Non-axial study of ^{222,224}Ra Isotopes

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Multi-nucleon transfer reactions have been used as an important tool for the spectroscopic study of heavy nuclei. By using this technique, Cocks et al [1] have studied the high spin states of some light actinides. Extensive experimental and theoretical studies are dedicated over the years to the study of the light actinides where it has been argued that the nuclei around Z~88, N~134 might present intrinsic octupole deformation. Zamfir and Kusnezov [2] have studied the transitional actinides in the *spdf* interacting boson model and found that the properties of the low-lying states can be understood without stable octupole deformation. As the low-lying states in light actinide nuclei can be understood without stable octupole deformation, we have employed non-axial cranking framework to study the properties of ^{222,224}Ra nuclei. In the present work, the non-axial study of ^{222,224}Ra isotopes in the Cranked Hartree-Bogoliubov (CHB) framework has been carried out. By using this framework, the results for yrast states, intrinsic quadrupole moments and occupation probabilities of ^{222,224}Ra are obtained. For the variational calculation of the yrast levels, the usual pairing-plus-quadrupole-quadrupole effective interaction operating in a valence space spanned by the $3p_{1/2}$, $3p_{3/2}$, $2f_{5/2}$, $2f_{7/2}$, $2g_{9/2}$, $1h_{9/2}$, $1i_{11/2}$, $1i_{13/2}$, and $1j_{15/2}$ orbits for protons as well as neutrons has been employed. The nucleus ^{164}Pb has been considered as an inert core.

In CHB formalism, potential parameters are determined self-consistently. Inspite of its several shortcomings, this formalism has been used extensively to investigate the complexity of nuclear spectra (arising from the interplay of single-particle and collective aspects of nuclear motion) as a function of rotational frequency. The CHB method has been discussed in detail by Goodman [3]. The single particle energies (SPEs) that have been employed are (in MeV) $(2f_{7/2})$=0, $(1h_{9/2})$=0.50, $(1i_{13/2})$=1.90, $(3p_{3/2})$=2.40, $(2f_{5/2})$=2.90, $(3p_{1/2})$=3.90, $(2g_{9/2})$=5.90, $(1i_{11/2})$=7.40, and $(1j_{15/2})$=7.70. This set of input SPEs are taken from Nilsson diagram.

The two-body effective interaction that have been employed is of pairing–plus-quadrupole-quadrupole type [4]. The pairing part can be written as

$$V_P = (G/4)\sum_{ij} S_i S_j a_i a_{\bar{\imath}} a_{\bar{\jmath}} a_j,$$

where i denotes the quantum numbers ($nljm$). The state $\bar{\imath}$ is same as i but with the sign of m reversed. Here S_i is the phase factor $(-1)^{j-m}$.

The q-q part of the interaction is given by

$$V_{qq} = \chi/2 \sum_{ijkl}\sum_{\nu}\langle i|q_\nu^2|k\rangle\langle j|q_{-\nu}^2|l\rangle(-1)^\nu a_i a_j a_l a_k ,$$

where the operator q_ν^2 is given by

$$q_\nu^2 = \left(\frac{16\pi}{5}\right)^{\frac{1}{2}} r^2 Y_\nu^2(\theta,\phi).$$

The strengths for the like particle neutron-neutron (nn) as well as neutron-proton (np) interaction were taken as

$$\chi_{nn}(=\chi_{pp}) = -0.00400 \text{ MeV b}^{-4}$$

$$\chi_{np} = -0.0104 \text{ MeV b}^{-4}$$

Here $b(=\sqrt{\hbar/m\omega})$ is the oscillator parameter.

