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NON-ROTATIONAL STATES OF ODD-Z DEFORMED NUCLEI IN THE REGION $153 \leqslant A \leqslant 177$

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Неротационные состояния деформированных ядер с нечётным числом протонов в области $153 \leq A \leq 177$

В рамках сверхтекучей модели с учётом взаимодействия квазичастиц с фононами рассчитаны энергия и структура неротационных возбужденных состояний в ряде деформированных ядер с нечётным числом протонов в области $153 \leq A \leq 177$. В расчётах использованы волновые функции и одночастичные энергии потенциала Саксона-Вудса. Получено удовлетворительное согласие с экспериментальными данными. Предсказано положение и структура большого числа новых уровней в исследуемых ядрах.

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Non-Rotational States of Odd-Z Deformed Nuclei in the Region $153 \leq A \leq 177$

The energy and structure of the non-rotational excited states for a number of odd-N deformed nuclei in the region $153 \leq A \leq 177$ were calculated in the framework of the superfluid nuclear model. The calculations were performed with the Saxon-Woods single-particle energies and wave functions. A satisfactory agreement of the experimental and theoretical data was obtained. The position and the structure of a large number of new levels in the nuclei in question is predicted.

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The excited non-rotational states of odd-Z nuclei are not pure quasiparticle states, they contain admixtures of many-quasiparticle components. Thus, in studying their structure it is necessary to take into account the connection between the quasiparticle and collective states and, first of all the interaction of quasiparticles with vibrational phonons.

The mathematical formalism for description of the interaction of quasiparticles with phonons in the framework of the superfluid nuclear model is presented in the monograph /1/. In refs. /2-8/ this formalism was used to calculate the non-rotational states of a large number of odd-A deformed nuclei. It was shown that the excited states of odd-A nuclei have a complex structure and only the lowest and a small number of higher excited states were found to be close to the one-quasiparticle states.

The present work is devoted to the study of the structure of nuclei with an odd number of protons in the region $153 \leq A \leq 177$. The main attention was paid to the nuclei the spectra of which were not calculated earlier.

In the present calculations the Saxon-Woods single-particle energies and wave functions calculated by the method suggested in ref./9/ were used. In the expansion of the nuclear radius in the multipoles the quadrupole and hexadecapole deformations have been taken into account. Taking into consideration the fact that the energy and wave functions of the Saxon-Woods potential are A-dependent the deformed nucklei of the region $150 \leq A \leq 190$ were divided into four zones. The nuclei of this region are computed with their parameters which slightly alter in the transition from zone to zone. Table 1 gives the Saxon-Woods parameters for the four zones. In the present paper the nuclei of three zones with $A=155$, 165 and 173 were studied. The calculations of the non-rotational states of odd-A nuclei in zone $A=181$ were carried out in refs./7,10/.

The atomic nuclei of zone $A=155$ (^{153}Eu, $^{155-161}Tb$, $^{159-161}Ho$) were studies with the quadrupole deformation $\beta_{20}=0.28$ and hexadecapole deformation $\beta_{40}=0.06$, the nuclei of zone $A=165$ (^{163}Ho, $^{165,167,171}Tm$) with $\beta_{20}=0.28$ and $\beta_{40}=0.02$; the nuclei of zone $A=173$ ($^{169,173,175}Lu$, ^{177}Ta) with $\beta_{20}=0.27$ and $\beta_{40}=-0.02$.

The wave function for an odd-Z nuclei is written in the form:

$$\Psi_i(K^\pi)=\frac{1}{\sqrt{2}}N_i(\rho_1\dots\rho_n)\{\sum_{\rho_n\sigma}C^i_{\rho_n}a^+_{\rho_n\sigma}+\sum_{\lambda\mu i\nu\sigma}D^{\lambda\mu ij}_{\nu\sigma}(\rho_1\dots\rho_n)a^+_{\nu\sigma}Q^+_1(\lambda\mu)\}\Psi_0 \quad (1)$$

Here $Q^+_1(\lambda\mu)$ is the phonon operator of multipolarity $(\lambda\mu)$, $a^+_{\nu\sigma}$ is the quasi-particle production operator, $\sigma=\pm 1$, Ψ_0 is the wave function of the ground state of an even-even nucleus. The quantity $N^2_i(\rho_1\dots\rho_n)(C^i_{\rho_n})^2$ characterizes the contribution to the state with a given K^π of the one-quasiparticle component ρ_n, the quantity $\frac{1}{2}N_i^2(\rho_1\dots\rho_n)\sum_\sigma(D^{\lambda\mu ii}_{\nu\sigma})^2$ is the contribution of the component quasiparticle in the ν - state and the phonon $\lambda\mu i$. The summation over ρ_n means that in the Saxon-Woods single-particle scheme one takes into account simultaneously several states with identical K^π. Using the variational principle, e.g. ref./1/, one obtains a secular equation the roots of which define the energy of the ground (K^π_0) and excited states of an odd-Z nucleus. A number of excited states has a considerable admixture of the component quasiparticle plus γ-vibrational phonon. Such states are characterized by large E2 transition probabilities. A part of them in given in Table 2. All the reduced $B(E2)$ probabilities (in single-particle units $B_{s.p.}(E2)=3A^{4/3}e^2\ 10^{-53}\ cm^4$ are calculated with the effective charge $e_{eff.}=0.2$. The experimental values of the reduced transition probabilities for even-even nuclei were taken from ref./11/.

