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PROPERTIES OF POSITIVE PARITY STATES IN 230-232th ISOTOPES

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Abstract: Non–adiabatic effects manifested in the energies and electrical characteristics of positive parity states of $^{230,232}Th$ nucleus been studied within the framework of a phenomenological model, taking into account the Coriolis mixing of low–lying rotational state bands. The energy and structure of low–laying state of $0_2^+(\beta-)$, $2_n^+(\gamma-)$ and 1_ν^+ bands which is constructed on intrinsic excitation are calculated. And also the reduced probabilities of $E2-$ transitions from the 0_2^+ and 2_n^+ bands to the ground $0_1^+(gr-)$ state band have been calculated. The non–adiabatic effect which is manifesting in electromagnetic transitions and significantly effects in the wave function of the states is shown.

Keywords: Energy, nucleus, spin, positive parity, Coriolis mixing, rotational, band

Introduction

The deformed $^{230,232}Th$ nucleus is an actinide nuclei with half–lives sufficient for it to be used as a target nucleus for beam experiments [1-6]. Experimental data on energy and electrical transitions indicate a deviation from the Alaga rule.

The most complete results on $^{230,232}Th$ nuclei are presented in [1, 2]. For instance, in ^{230}Th nuclei the rotational bands with a $K^\pi = 0_1^+(gr-)$ up to $I = 24\hbar$, $K^\pi = 0_2^+(\beta-)$ up to $I = 8\hbar$, $K^\pi = 2_1^+(\gamma-)$ up to $I = 10\hbar$, $K^\pi = 2_2^+(\gamma-)$ up to $I = 8\hbar$, and several states with $K^\pi = 1_\nu^+$ were obtained. In case ^{232}Th nuclei experimentally known $K^\pi = 0_1^+(gr-)$ up to $I = 30\hbar$, $K^\pi = 0_2^+(\beta-)$ up to $I = 20\hbar$, $K^\pi = 2_1^+(\gamma-)$ up to $I = 10\hbar$, and fourteen states with $K^\pi = 1_\nu^+$.

In this work, the energy and electrical properties of positive parity states in $^{230,232}Th$ nuclei are studied within the framework of the phenomenological model [7–9], which is takes into account the Coriolis mixing of low–lying rotational state bands.

The energy spectra, structure state of rotational band and reduced probabilities of $E2-$ transitions from the $K^\pi = 0_2^+$ and $K^\pi = 2_n^+$ bands to ground state band has been calculated. The calculated values of energy, reduced probability and their ratio are compared with a known experimental data.

Model description

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To study of the properties of positive parity states of deformed $^{230,232}Th$ nuclei we use phenomenological model [7–9]. Let us outline the main advantage of this model. Within this model, mixture of bands occurs only as a result of the action of Coriolis forces.

The model Hamiltonian has the form

$$H = H_{rot} + H_{K,K'},$$

$$H_{K,K'} = \omega_K \delta_{K,K'} - \omega_{rot}(I) \left\langle K \middle| \hat{j}_x \middle| K' \right\rangle \delta_{K,K' \pm 1}, \quad (1)$$

where $\text{щ}_{rot}(I) = dE_{rot}(I)/dI -$ is angular frequency of rotational core; $\left\langle K \middle| \text{₣}_x \middle| K \right\rangle -$ matrix element of Coriolis interaction between the states of rotational bands K and K . Coefficients $\text{ч}(I,K)$ are given by the following relations:

$$\text{ч}(I,0) = 1, \quad \text{ч}(I,1) = \ 1 - \frac{2}{I(I+1)} \ ^{1/2}.$$

An Eigen wave function (Eigen function) of Hamiltonian (1) follows as

$$\left| IMK \right\rangle = \sqrt{\frac{2I+1}{16\text{р}^2}} \left\{ \sqrt{2}\, \text{ш}^I_{0,K} D^I_{M,0}(\text{и}) + \right.$$

$$+ \ _{K'} \frac{\text{ш}^I_{K',K}}{\sqrt{1+\text{д}_{K',0}}} \ D^I_{M,K'}(\text{и}) b^+_{K'} + (-1)^{I+K'} D^I_{M,-K}(\text{и}) b^+_{-K'} \quad \left| 0 \right\rangle. \quad (2)$$

Here $D^I_{M,K'}(\text{и}) -$ are generalized spherical functions; $\left| 0 \right\rangle -$ vacuum for the operator $b^\dagger_K$, in other words, the ground state of the nucleus in the internal system; $\text{ш}^I_{K,K} -$ amplitudes of mixing states of different bands with the same angular momentum I due to the Coriolis interaction.

