QUADRUPOLE AND OCTUPOLE ONE-PHONON STATES OF NUCLEI IN THE REGION \(174 \leq A \leq 188\)

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Abstract

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QUADRUPOLE AND OCTUPOLE ONE-PHONON STATES OF NUCLEI IN THE REGION $174 \leq A \leq 188$

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In ([1–8]) the energies, wave functions, and the quantities $B(E2)$, $B(E3)$ were calculated for quadrupole and octupole one-phonon states in even-even deformed nuclei. The mathematical methods for treating one-phonon states and the experimental data are summarized in ([9]). The component composition of one-phonon states is given in ([10]). In all the works cited, the calculations were performed with wave functions and single-particle energies of the Nilsson potential. In ([11]) the characteristics of one-phonon quadrupole states of even-even nuclei in the region $150 \leq A \leq 174$ were calculated using the single-particle energies and wave functions of the Saxon–Woods potential calculated in ([12]), and also the Nilsson potential modified in ([13]). In the present work, by the same method as in ([11]), we have calculated the energies, wave functions, and the quantities $B(E2)$, $B(E3)$ for the first two quadrupole states with $K^\pi = 0+$ and $2+$, and octupole states with $K^\pi = 0^-$, 1^-, and 2^-, of even-even nuclei in the region $174 \leq A \leq 188$.

In the present calculations the same formulas and corresponding computer programs were used as in ([11]). As wave functions and single-particle energies, as in ([11]), the following were taken: a) for the modified Nilsson potential at deformation $\beta = 0.21$; b) for the Saxon–Woods potential at $A = 181$ and deformation $\beta = 0.23$. The calculations (with the Saxon–Woods potential) were performed with the quadrupole-interaction constant $\chi^{(2)} = 2.0A^{-4/3}$ MeV/cm^4 $= 184A^{-7/3}$ MeV/cm^4, with the value $\chi^{(2)}A^{-7/3}$ taken to be the same as in ([11]). The octupole-interaction constant was taken equal to $\chi^{(3)} = 0.04A^{-4/3}$ MeV/cm^6. In calculations based on the modified Nilsson potential, the following constants were used: $\chi^{(2)} = 5.8A^{-4/3}\hbar\omega_0^0$ (for $K^\pi = 2+$), $\chi^{(2)} = 7A^{-4/3}\hbar\omega_0^0$ (for $K^\pi = 0+$), $\chi^{(3)} = 0.59A^{-4/3}\hbar\omega_0^0$.

The difference in $\chi^{(2)}$ compared with the value in ([6]) is due to the fact that in ([6]) the density of single-particle levels was artificially reduced. The pairing-interaction constants G_N and G_Z were taken to be the same as in ([11]). In calculating the reduced probabilities of electric $E2$- and $E3$-transitions, the

following values of the effective charges were taken: $e_{\text{eff}}^{(2)} = 0.2$, $e_{\text{eff}}^{(3)} = 0.2$; the quantities $B(E2)$ and $B(E3)$ are given in single-particle units.

A small part of the results obtained is presented in Tables 1, 2, and 3. Some of our results are given in ([14]).

From Table 1 it is seen that the calculations correctly reproduce the tendency for the energies of the first $K^\pi = 2+$ states to decrease with increasing A. The calculated energies of the first $K^\pi = 0+$ states do not contradict the available experimental data. However, this agreement is to some extent conditional, since the low-lying states with $K^\pi = 0+$ have different natures.