The experimental data on $B(E2)$ values in the odd-Z nuclei question are very poor. The experimental value

$B(E2)$ s.p.u.$=1.5$ for the excited $1/2^+$ state of energy 531 keV in ^{159}Tb essentially differs from the calculated value. However, the value $B(E2)$ s.p.u.$=1.5$ is surprising if the experimental value $B(E2)$ s.p.u.$=2.7$ in ^{158}Gd is true.

The Coriolis forces have been neglected. According to ref./12/ and other papers these forces are important for levels from spherical subshells with large j and especially for rotational states with large spins. In the region under consideration the Coriolis forces may most strongly affect the $h_{11/2}$ subshell states. Therefore the energies of states $550\uparrow$, $541\uparrow$, $532\uparrow$, $523\uparrow$, $514\uparrow$ and $505\uparrow$ may little change due to Coriolis interaction.The latter effect can be estimated for the simple case of mixing of two bands using the matrix elements of the operator j_+ given in the review /13/.

We should bear in mind that the Coriolis forces little affect the energy and the structure of the ground state rotational bands. In the framework of the superfluid nuclear model the Coriolis forces can easily be taken into account in just the same way as it has been done in refs./14/.

The energy and structure of a state close to the one-quasiparticle state can essentially be affected by the deflection of the equilibrium deformation of a nucleus in the excited state from that for the nucleus in the ground state. A preliminary analysis shown that this effect is especially important for the behaviour of the levels $404\downarrow$, $541\downarrow$ and $402\uparrow$. For example, the investigations /15/ showed that for the $541\downarrow$ state this deflection $\Delta\beta$ can reach 0.04. For such a change of the quadrupole deformation the single-particle $541\downarrow$ state energy decreases by 0.5 MeV. Thus, the qualitative analysis of this effect makes it possible to improve the description of the energies of states $404\downarrow$, $541\downarrow$ and $402\uparrow$.

The results of calculations of the energies and wave functions for a number of nuclei with an odd number of protons are given in Tables 3-17. The energies and the structure of the ground and excited non-rotational states of nuclei up to 1.5 MeV and some states higher than 1.5 MeV are given there. The forth column of the tables gives the contribution (in percents) of a few largest components obtained from the wave function normalization condition to the state in question. The second single-particle state with the same K^{π} as that under investigation was included in the table in the case when the value of this component exceeded 1%. For example, in ^{159}Ho the contribution to the $K^{\pi} = 5/2^{+}$ state comes from: one-quasiparticle $413\downarrow$ state - 69%, one-quasiparticle $402\uparrow$ state - 23% and component quasiparticle $532\uparrow$ plus phonon $Q_1(30)$ - 5%.

The experimental data are taken from two reviews /13,16/. They include the data published in literature before May 1, 1970. The experimental data obtained after this data are taken from refs. /17-25/. Some tables give the energies of three-quasiparticle states of the type $(p,2n)$ with large spins. The analysis of three-quasiparticle states in odd-A deformed nuclei is performed in ref.[26].

The calculations of the non-rotational states in ^{155}Eu, ^{165}Ho, ^{169}Tm and ^{171}Lu with the Saxon-Woods wave functions and single-particle energies showed that the improvement of the description of these states is insignificant compared to the description based on the Nilsson potential in ref.[6]. Therefore the present work does not contain the results of calculation for these nuclei. The nuclei at the boundary of the two zones, like ^{161}Ho, ^{169}Lu, ^{171}Tm were calculated with the schemes of both zones. The comparison of the results showed that there are some insignificant differences in the energy and structure of the states under investigation. The present paper gives the results for these nuclei obtained with the schemes which were used for the calculation of the majority of isotopes.

It should be noted that the Saxon-Woods potential calculations are essentially more unambiguous as compared with the Nilsson potential calculations. The Saxon-Woods single-particle energies and wave functions are calculated with the same parameters for all the subshell without additional shifts of some levels and subshells. The calculations given showed that the Saxon-Woods single-particle energies and wave functions makes it possible to describe satisfactorily a large amount of experimental data on the levels of nuclei with an odd number of protons in the range $153 \le A \le 177$. Besides, the position of a large number of levels in the nuclei in question is predicted.

In conclusion we express our gratitude to L.A. Molov, U. Fainer and H. Strusny for fruitful discussions.