Were, energy $\varepsilon_K(I)$ and mixing amplitudes $\text{ш}^I_{K,K}$ are found by diagonalizing the Hamiltonian (1):

$$H_{K,K'} \text{ш}^I_{K,K} = \varepsilon_K(I) \text{ш}^I_{K,K}, \quad (3)$$

where, $\varepsilon_K(I) -$ is energy of internal excitation of the nucleus after taking into account the interaction of the bands.

In this case, the total energy of the state is determined as follows:

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$$E_K(I) = \varepsilon_K(I) + E_{rot}(I)\,. \tag{4}$$

The rotational energy of core $E_{rot}(I)$ is calculated using the Harris's two–parameter formula [10].

$$E_{rot}(I) = \frac{1}{2}\ {}_0\omega^2_{rot}(I) + \frac{3}{4}\ {}_1\omega^4_{rot}(I)\,. \tag{5}$$

The angular frequency of rotational core $\omega_{rot}(I)$ is determined by the following formula [6]:

$$ш_{rot}(I) = \left[\frac{\tilde{I}}{2\ _1} + \left(\left(\frac{_0}{3\ _1}\right)^3 + \left(\frac{\tilde{I}}{2\ _1}\right)^2\right)^{\frac{1}{2}}\right]^{\frac{1}{3}} + \left[\frac{\tilde{I}}{2\ _1} - \left(\left(\frac{_0}{3\ _1}\right)^3 + \left(\frac{\tilde{I}}{2\ _1}\right)^2\right)^{\frac{1}{2}}\right]^{\frac{1}{3}}, \tag{6}$$

where

$$\tilde{I} = \sqrt{I(I+1)}$$

Numerical calculations

Calculations were carried out for the ^{230,232}Th nucleus. The inertial parameters of the core $_0$ and $_1$ were determined by formula (5), using the experimental values of the energy of ground state band up to spin $I \quad 8\hbar$. In the case ^{230}Th, ground band (0^+_1), beta vibrational band $K^\pi = 0^+_2$, two bands with $K^\pi = 2^+_n$ and experimentally known twenty $K^\pi = 1^+_\nu$ states have been included to the basis of model Hamiltonian (1). And in the case ^{232}Th, ground (0^+_1), $K^\pi = 0^+_2$, $K^\pi = 2^+_n$ vibrational bands and experimentally known fourteen $K^\pi = 1^+_\nu$ states have been included to the basis of model Hamiltonian (1)

Model parameters were determined as follows:

- parameters of the headband energies of the ground (0^+_1), в − vibrational (0^+_2) and $K^р = 1^+_н$ bands $-$ $ш_{0_1}$, $ш_{0_2}$ and $ш_{1_н}$ are not excited by Coriolis forces. Therefore, their values were taken from the experiment;
- the headband energies of $K^р = 2^+_{1,2}$ bands $ш_{2_{1,2}}$ and matrix elements $(\mathfrak{J}_x)_{K,1_н} = \langle K | \mathfrak{J}_x | 1_н \rangle -$ describing the Coriolis interactions were determined using the

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least squares method from the condition of good agreement between the calculated and experimental energy values.

The values of the model parameters used to describe the energy are given in Table 1.

Table 1. Values of the model parameter, which is used in the calculation of energy.

A	$_0$ $\hbar^2 / MeV$	$_1$ $\hbar^4 / MeV^3$	$Ш_{2_1}$ MeV	$Ш_{2_2}$ MeV	$(j_x)_{0_1,1_н}$	$(j_x)_{0_2,1_н}$	$(j_x)_{2_1,1}$	$(j_x)_{2_2,1_н}$
^{230}Th	55.89	519.8	0.732	0.973	0.1542	0.688	).90	1.3
^{232}Th	60.31	534.64	0.737	-	0.226	0.909	).90	-

Where, $_0$ − and $_1$ − inertial parameters of the rotating frame; $\omega_{2_{1,2}}$ − headband energy of gamma bands $K^p = 2^+_{1,2}$; $(\hat{j}_x)_{K,1_н} = \langle K | \hat{j}_x | 1_н \rangle$ − matrix element of Coriolis interaction.