In the region of nuclei under consideration there are the following experimental data on the values of $B(E2)$ for excitation of the first states with $K^\pi = 2+$: the values obtained in ([15]), 1.4 for Yb^{174} and 2.1 for Yb^{176}; the obtained

Table 1

Energies (in MeV) of the first β- and γ-vibrational states, calculated by the single-particle Saxon–Woods scheme (S–W) at $\beta = 0.23$ and by the modified Nilsson scheme (N) at $\beta = 21$

Nuclei	$K^\pi =$ 0+ exp.	$K^\pi =$ 0+ S–W	$K^\pi =$ 0+ N	$K^\pi =$ 2+ exp.	$K^\pi =$ 2+ S–W	$K^\pi =$ 2+ N
Yb^{174}	–	1,0	1,3	1,63	1,6	1,6
Yb^{176}	–	1,2	1,5	1,254	1,4	1,5
Yb^{178}	–	1,2	1,4	–	1,1	1,3
Hf^{176}	1,28	1,2	1,2	–	1,7	1,6
Hf^{178}	1,197	1,4	1,5	1,174	1,5	1,5
Hf^{180}	–	1,3	1,4	–	1,2	1,3
W^{178}	–	1,2	1,1	–	1,7	1,5
W^{180}	–	1,4	1,5	–	1,5	1,4
W^{182}	–	1,3	1,4	1,222	1,2	1,2
W^{184}	–	1,3	1,6	0,904	0,7	1,0
W^{186}	–	1,4	1,4	0,730	0,7	1,1
Os^{182}	–	0,8	1,1	–	1,4	1,3
Os^{184}	–	0,8	1,2	0,94	1,1	1,1
Os^{186}	–	0,8	1,1	0,768	0,6	0,8
Os^{188}	1,086	0,9	0,8	0,633	0,6	1,0

Table 2

Energies (in MeV) of the first octupole states with $K^\pi = 0-$, $1-$, and $2-$, calculated by the single-particle Saxon–Woods scheme (S–W) and by the modified Nilsson scheme (N)

Nuclei	$K^\pi = 0-$ S–W	$K^\pi = 0-$ N	$K^\pi = 1-$ S–W	$K^\pi = 1-$ N	$K^\pi = 2-$ exp.	$K^\pi = 2-$ S–W	$K^\pi = 2-$ N
Yb^{174}	1,5	1,6	1,8	1,6	1,321	1,3	1,4
Yb^{176}	1,9	2,0	1,3	1,5	–	1,4	1,4
Yb^{178}	2,1	2,1	1,6	1,8	–	2,1	2,1
Hf^{176}	1,6	1,6	1,4	1,6	1,250	1,2	1,3
Hf^{178}	2,0	2,0	1,3	1,5	1,280	1,3	1,3
Hf^{180}	2,3	2,1	1,4	1,8	–	1,7	1,8
W^{178}	1,6	1,6	1,8	1,5	1,044	0,9	1,2
W^{180}	2,0	2,0	1,3	1,5	–	1,0	1,2
W^{182}	2,3	2,1	1,6	1,8	1,29	1,2	1,3
W^{184}	2,4	2,0	1,7	2,0	–	1,2	1,3
W^{186}	2,5	1,9	2,1	1,9	–	1,1	1,3
Os^{182}	2,0	1,9	1,3	1,5	–	1,4	1,3
Os^{184}	2,3	2,1	1,6	1,8	–	1,7	1,9
Os^{186}	2,4	2,0	1,7	2,0	–	1,7	1,9
Os^{188}	2,5	1,9	2,1	1,9	1,45	1,3	1,7

obtained in (16) values 5.5 for W^{184} and W^{186}. Our calculations do not contradict these data. The quantities $B(E2)$ calculated in (17) according to the theory of the surface delta interaction are close to ours for a value of $e_{\text{eff}}^{(2)}$ 2.5 times larger than in our work.