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Table 1

Saxon-Woods Potential Parameters

	Neutron System				Proton System			
A	V_0 Mev	r_0 fm	$\varkappa$ fm^2	α fm^{-1}	V_0 Mev	r_0 fm	$\varkappa$ fm^2	α fm^{-1}
I55	47.2	I.26	0.40	I.67	59.2	I.24	0.36	I.63
I65	44.8	I.26	0.43	I.67	59.2	I.25	0.355	I.63
I73	44.8	I.26	0.42	I.67	59.2	I.25	0.32	I.59
I8I	43.4	I.26	0.40	I.67	59.8	I.24	0.33	I.67

Table 2

Reduced B(E2,Ko → Ko ± 2) Transition Probabilities

Nucleus	K^π	Energy (keV)		$B(E2)_{s.p.u.}$	Structure, %
		Experiment	Theory	Theory	
^{I53}Eu	I/2$^+$ 9/2$^+$ I/2$^+$	— — —	670 I300 I380	0.4 I.7 I.I	4I3↓+Q_1(22) - 23; 4II↓-48 4I3↓+Q_1(22) - I00 4I3↓$\bar{+}$$Q_1$(22) - 67
^{I55}Tb	I/2$^+$ 7/2$^+$ I/2$^+$	— — —	6I0 I280 I3I0	0.5 2.I I.8	4II↑+Q_1(22) - 20, 4II↓-60 4II↑+Q_1(22) - 98 4II↑$\bar{+}$$Q_1$(22) - 80; 420↑- 6
^{I57}Tb	I/2$^+$ 7/2$^+$ I/2$^+$	598 — —	640 I400 I425	0.6 I.8 I.3	4II↑+Q_1(22) - 26; 4II↓-64 4II↑$\bar{+}$$Q_1$(22) - 97 4II↑$\bar{+}$$Q_1$(22) - 72; 420↑-I4
^{I59}Tb	I/2$^+$ 7/2$^+$ I/2$^+$	58I — —	650 I420 I650	0.4 I.2 0.7	4II↑+Q_1(22) - 27; 4II↓-64 4II↑$\bar{+}$$Q_1$(22) - 97; 4I3↓- 2 4II↑$\bar{+}$$Q_1$(22) - 52; 4II↓-30
^{I6I}Tb	I/2$^+$ 7/2$^+$ I/2$^+$	— — —	590 II80 I220	0.5 I.3 0.6	4II↑+Q_1(22) - 35; 4II↓-54 4II↑+Q_1(22) - 99; 4II↑+Q_1(22) - 4I
^{I59}Ho	3/2$^-$ II/2$^-$	— —	II00 II30	2.8 3.I	523↑+Q_1(22) - 93; 54I↓- 5 523↑$\bar{+}$$Q_1$(22) -I00
^{I6I}Ho	3/2$^-$ II/2$^-$	— —	II40 II60	2.7 2.8	523↑+Q_1(22) - 96; 54I↓- 3 523↑$\bar{+}$$Q_1$(22) -I00
^{I63}Ho	3/2$^-$ II/2$^-$	— —	I0I5 I040	2.2 2.4	523↑+Q_1(22) - 95; 54I↓- 4 523↑$\bar{+}$$Q_1$(22) -I00
^{I65}Tm	5/2$^+$ 3/2$^+$ 5/2$^+$	— — —	990 II00 III0	I.7 3.2 I.6	4II↓+Q_1(22) - 49; 402↑-42 4II↓$\bar{+}$$Q_1$(22) - 94; 4II↑- 4 4II↓$\bar{+}$$Q_1$(22) - 46; 402↑-44

Table 2 (continuation)

Nucleus	K^π	Energy, keV		$B(E2)_{s.p.u.}$	Structure, %
		Experiment	Theory	Theory	
^{I67}Tm	3/2$^+$ 5/2$^+$ 3/2$^+$	47I — —	670 820 990	0.3 2.4 2.5	4II↓+Q_1(22) - II; 4II↑ - 82 4II↓+Q_1(22) - 84; 402↑ - I2 4II↓+Q_1(22) - 89; 4II↑ - I0
^{I7I}Tm	5/2$^+$ 5/2$^+$ 3/2$^+$	9I3 — —	930 I090 II00	0.3 I.5 I.8	4II↓+Q_1(22) - I8; 402↑ - 70 4II↓+Q_1(22) - 75; 402↑ - I6 4II↓+Q_1(22) - 93
^{I69}Lu	3/2$^+$ II/2$^+$	— —	I050 II30	2.0 2.2	404↓+Q_1(22) - 89; 402↓ - I0 404↓$\bar{+}$$Q_1$(22) -I00
^{I73}Lu	3/2$^+$ II/2$^+$	— —	I450 I460	0,6 0.6	404↓+Q_1(22) -I00 404↓$\bar{+}$$Q_1$(22) -I00
^{I77}Ta	3/2$^+$	—	II30	I.0	404↓+Q_1(22) - 83; 402↓ - I5