In Fig. 1 and 2 compare the experimental and theoretical energy values calculated within the framework of the model described above for the ^{230,232}Th isotopes, respectively. As can be seen from Figure 1, the model qualitatively reproduces the experimental data.

In case ^{232}Th in band $K^p = 2^+$ for odd states $I = 7\hbar$, $I = 13\hbar$, $I = 15\hbar$ and $I = 17\hbar$ there are no experimental energy values. Our calculations for the energies of these states give the following results $E_2(7) = 1.158 MeV$, $E_2(13) = 2.005 MeV$, $E_2(15) = 2.365 MeV$ and $E_2(17) = 2.759 MeV$.

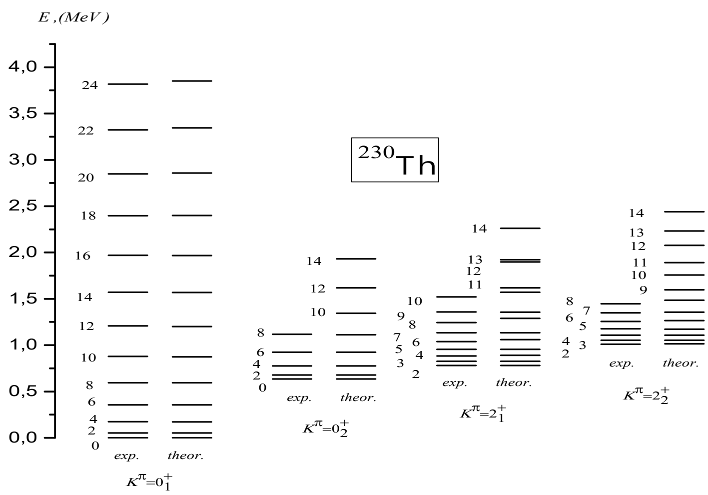

Fig. 1. Experimental and theoretical energies of ^{230}Th isotope

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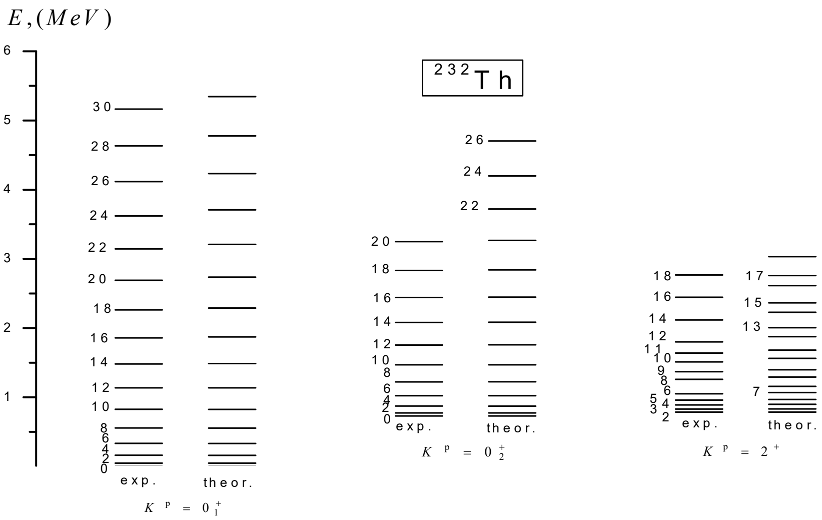

Fig. 2. Experimental and theoretical energies of $^{232}\mathrm{Th}$ isotope

Conclusion

The energy and electrical properties of the positive parity states of ^{230,232}Th nuclei have been studied within the framework of the phenomenological model that considers Coriolis mixing of the states of low – lying rotational bands. The energies, the structure of the states of the ground, в − vibrational bands, $K^p = 2_1^+$ and 2_2^+ It is shown that, due to the proximity of the head energies of bands with $K^p = 0_2^+$, 2_1^+ and 2_2^+, the states corresponding to these bands mix more strongly. It is shown that this effect is noticeably manifested in the nonadiabaticity of the electric characteristics of these states.

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