty principle, is not a state of good angular momentum (J).Thus $|\Phi_K>$ does not have a unique J quantum number and is a superposition of various J states [6–8],

$$|\Phi_K> = \sum_I C_{IK} \,|\, \Psi_{IK} > . \qquad 1$$

One needs to project out states of good angular momenta from the intrinsic state Φ_K with the Angular Momentum Projection operator,

$$P_K^{IM} = \frac{2I+1}{8\pi^2} \int d\Omega D_{MK}^{I\,*}\, \Omega\, \mathrm{R}(\Omega) \qquad 2$$

Results and Discussion

The deformed HF orbits are calculated with a spherical core of ^{132}Sn; the model space spans the $3s_{1/2}$, $2d_{3/2}$, $2d_{5/2}$, $1g_{7/2}$, $1h_{11/2}$ and $1h_{9/2}$ orbits for protons have energies 3.654, 3.288, 0.731, 0.0, 1.705 and 6.46 MeV, and the $3p1/2$, $3p_{3/2}$, $2f_{5/2}$, $2f7/2$, $1h9/2$ and $1i_{13/2}$ neutron states have energies 4.462, 2.974, 3.432, 0.0, 0.686 and 1.487 MeV respectively. We use a surface delta interaction (with Interaction [9] strength 0.3 MeV for $p-p$, $p-n$ and $n-n$ interactions) as the residual interaction among the active nucleons in these orbits. It is to be noted that the theoretical spectra shown in FIG.

1 and 2 have good K quantum numbers ($K=0^+$ and $K=6^+$). The $K=6^+$ isomers are obtained by particle hole excitations over the ground state having $5/2^+$ and $7/2^+$ neutron intrinsic structures. The spectra are shown in Figures 1 and 2 for ^{172,176}Hf nuclei.

We have calculated E2 transition matrix elements for the $K=0^+$, $K=6^+$ (in-band) states as also between the $K=6^+$ isomers and the ground bands. We find, in our angular momentum projection calculation, quite enhanced collective matrix element values for the in-band transitions; while the E2 transition matrix elements from $K=6^+$ isomer band-heads to $J=4^+$ of the ground band are retarded by a factor of about 10-5. Similar retarded matrix elements are also obtained for M1 transitions from the $K=6^+$ isomers to the ground bands. Thus, a theoretical understanding of the retarded decay of a K-isomer to lower K bands is possible by angular momentum projection from the deformed intrinsic states.

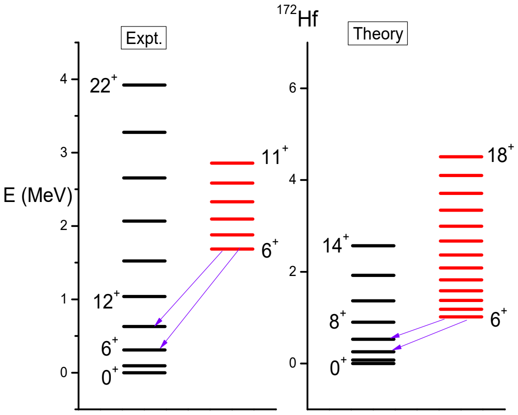

FIG. 1: Energy spectra of ^{172}Hf. Experimental values are taken from Ref. [10]

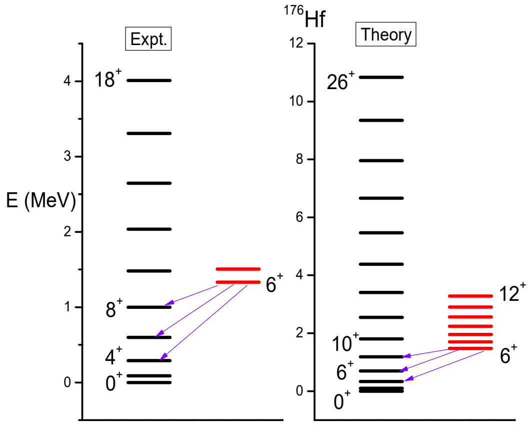

FIG. 2: Energy spectra of ^{176}Hf. Experimental values are taken from Ref. [10]

References

[1] P. M. Walker, Phys. Scr. T4, 29 (1983).

[2] Y. C. Zhang et al., Phys. Rev. C 76, 064321, (2007).

[3] P. M. Walker et al., Phys. Rev. C 49, 1718,(1994).

[4] P. M. Walker, and G. D. Dracoulis, Nature 399, 35 (1999).

[5] P. M. Walker et. al., Phys. Rev. Lett., 65, 416 (1990).

[6] G. Ripka, Advances in Nuclear Physics, Edited by M. Baranger and E. Vogt (1968) Vol. I page 183.

[7] Zashmir Naik and C. R. Praharaj, Phys. Rev. C 67, 054318 (2003).

[8] B. B. Sahu, et al., Acta. Physica Pol. B, 43, 451 (2012).

[9] A. Faessler, P. Plastino and S.A. Moszkowski, Phys. Rev. 156, 1064 (1967).

[10] http://www.nndc.bnl.gov