Table 3

^{153}Eu

K^{π}	Energy, keV		Structure %			
	Experiment	Theory				
$5/2^+$	0	0	413↓96%,	411↓+Q_1(22) 2%		
$3/2^+$	103	-20	411↑89%,	411↓+Q_1(22) 5%,	523↑+Q_1(32) 3%	
$5/2^-$	97	20	532↑94%,	420↑+Q_1(32) 1%		
$7/2^-$		550	523↑86%,	411↑+Q_1(32) 10%		
$1/2^+$		670	411↓48%,	411↑+Q_1(22) 26%,	413↓+Q_1(22)23%	
$3/2^-$		820	541↑86%	550↑+Q_1(22) 5%,	420↑+Q_1(31) 2%	
$5/2^-$		860		532↑+Q_1(20)100%		
$5/2^+$		900		413↓+Q_1(20)100%		
$1/2^+$		920	420↑75%,	532↑+Q_1(32) 8%,	550↑+Q_1(30) 5%,	422↓+Q_1(22)4%
$1/2^-$		1000	550↑42%,	532↑+Q_1(22) 39%,	541↑+Q_1(22) 8%,	420↑+Q_1(30)6%
$3/2^+$		1150		411↑+Q_1(20)100%		
$9/2^-$		1230	514↑ 3%,	532↑+Q_1(22) 97%		
$9/2^+$		1300		413↓+Q_1(22)100%		
$1/2^+$		1380		413↓+Q_1(22) 67%,	411↑+Q_1(22) 31%	
$1/2^-$		1400	550↑19%,	532↑+Q_1(22) 59%,	541↑+Q_1(22)11%,	420↑+Q_1(30)9%
$3/2^-$		1400		411↑+Q_1(30)100%		
$3/2^+$		1510	422↓50%,	420↑+Q_1(22) 26%,	541↑+Q_1(30)16%,	532↑+Q_1(31)5%
$7/2^+$		1520		411↑+Q_1(22) 94%,	532↑+Q_1(31) 5%	

Table 4

^{155}Tb

K^{π}	Energy, keV		Structure %			
	Experiment	Theory				
$3/2^+$	0	0	411↑92%,	411↓+Q_1(22) 4%		
$7/2^-$	545	341	523↑94%,	411↑+Q_1(32) 2%		
$5/2^+$	271	390	413↓96%,	411↓+Q_1(22) 2%		
$5/2^-$	227	530	532↑93%,	550↑+Q_1(22) 2%		
$1/2^+$		610	411↓60%,	411↑+Q_1(22) 20%,	413↓+Q_1(22) 8%	
$3/2^+$		1000		411↑+Q_1(20)100%		
$5/2^+$		1100		413↓+Q_1(20)100%		
$7/2^+$		1280	413↑1%,	411↑+Q_1(22) 98%		
$1/2^-$		1300	550↑18%,	532↑+Q_1(22) 76%,	541↑+Q_1(22) 3%	
$1/2^+$		1310	420↑ 6%	411↑+Q_1(22) 80%		
$1/2^+$		1330		413↓+Q_1(22)100%		
$9/2^+$		1330		413↓+Q_1(22)100%		
$3/2^-$		1350	541↑52%,	411↑+Q_1(30) 35%,	550↑+Q_1(22) 3%	
$5/2^+$		1420	402↑73%,	523↑+Q_1(31) 9%,	660↑+Q_1(22) 6%,	532↑+Q_1(30) 5%
$9/2^-$		1460	514↑ 7%,	532↑+Q_1(22) 92%		
$3/2^-$		1650	541↑ 6%,	523↑+Q_1(22) 56%,	411↑+Q_1(30)34%	
$7/2^+$		1680	404↓68%,	523↑+Q_1(30) 28%,	651↑+Q_1(22) 3%	

Table 5

^{157}Tb

K^{π}	Energy, keV		Structure %			
	Experiment	Theory				
$3/2^+$	0	0	4II↑93%,	4II↓+Q_1(22) 4%		
$7/2^-$	572	360	523↑95%,	4II↑+Q_1(32) 2%		
$5/2^+$	328	380	4I3↓96%,	4II↓+Q_1(22) 2%		
$5/2^-$	326	530	532↑94%,	550↑+Q_1(22) 2%		
$I/2^+$	598	640	4II↓64%,	4II↑+Q_1(22) 26%,	4I3↓+Q_1(22)7%	
$3/2^+$	993	I300		4II↑+Q_1(20)I00%		
$3/2^-$		I370	54I↑48%,	4II↑+Q_1(30) 39%		
$5/2^+$		I390	402↑49%,	4I3↓+Q_1(20) 32%,	523↑+Q_1(3I)I0%,	660↑+Q_1(22)4%
$7/2^+$		I400		4II↑+Q_1(22) 97%		
$I/2^-$		I4I0	550↑2I%,	532↑+Q_1(22) 72%,	54I↑+Q_1(22) 3%	
$I/2^+$		I425	420↑I4%,	4II↑+Q_1(22) 72%,	532↑+Q_1(32) 2%	
$5/2^+$		I450	402↑2I%,	4I3↓+Q_1(20) 68%,	523↑+Q_1(3I) 5%	
$9/2^+$		I460		4I3↓+Q_1(22)I00%		

