Band Structures and K Isomers of ^{178}Hf

B.B. Sahu[1],* Z. Naik[2], S. K. Ghorui[3], S.K. Patra[4], and C. R. Praharaj[4†]
[1]*Department of Physics, School of Applied Sciences, Kalinga Institute of Industrial Technology (KIIT) University, Bhubaneswar-751 024, INDIA*
[2]*School of Physics, Sambalpur University, Jyotivihar, Sambalpur-768 019, INDIA*
[3]*Department of Physics, IIT Ropar, Rupnagar-140001, INDIA and*
[4]*Institute of Physics, Sachivalaya Marg, Bhubaneswar-751 005, INDIA*

Introduction

In the mass region of A∼180, the four- and five-quasiparticle isomers of Lu, Hf, and Ta are of interest because the decays from a high K-isomers to the rotational states of low K-band are forbidden therefore, a relatively long life time is inevitable. From the Nilsson model point of view, proton and neutron deformed single-particle states are filled up to the upper part of the shell where there are many high-Ω states for prolate deformation. The presence of long-lived high K-isomers indicates the existence of axial symmetry with K a good quantum number. ^{178}Hf has a rich band structure and has well-known K-isomers, the most famous of them being the K=16$^+$ isomer with a half-life of 31 years [1]. The structure of the ground bands and those built on the K-isomers of ^{178}Hf are studied using deformed Hartree-Fock and Angular Momentum Projection model [2–5]. A surface delta two-body interaction, which is a quite reasonable interaction for the rare-earth region, is used in the calculation. For the prolate HF solution, the orbits of protons and neutrons are such that large Ω orbits are available near the Fermi surface and thus 1 particle 1 hole (2-quasiparticle) configurations of neutrons and protons of large K values are possible. An extensive study of the normal deformed level structures of ^{178}Hf and the rotational properties of high K bands are studied in the present work.

Theoretical Framework

A deformed shape such as one described by slater determinant of deformed orbits $\mid \Phi_K >$ is localized in angle and, by the uncertainty principle, is not a state of good angular momentum (J). Thus $\mid \Phi_K >$ does not have a unique J quantum number and is a superposition of various J states [2–4],

$$\mid \Phi_K >= \sum_I C_{IK} \mid \Psi_{IK} > . \qquad (1)$$

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

$$P^{IM}_K = \frac{2I+1}{8\pi^2} \int d\Omega {D^I_{MK}}^*(\Omega) R(\Omega). \qquad (2)$$

The two states $\mid \Psi^{JM}_{K_1} >$ and $\mid \Psi^{JM}_{K_2} >$ projected from two intrinsic configurations are generally not orthogonal to each other even if $\mid \Phi_{K_1} >$ and $\mid \Phi_{K_2} >$ are orthogonal. Thus, we do band-mixing whenever necessary, using the following equation:

$$\sum_{K'} (H^J_{KK'} - E_J N^J_{KK'}) C^J_{K'} = 0. \qquad (3)$$

Results and Discussion

The deformed HF orbits are calculated with a spherical core of ^{132}Sn, the $\mathrm{sdg_{7/2}h_{11/2}h_{9/2}}$ space with single particle enrgies 3.654, 3.288, 0.731, 0.0, 6.46 and 3.205 MeV for protons and $\mathrm{pfh_{9/2}i_{13/2}}$ space with energies 4.462, 2.974, 3.432, 0.0, 0.686 and 1.487 MeV for neutrons, respectively. We use surface delta matrix elements as the residual two-body interaction. The interaction strength is taken as 0.3 MeV for p-p, n-n and n-p interactions. This interaction gives a good description of the systematics of deformations in this mass region. The spectra of this nucleus, for various intrinsic states using Angular Momentum Projection techniques [2–4], are shown in Fig.1. Apart from the energy spectra one can study the reduced transition matrix elements B(E2) and B(M1) for the nucleus ^{178}Hf.

*Electronic address: bbsnou@gmail.com
†Electronic address: crp@iopb.res.in

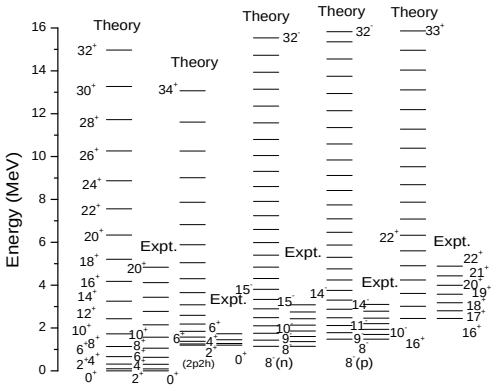

FIG. 1: Energy spectra with deformed HF model of ^{178}Hf.

The quantity B(E2) for a transition from an initial state αJ_1 to final state βJ_2 is given by

$$B(E2;\alpha J_1 \rightarrow \beta J_2) = \frac{1}{2J_1+1}\Big|\sum_{i=p,n}\langle\Psi^{\beta J_2}_{K_2} \mid\mid Q^i_2 \mid\mid \Psi^{\alpha J_1}_{K_1}\rangle\Big|^2. \quad (4)$$

Here the summation is for quadrupole moment operators of protons and neutrons. The effective charges of $1.7e$ and $0.7e$ are used for protons and neutrons respectively in our calculations. Extensive values of the electromagnetic properties will be presented latter.

Conclusions

For ^{178}Hf we thus have K=8^- neutron and proton configurations. The K=16^+ configuration is of $8^-_n \times 8^-_p$ structure. The spectrum of states based on each intrinsic configuration (ground and K-isomeric configurations) are obtained by projecting good angular momentum states from the respective intrinsic configurations. Besides these we get a more deformed (prolate) K=0^+ configuration, the β-band head, by proton 2p-2h excitation from $\pm\frac{7}{2}^+$ to $\pm\frac{1}{2}^-$ deformed states of $h_{\frac{9}{2}}$ origin. We thus have the more defomed β band at fairly low excitation energy. The agreement between the results of our calculations and the experimental spectra of the various bands are reasonable up to moderate spin values. Theoretically we predict the spectra upto larger J values than known experimentally so far.

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