Ground State rotational bands in ^{168}Yb Nucleus

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Introduction

Ytterbium lies in the Lanthanide series of perodic table. Nuclei of Lanthanide elements are rare-earth nuclei. Stable rare-earth nuclei are known to have large deformation in their ground states. Ground state properties of these nuclei are studied with different theoretical models since many years in the field of nuclear structure. These nuclei have also been studied up to very high spin states. At higher spins, the neutrons and protons in high spin intruder orbitals suffer pair breaking under the effect of Coriolis force. This gives rise to changes in the moment of inertia and the phenomenon of back-bending. Ytterbium is also an important element in r-process nucleosynthesis as the r-process abundance peak at $A \approx 195$ corresponds to the $N = 126$ closed neutron shell in nuclei around Yb.[1]

Rotational bands in stable even-even $^{166-172}$Yb nuclei have been studied by Zhang.[2] in cranked relativistic Hartree-Bogoliubov formalism. The role of pairing has not been adequately investigated in neutron deficient as well as neutron rich Yb nuclei, particularly in high spin states. Pairing significantly modifies the moment of inertia and gives rise to band crossings. In the present work we study the role of the pairing interaction in high spin states in even-even ^{168}Yb nucleus.

Theory

The Hartree-Fock-Bogoliubov (HFB) approach is known to be suitable for the study of nuclei far away from the stability where data are scarce. This has the advantage is that we can use this to study nuclear rotation including pairing interaction. HFB is an approach which is suitable for our calculation. The calculation has been performed using the publicly available code HFODD(ver 2.49t) by Schunck et. al. This code solves the HFB equations in a three dimensional Cartesian harmonic oscillator basis. There are numerous options for different energy functionals; we have chosen SLy6. Since pairing is expected to play an important role in our study, the pairing strength values for ^{168}Yb have been chosen so as to reproduce the proton and neutron pairing gaps for this nucleus as obtained by the three point formula.

Results

We present the results for the ground state as well as rotational state properties of ^{168}Yb nucleus and compare with experimental values. Our results for binding energy, deformations, charge radius and the ratio R_{42} are presented in Table I. We find that our calculation can reproduce the ground state binding energy and particularly the deformation values very well. Experimental values are taken from the NNDC website.

TABLE I: Calculated and experimental values for the ground state properties of even-even ^{168}Yb nucleus.

G.S.properties	Exp	Theory
BE(MeV)	1362.797	1362.3249
β_2	0.327	0.3217
r_c(fm)	5.2702	5.3009
R_{42}	3.2662	3.5326

Binding Energy and Deformation

We have calculated the binding energy and deformation of even-even ^{168}Yb nucleus and compared with experimental values in

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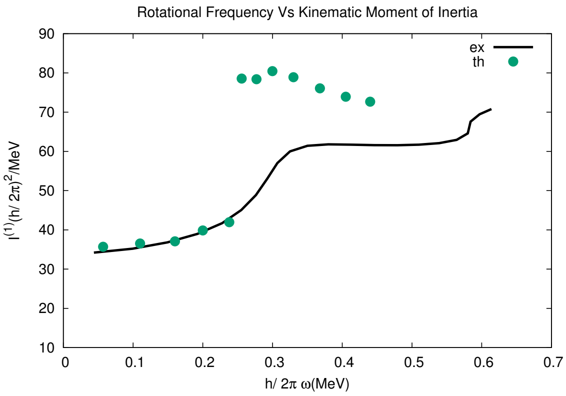

FIG. 1: Kinematic moments of inertia of the ground state band in ^{168}Yb.

TABLE-I. Our results are in very good agreement with experimental values. ^{168}Yb nucleus is prolate in shape in their ground state.

Charge Radius

Another important property of the ground state that has been measured is the charge radius. The charge radius (r_{ch}), in fm have been obtained from the root mean square point proton radius (r_p) using the formula

$$r_{ch} = \sqrt{r_p^2 + 0.64} \qquad (1)$$

Our result of charge radius is close to the experimental value.

The Ratio R_{42}

A number of Ytterbium isotopes near N=100 have deformation values $\beta_2 \geq 0.3$. They are expected to be very good rotors. For a purely rotational excitation, collective model predicts the ratio $R_{42} = E(4^+)/E(2^+)$ to be 3.33. We have calculated it and from TABLE I one can see that ^{168}Yb nucleus come very close to this limit.

Kinematic moments of inertia of ^{168}Yb

Generally, the ground state band is found to be crossed by a neutron pair broken band around spin $J^\pi = 14^+$ in Yb nuclei. In this work we investigate the ground state rotational bands in ^{168}Yb. As the deformation value shows from TABLE-I, the nucleus is only moderately deformed and prolate in nature. At lower energy and spin, effects such as contributions of other modes of excitation and band-mixing makes affects the moment of inertia. However, at high spin, away from the crossings, one may consider the states to be adequately described by a cranking calculation.

The experimental moment of inertia have been obtained from the well-known prescription

$$\mathcal{I}^{(1)}(J) = \frac{2J-1}{E_\gamma(J \longrightarrow J-2)}\hbar^2 \qquad (2)$$

The corresponding rotation frequency is

$$\hbar\omega(J) = \frac{E_\gamma(J \longrightarrow J-2)}{2} \qquad (3)$$

By convention, rotation frequency is expressed in energy units,*viz.* MeV.

In FIG-I, the experimental moment of inertia show two backbends corresponding to neutron and proton pair breaking around $J = 26$ and 42, respectively. In cranked calculation pairing collapse suddenly; thus we do not expect that the crossing frequency will be reproduced accurately. our calculations under predict the crossing frequencies. However, one can see that the general trend has been reproduced. This nucleus is moderately deformed in the ground state and is prolate. As we have seen, the minima for $\hbar\omega = 0$ corresponds to a deformation value of 0.321. We also note that the hexadecapole deformation is $\beta_{40} = 0.0754$. At a higher frequency of $\hbar\omega = 0.36$ MeV, the minima has a deformation value of $\beta = 0.2869$ and $\beta_{40} = 0.0178$. Our calculations indicate that the deformation decreases slightly beyond the proton pair break.

Acknowledgments

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References

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