Table 6

^{159}Tb

K^{π}	Energy, keV		Structure %		
	Experiment	Theory			
$3/2^+$	0	0	4II↑93%,	4II↓+Q_1(22) 4%	
$5/2^+$	348	370	4I3↓96%,		
$7/2^-$		380	523↑96%,	4II↑+Q_1(32) 2%	
$5/2^-$	364	570	532↑93%,	4I3↓+Q_1(30) 2%,	550↑+Q_1(22) 2%
$I/2^+$	58I	650	4II↓64%,	4II↑+Q_I(22)27%,	4I3↓+Q_1(22) 7%
$3/2^-$		II70	54I↑I7%,	4II↑+Q_1(30)80%	
$I/2^+$		I350	420↑I2%,	4I3↓+Q_1(22)63%,	4II↑+Q_1(22)I9%
$5/2^+$		I360	402↑29%,	532↑+Q_1(30)64%,	660↑+Q_1(22) 2%
$I/2^-$		I390	550↑26%,	532↑+Q_1(22)65%,	54I↑+Q_1(22) 4%
$7/2^+$		I420		4II↑+Q_1(22)97%	
$9/2^+$		I470		4I3↓+Q_1(22)I00%	
$3/2^+$		I480		4II↑+Q_1(20)I00%	
$3/2^-$		I580	54I↑35%,	4I3↓+Q_1(3I)44%,	4II↑+Q_1(30)I2%
$I/2^+$		I650	4II↓30%,	4II↑+Q_1(22)52%,	4I3↓+Q_1(22)I4%
$I5/2^+$		I860		$p523{\uparrow}_{n}52I{\downarrow}n642{\uparrow}$	

Table 7

^{161}Tb

K$^{\pi}$	Energy, keV		Structure %		
	Experiment	Theory			
3/2$^+$	0	0	411↑93%,	411↓+Q_1(22) 5%	
5/2$^+$	315	360	413↓97%,	411↓+Q_1(22) 2%	
7/2$^-$	417	390	523↑97%,	411↑+Q_1(32) 1%	
1/2$^+$		590	411↓54%,	411↑+Q_1(22) 35%,	413↓+Q_1(22)10%
5/2$^-$	480	600	532↑96%,	550↑+Q_1(22) 2%	
7/2$^+$		1180		411↑+Q_1(22) 99%	
1/2$^+$		1220		413↓+Q_1(22) 58%,	411↑+Q_1(22)41%
9/2$^+$		1230		413↓+Q_1(22)100%	
1/2$^-$		1250	550↑12%,	532↑+Q_1(22) 85%,	541↑+Q_1(22) 2%
9/2$^-$		1370	514↑ 4%,	532↑+Q_1(22) 96%	
3/2$^-$		1420	541↑16%,	411↑+Q_1(30) 78%,	523↑+Q_1(22) 4%
5/2$^+$		1530	402↑65%,	413↓+Q_1(20) 12%,	532↑+Q_1(30)11%
3/2$^+$		1550		411↑+Q_1(20) 100%	
5/2$^+$		1560		413↓+Q_1(20) 100%	
15/2$^-$		1680		p412↓n642↑n523↓	
17/2$^+$		1730		p523↑n642↑n523↓	

Table 8

^{159}Ho

K	Energy, kev		Structure %			
	Experiment	Theory.				
7/2$^-$	0	0	523↑97%			
3/2$^+$		250	411↑94%			
1/2$^+$	206	380	411↓88%,		411↑+Q_1(22) 9%	
5/2$^+$		700	402↑56%,	413↓28%,	660↑+Q_1(22) 8%,	411↓+Q_1(22)3%
5/2$^+$	650	730	413↓69%,	402↑23%,	532↑+Q_1(30) 5%	
5/2$^-$	624	900	532↑90%,		550↑+Q_1(22) 3%,	413↓+Q_1(30)3%
7/2$^+$		1000	404↓90%,		651↑+Q_1(22) 5%,	523↑+Q_1(30) 3%
7/2$^+$		1050	413↓ 2%,		411↑+Q_1(22)97%	
3/2$^-$		1100	541↑ 5%,		523↑+Q_1(22)93%	
11/2$^-$		1130			523↑+Q_1(22)100%	
1/2$^+$		1140	420↑1%,		411↑+Q_1(22)91%	
9/2$^-$		1145	514↑92%,		402↑+Q_1(32) 4%	
3/2$^+$		1190			411↑+Q_1(20)100%	
1/2$^-$		1330	541↓86%,		411↓+Q_1(30) 10%	
9/2$^+$		1390			413↓+Q_1(22)100%	
3/2$^-$		1420	541↑ 8%,		411↑+Q_1(30) 87%	
1/2$^-$		1470	550↑14%,		532↑+Q_1(22) 81%,	541↑+Q_1(22)2%