In Table 1, the calculated results of intrinsic quadrupole moments of ground state and E_2^+ energies are presented for ^{222,224}Ra. The values for the two components of quadrupole moments $\langle Q_0^2\rangle$ and $\langle Q_2^2\rangle$ are presented separately for protons and neutrons. From Table 1, one finds that the values of intrinsic quadrupole moments $\langle Q_0^2\rangle_{\pi,\nu}$ increase as one goes from ^{222}Ra to ^{224}Ra. The increase in the quadrupole moments show that the deformation increases as one moves from ^{222}Ra to ^{224}Ra. The quadrupole moments have an inverse relation with E_2^+ energy. The E_2^+ energy decreases as one goes from ^{222}Ra to ^{224}Ra and therefore quadrupole moments $\langle Q_0^2\rangle$ show an increasing trend. The comparison of the calculated and experimental yrast bands of ^{222,224}Ra isotopes are presented in Fig.1. For ^{222,224}Ra, the results of the yrast bands are obtained upto spin 20^+ which are in reasonably good agreement with the experimental data upto spin 14^+ in ^{222}Ra and 20^+ in ^{224}Ra. The $\langle Q_2^2 \rangle$ component of quadrupole moments measures the degree of non-axiality present in a nucleus. The values of $\langle Q_2^2 \rangle_{\pi,\nu}$ are not showing significant variation as one moves from ^{222}Ra to ^{224}Ra. But our calculations predict that non-axiality is present in these nuclei.

In table 2, the subshell occupation numbers of protons and neutrons for the ground state of ^{222,224}Ra are presented. From this table, it is observed that the down slopping components of $1j_{15/2}$ orbit are getting occupied and the occupation probability of $1j_{15/2}$ orbit increases from 4.00 to 6.00 as one moves from ^{222}Ra to ^{224}Ra. This increase in the occupation probability of $1j_{15/2}$ orbit could be linked with the increase in the value of quadrupole moments.

Table 1 Comparison of experimental and theoretical E_2^+ energies (in MeV). In the last four columns the calculated values of intrinsic quadrupole moments are presented.

Nuclei	E_2^+ Exp.	E_2^+ Th.	$\langle Q_0^2 \rangle_\pi$	$\langle Q_2^2 \rangle_\pi$	$\langle Q_0^2 \rangle_\nu$	$\langle Q_2^2 \rangle_\nu$
^{222}Ra	0.11	0.19	29.61	12.91	59.15	59.79
^{224}Ra	0.08	0.15	33.79	11.23	63.77	60.17

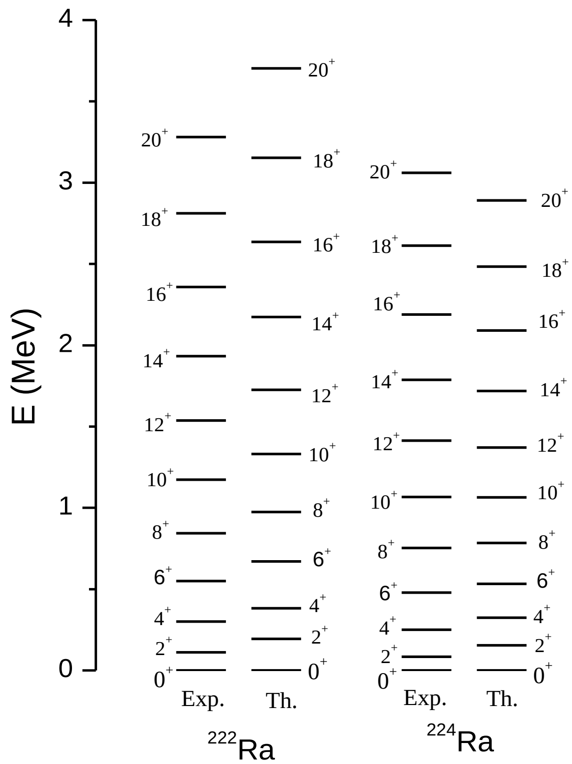

Fig. 1 Comparison of the experimental and theoretical yrast bands of ^{222,224}Ra isotopes.

Table 2: The subshell occupation numbers of protons and neutrons for ground states of ^{222,224}Ra.

Nucleus	$3p_{1/2}$	$3p_{3/2}$	$2f_{5/2}$	$2f_{7/2}$	$2g_{9/2}$	$1h_{9/2}$	$1i_{11/2}$	$1i_{13/2}$	$1j_{15/2}$
Protons									
^{222}Ra	0.02	0.24	0.21	1.66	0.05	1.87	0.0003	1.94	0
^{224}Ra	0.06	0.37	0.35	1.54	0.10	1.68	0.0006	1.91	0
Neutrons									
^{222}Ra	1.39	2.97	4.51	7.57	5.11	9.56	4.27	12.63	4.00
^{224}Ra	1.39	2.97	4.50	7.57	5.10	9.56	4.28	12.61	6.00

References

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