Calculations of the octupole states with $K^\pi = 0-$, $1-$, and $2-$ showed that the states with $K^\pi = 0-$ are somewhat more strongly collectivized than the states with $K^\pi = 1-$ and $2-$. The states with $K^\pi = 1-$ and $2-$ calculated in the present work (i.e., the corresponding quantities $Y_{1(31)}$, $Y_{1(32)}$ are more collectivized in comparison with the data in (9). The states with $K^\pi = 0-$ in this region of nuclei lie rather high, and therefore there are no corresponding experimental data. The calculation of the energy of the $K^\pi = 0-$ states depends strongly on the value $\chi^{(3)}$, more strongly than for the energies of the $K^\pi = 1-$ and $2-$ states. For the energies of states with $K^\pi =$

Table 3

Reduced probabilities of $B(E\lambda, O_g \to I = \lambda, K)$ transitions, calculated according to two schemes: Saxon–Woods (S–W) and the modified Nilsson scheme, from the ground state to quadrupole and octupole states with $K^\pi = 0^-, 1^-$, and 2^-, with $e_{\text{eff}} = 0.2$

Nuclei	$B(E2)$, $K^\pi = 0^+$, S–W	$B(E2)$, $K^\pi = 0^+$, N	$B(E2)$, $K^\pi = 2^+$, S–W	$B(E2)$, $K^\pi = 2^+$, N	$B(E3)$, $K^\pi = 0^-$, S–W	$B(E3)$, $K^\pi = 0^-$, N	$B(E3)$, $K^\pi = 1^-$, S–W	$B(E3)$, $K^\pi = 1^-$, N	$B(E3)$, $K^\pi = 2^-$, S–W	$B(E3)$, $K^\pi = 2^-$, N
Yb^{174}	2.9	0.6	2.7	1.2	5.8	0.9	1.3	0.4	2.6	0.6
Yb^{176}	2.2	0.1	2.4	1.9	3.5	1.7	0.1	0.3	1.6	0.5
Yb^{178}	1.8	0.1	2.6	2.0	1.5	3.2	0.3	0.5	1.9	0.6
Hf^{176}	2.4	0.4	2.2	1.0	5.3	1.0	0.3	0.5	3.6	1.0
Hf^{178}	1.8	0.1	2.0	1.8	3.3	1.9	0.1	0.4	2.4	0.8
Hf^{180}	1.5	0.03	2.2	2.0	3.7	3.8	0.1	0.7	1.9	1.6
W^{178}	2.7	0.6	2.4	2.2	5.1	1.2	1.4	0.5	3.9	2.0
W^{180}	2.0	0.1	2.2	2.7	3.1	2.2	0.1	0.4	2.8	1.8
W^{182}	1.6	0.003	2.3	3.0	3.5	4.2	0.4	0.4	1.7	1.7
W^{184}	1.7	0.1	3.0	3.2	2.3	4.6	0.3	3.0	1.5	1.8
W^{186}	1.4	0.5	2.1	3.0	1.5	5.2	0.3	5.8	1.5	2.0
Os^{182}	5.2	0.3	3.3	4.9	3.0	1.9	0.1	0.4	1.5	0.6
Os^{184}	4.6	0.4	3.4	5.4	3.4	3.8	0.4	0.7	0.7	2.1
Os^{186}	4.5	1.7	4.6	6.2	2.2	4.3	0.3	3.2	0.5	2.1
Os^{188}	3.7	3.4	3.3	6.0	1.4	4.9	0.3	6.4	0.6	1.0

$= 1^-$ there is one experimental value in Hf^{176}, equal to 1.343 MeV, which agrees with the results of the calculations.

From Table 2 it is seen that the experimental data on the $K^\pi = 2^-$ states are described theoretically rather well. It should be noted that the values we calculated for the energies of the first $K^\pi = 2^-$ states lie lower and are more strongly collectivized in comparison with the results obtained in (17), in which a simplified form of the surface delta interaction was used.

The calculations carried out showed that the first quadrupole and octupole states of nuclei in the region $174 \leq A \leq 188$ are described rather well within the framework of the superfluid nuclear model using the method of approximate second quantization. Calculations in which the eigenvalues of the energies and wave functions of the Saxon–Woods potential are used are more consistent, and employ a smaller number of parameters, in comparison with calculations based on the Nilsson potential.

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