Table 9

^{161}Ho

K^{π}	Energy, keV		Structure %		
	Experiment	Theory			
$7/2^-$	0	0	523↑97%		
$3/2^+$	299	260	411↑94%,		411↓+Q_1(22) 3%
$1/2^+$	211	380	411↓88%,		411↑+Q_1(22) 9%
$5/2^+$		700	402↑79%, 413↓2%,		660↑+Q_1(22) 8%
$5/2^+$	760	740	413↓96%, 402↑2%		
$5/2^-$	827	950	532↑89%,		411↑+Q_1(31) 5%, 550↑+Q_1(22)3%
$7/2^+$	253	1040	404↓93%,		651↑+Q_1(22) 6%
$7/2^+$		1070	413↑2%,		411↑+Q_1(22) 98%
$9/2^-$		1110	514↑89%,		402↑+Q_1(32) 7%
$3/2^-$		1140	541↑3%,		523↑+Q_1(22) 96%
$1/2^+$		1150	420↑2%,		411↑+Q_1(22) 98%
$11/2^-$		1160			523↑+Q_1(22)100%
$1/2^-$	424	1370	541↓72%,		411↑+Q_1(32) 20%, 411↑+Q_1(31)5%
$1/2^+$		1400	660↑32%,		402↑+Q_1(22) 58%, 651↑+Q_1(22)5%
$9/2^+$		1415			413↓+Q_1(22)100%
$3/2^+$		1420	402↓3%		523↑+Q_1(32) 96%
$1/2^-$		1460	550↑2%,		411↑+Q_1(32) 82%, 532↑+Q_1(22)10%
$3/2^+$		1465			411↑+Q_1(20)100%

Table 10

^{163}Ho

K^{π}	Energy, keV		Structure	%	
	Experiment	Theory			
$7/2^-$	0	0	523↑98%		
$3/2^+$		240	4II↑95%,	4II↓+Q_1(22) 2%	
$I/2^+$	298	390	4II↓9I%,	4II↑+Q_1(22) 8%	
$5/2^-$		950	532↑9I%,	550↑+Q_1(22) 3%	
$5/2^+$		I000	4I3↓97%		
$7/2^+$		I0I0	4I3↓ I%,	4II↑+Q_1(22) 99%	
$3/2^-$		I0I5	54I↑ 4%,	523↑+Q_1(22) 95%	
$II/2^-$		I040		523↑+Q_1(22)I00%	
$I/2^+$		II20	4II↓8%,	4II↑+Q_1(22) 92%	
$9/2^-$		II80	5I4↑95%,	402↑+Q_1(32) 2%	
$7/2^+$	440	I200	404↓9I%,	523↑+Q_1(30) 6%	
$3/2^+$		I300		4II↑+Q_1(20)I00%	
$I/2^-$		I320	550 ↑I%,	4II↑+Q_1(32) 95%	
$I/2^-$		I400	550 ↑I6%,	532↑+Q_1(22) 75%,	4II↑+Q_1(32) 4%
$3/2^-$		I4I0	54I ↑7%,	4II↑+Q_1(30) 90%	
$5/2^+$		I4I5	402 ↑34%,	4II↓+Q_1(22) 58%,	523↑+Q_1(3I) 2%
$I7/2^+$		I570		p523↑n 642↑n 523↓	

Table 11

^{165}Tm

K^{π}	Energy, keV		Structure %
	Experiment	Theory	
$1/2^+$	0	0	411↓96%
$7/2^-$	149	300	523↑94%, 411↓+Q_1(32) 3%
$9/2^-$		550	514↑94%, 402↓+Q_1(32) 3%
$7/2^+$	69	630	404↓96%
$3/2^+$		660	411↑84%, 523↑+Q_1(32) 7%, 411↓+Q_1(22)6%
$5/2^+$		990	402↑42%, 413↓2%, 411↓+Q_1(22)49%, 514↑+Q_1(32)3%,
$3/2^-$		1010	541↓3%, 523↑+Q_1(22)96%
$11/2^-$		1060	523↑+Q_1(22)100%
$3/2^+$		1100	411↑4%, 411↓+Q_1(22) 94%
$5/2^+$		1100	402↑44%, 413↓3%, 411↓+Q_1(22) 46%, 514↑+Q_1(32)3%
$7/2^+$		1250	413↓ 1%, 411↓+Q_1(22) 98%
$1/2^+$		1320	411↓+Q_1(22)100%
$1/2^-$		1340	541↓89%, 411↓+Q_1(30) 8%
$5/2^-$		1400	532↑75%, 411↑+Q_1(31) 14%, 411↓+Q_1(32) 3%
$3/2^+$		1470	651↑11%, 404↓+Q_1(22) 86%, 523↑+Q_1(32) 2%
$17/2^+$		1960	p523↑n642↑n523↓

Table 12

^{167}Tm

K^{π}	Energy, keV		Structure %
	Experiment	Theory	
$1/2^+$	0	0	411↓97%
$7/2^-$	293	360	523↑96%, 411↓+Q_1(32) 2%
$9/2^-$		560	514↑96% 402↓+Q_1(32) 2%
$7/2^+$	179	600	404↓97% 651↑+Q_1(22) 2%
$3/2^+$	471	670	411↑82% 411↓+Q_1(22) 11%, 523↑+Q_1(32)4%
$5/2^+$		820	402↑12%, 413↓3%, 411↓+Q_1(22) 84%
$3/2^-$		900	541↓3%, 523↑+Q_1(22) 97%
$11/2^-$		940	523↑+Q_1(22)100%
$3/2^+$		990	411↑10% 411↓+Q_1(22) 89%
$5/2^+$		1000	402↑74% 411↓+Q_1(22) 13%, 660↑+Q_1(22)4%
$7/2^+$		1140	413↓1%, 411↓+Q_1(22) 98%
$1/2^+$		1200	411↓+Q_1(22)100%
$1/2^-$	172	1290	541↓90%, 411↓+Q_1(30) 8%
$5/2^-$	1527	1510	532↑81%, 514↑+Q_1(22) 6%, 411↓+Q_1(32)5%
$5/2^+$	1581	1620	413↓94% 411↓+Q_1(22) 3%
$19/2^+$		2110	p523↑n523↓n633↑

Table 13

^{171}Tm

K^{π}	Energy, keV Experiment	 Theory	Structure %			
I/2$^+$	0	0	4II↓97%			
7/2$^-$	425	360	523↑97%			
9/2$^-$		550	5I4↓97%			
7/2$^+$	635	560	404↓96%,		65I↑+Q_1(22) 3%	
3/2$^+$	676	680	4II↑88%,		4II↓+Q_1(22) 7%	
5/2$^+$	9I3	930	402↑70%,		4II↓+Q_1(22) I8%,	660↑+Q_1(22)4%
3/2$^-$		I0I5	54I↑ 4%,		523↑+Q_1(22) 95%	
I/2$^+$		I040			4II↓+Q_1(20)I00%	
II/2$^-$		I070			523↑+Q_1(22)I00%	
5/2$^+$		I090	402↑I6%,	4I3↓ 6%,	4II↓+Q_1(22) 75%	
3/2$^+$		II00			4II↓+Q_1(22) 93%	
7/2$^+$		I250	4I3↑ 2%		4II↑+Q_1(22) 98%	
I/2$^-$		I260	54I↓86%,		4II↓+Q_1(30) II%	
I/2$^-$		I460			4II↓+Q_1(3I)I00%	
9/2$^+$		I440			523↑+Q_1(3I)I00%	
5/2$^+$		I445			523↑+Q_1(3I)I00%	
5/2$^-$		I500	532↑84%,		4II↑+Q_1(3I) 8%,	550↑+Q_1(22)4%
5/2$^+$		I530	4I3↓26%		4II↓+Q_2(22) 70%	
5/2$^+$		I640	4I3↓63%		4II↓+Q_2(22) 29%	

Table 14

^{169}Lu

K^{π}	Energy, keV Experiment	 Theory	Structure %		
7/2$^+$	0	0	404↓97%,	402↓+Q_1(22) 2%	
9/2$^-$		60	5I4↓96%,	402↑+Q_1(32) I%	
I/2$^+$		220	4II↓90%,	4II↑+Q_1(22) 6%	
5/2$^+$		540	402↑87%,	5I4↓+Q_1(32) 4%,	660↑+Q_1(22) 4%
3/2$^+$		730	4II↑39%,	4II↓+Q_1(22) 56%	
7/2$^-$	493	740	523↑93%,	4II↑+Q_1(32) 3%	
I/2$^-$	30	980	54I↓94%,	532↓+Q_1(22) 2%	
5/2$^+$		I000	4I3↓ 6%,	4II↓+Q_1(22) 93%	
3/2$^+$		I050	402↓I0%,	404↓+Q_1(22) 89%	
II/2$^+$		II30		404↓+Q_1(22)I00%	
I/2$^+$		I270		4II↓+Q_1(20)I00%	
5/2$^-$		I300	532↑ 2%,	5I4↓+Q_1(22) 97%	
7/2$^+$		I305		404↓+Q_1(20)I00%	
I3/2$^-$		I3I0		5I4↓+Q_1(22)I00%	
3/2$^-$		I340	54I↑I2%,	523↑+Q_1(22) 85%	
9/2$^-$		I430		5I4↓+Q_1(20)I00%	
II/2$^-$		I450		523↑+Q_1(22)I00%	
I/2$^+$		I5I0	660↑30%,	402↓+Q_1(22) 63%,	402↑+Q_1(22) 2%
3/2$^-$		I530	532↓59%,	4II↓+Q_1(3I) 22%,	54I↓+Q_1(22) 9%
I/2$^-$		I550	530↑ 7%,	4II↓+Q_1(30) 85%,	4II↓+Q_1(3I) 7%
I9/2$^-$		I720		p404↓n 523↑n 633↑	

Table 15

^{173}Lu

K^{π}	Energy, keV		Structure %		
	Experiment	Theory			
$7/2^+$	0	0	404↓ 99%		
$9/2^-$		40	5I4↑97%,	402↑ +Q_1(32) 2%	
$I/2^+$	425	3I0	4II↓98%		
$5/2^+$	357	600	402↑84%,	5I4↑ +Q_1(32) I4%	
$7/2^-$		720	523↑93%,	4II↑ +Q_1(32) 6%	
$I/2^-$	I28	I030	54I↓97%,	4II↓ +Q_1(3I) I%	
$I/2^+$		I070		4II↓ +Q_1(20)I00%	
$3/2^+$		I080	4II↑67%,	523↑ +Q_1(32) 27%,	4II↓+Q_1(22) 2%
$I/2^-$		II60	530↑I%,	4II↓ +Q_1(3I) 98%	
$3/2^-$		II70	532↓2%,	4II↓ +Q_1(3I) 98%	
$7/2^+$		II80		404↓ +Q_1(20)I00%	
$3/2^-$		I270		4II↓ +Q_1(32)I00%	
$5/2^-$		I280	532↑3%,	4II↓ +Q_1(32) 92%,	404↓+Q_1(3I) 4%
$5/2^-$		I290		404↓ +Q_1(3I) 95%,	4II↓+Q_1(32) 4%
$5/2^+$		I330	642↑2%,	4II↓ +Q_1(22) 97%	
$3/2^+$		I330		4II↓ +Q_1(22)I00%	
$7/2^+$		I390		5I4↑ +Q_1(3I)I00%	
$3/2^-$		I395	532↓5%	404↓ +Q_1(32) 95%	
$II/2^-$		I400		404↓ +Q_1(32)I00%	
$3/2^+$		I450		404↓ +Q_1(22)I00%	
$II/2^+$		I460		404↓ +Q_1(22)I00%	
$9/2^+$		I500	404↑I%	523↑ +Q_1(3I) 99%	
$I/2^-$		I620		4II↓ +Q_1(30)I00%	

Table 16

^{175}Lu

K^{π}	Energy, keV		Structure %	
	Experiment	Theory		
$7/2^+$	0	0	404↓ 99%	
$9/2^-$	396	I00	5I4↑99%	
$I/2^+$		3I0	4II↓97%	
$5/2^+$	343	700	402↑96%,	660↑ +Q_1(22) 2%
$7/2^-$		850	523↑99%	
$I/2^-$	358	I000	54I↓97%	
$3/2^+$		II80	4II↑69%,	4II↓ +Q_1(22) 29%
$3/2^-$		I280		4II↓+Q_1(32)I00%
$5/2^-$		I280		4II↓ +Q_1(32)I00%
$I9/2^+$	I40I	I300		p404↓ n5I2↑n5I4↓
$I/2^+$		I340		4II↓ +Q_1(20)I00%
$2I/2^-$		I360		p5I4↑n5I2↑n5I4↓
$7/2^+$		I380		404↓ +Q_1(20)I00%
$II/2^-$		I390		404↓ +Q_1(32)I00%
$3/2^-$		I400		404↓ +Q_1(32)I00%
$9/2^-$		I470		5I4↑ +Q_1(20)I00%
$5/2^+$		I490		5I4↑ +Q_1(32)I00%
$I3/2^+$		I490		5I4↑ +Q_1(32)I00%
$I/2^-$		I520		4II↓ +Q_1(30)I00%
$3/2^-$		I600	532↓ 9%	4II↓ +Q_1(3I) 90%
$3/2^-$		I680	532↓82%	4II↓ +Q_1(3I) I0%

^{177}Ta

K^{π}	Energy, keV		Structure %		
	Experiment	Theory			
7/2$^+$	0	0	404↓ 99%		
9/2$^-$	74	-60	5I4↑ 99%		
5/2$^+$	7I	I80	402↑ 95%		
I/2$^-$	2I7	480	54I↓ 98%	532 + Q_1(22) I%	
I/2$^+$		6I0	4II↓ 92%	4II + Q_1(22) 6%	
3/2$^-$		I020	532↓ 9I%	54I + Q_1(22) 6%	530 + Q_1(22) 3%
3/2$^+$		II30	402↓ I5%	404↓+Q_1(22) 83%	
II/2$^-$		I200		404↓+Q_1(32)I00%	
3/2$^-$		I200		404↓+Q_1(32)I00%	
7/2$^+$		I2I0		404↓+Q_1(20)I00%	
5/2$^+$		I220		5I4↑+Q_1(32)I00%	
I3/2$^+$		I220		5I4↑+Q_1(32)I00%	
I/2$^+$		I230	660↑ 36%	402↑+Q_1(22) 58%,	402↓+Q_1(22) 3%
3/2$^+$		I250	4II↑ 43%	4II↓+Q_1(22) 56%	
9/2$^-$		I260		5I4↑+Q_1(20)I00%	
7/2$^-$		I270	523↑ 98%		
5/2$^-$		I300	532↑ I%,	5I4↑+Q_1(22) 99%	
I/2$^-$		I390	530↑ 90%,	532↓+Q_1(22) 7%	
23/2$^+$		I460		p5I4↑n5I2↑n624↑	
2I/2$^-$		I470		p5I4↑n5I2↑n5I4↓	
I/2$^+$		I490	400↑ 37%,	402↑+Q_1(22) 58%,	402↓+Q_1(22) 2%
2I/2$^-$		I5I0		p404↓n5I2↑n624↑	