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PROTON ONE-QUASIPARTICLE STATES OF HEAVIEST NUCLEI

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Proton one-quasiparticle states of heaviest nuclei are calculated within a macroscopic-microscopic approach. Basic characteristics of these states (projection of spin on the symmetry axis, parity, excitation energy, Nilsson label) are given. Much attention is paid to systematics of them (especially of the ground state), as functions of neutron number. Other important properties of the analyzed nuclei, as deformation, deformation energy, shell correction to energy and proton pairing-energy gap parameter, are also given. Heavy and super heavy odd-Z, even-N nuclei with proton number Z=93–117 and neutron number N=136–178 are considered. Most of them are expected to be deformed. It is obtained that characteristics of the ground states, which are known experimentally, is rather well reproduced.

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1. Introduction

Studies of single-particle states of heavy nuclei have a rather long history (*cf. e.g.* [1] and references given therein). Recently, however, these studies have been much intensified and extended [2–8]. This is connected with a fast progress in synthesis of these nuclei and in detection of their decays. The experimental studies have been accompanied by respective theoretical research (*e.g.* [9–12]).

The objective of this paper is an analysis of proton single-particle states of heavy and super heavy nuclei. The analysis is done within a macroscopic–microscopic approach, which appeared to be successful in description and predictions of a number of properties of these nuclei (*e.g.* [13–16]). We concentrate on nuclei with odd proton (Z=93–117) and even neutron (N=136–178) numbers. With respect to a previous macroscopic–microscopic analysis [9], the present one uses a larger deformation space and studies a larger region of nuclei.

2. Theoretical model

As already stated in the Introduction, the calculations are done within a macroscopic–microscopic approach. The Yukawa plus-exponential model [17] is used for the calculation of the macroscopic part of energy of a nucleus, and the Strutinski shell correction is taken for its microscopic part. The Woods–Saxon single-particle potential, with the "universal" variant of its parameters found in [18] and also specified explicitly in [13], is used for description of the single-particle properties of a nucleus. Values of parameters of the macroscopic part of mass are taken the same as in [19], where they were adjusted to experimental masses [20] of even–even heaviest nuclei with atomic number $Z \geq 84$.

A large, 7-dimensional deformation space, $\{\beta_\lambda\}$, $\lambda = 2, 3, ..., 8$, is used to obtain the equilibrium deformation of a nucleus. The contribution of an odd nucleon, occupying a single-particle state $|\,\mu\rangle$, to energy of a nucleus is described by the one-quasiparticle energy $E_\mu = \sqrt{(e_\mu - \lambda)^2 + \Delta^2}$. Here, e_μ is the energy of the odd nucleon in the state $|\,\mu\rangle$ and Δ is the pairing-energy gap parameter, calculated in the BCS approximation. Pairing interaction of the monopole type, with the same strength parameters as in [19], is taken. No blocking is used. The calculations are done in a similar way to that of Refs. [16, 21].

3. Results

3.1. Equilibrium deformations

As stated in the previous section, equilibrium deformation of a nucleus is calculated in the 7-dimensional deformation space, $\{\beta_\lambda\}$, $\lambda = 2, 3, ..., 8$. Non-zero equilibrium deformation parameters of odd multipolarity, $\beta^0_\lambda \neq 0$, $\lambda = 3, 5, 7$, are obtained, however, only for very neutron-deficient isotopes of the analyzed elements (*cf.* [22]), *e.g.* ^{223,225,227}Np. We do not include these nuclei into the present analysis. Thus, for all nuclei studied here, only deformations of even multi polarities $\beta^0_\lambda, \lambda = 2, 4, 6, 8$, may be different from zero. Their values are given in Table I.

3.2. Deformation energy, shell correction energy and proton pairing-energy gap

Table I also shows a few other important characteristics of the considered nuclei: deformation energy $E_{\rm def}$, shell correction energy $E_{\rm sh}$ and proton energy gap parameter $\Delta_{\rm p}$. The energy $E_{\rm def}$ tells us how well is a nucleus deformed and $E_{\rm sh}$ informs us how much it gains in energy from its shell structure. Value of the parameter $\Delta_{\rm p}$ gives an information how good is the BCS approximation. If $\Delta_{\rm p}$ is not too close to zero, the approximation is good.

TABLE I

Deformation parameters β^0_λ, deformation energies $E_{\rm def}$, shell correction energies $E_{\rm sh}$, proton energy-gap parameters $\Delta_{\rm p}$ and ground-state quantum characteristics: theoretical (th) and experimental (exp) given for odd-Z and odd-A nuclei with Z=93–117.

N	A	β^0_2	β^0_4	β^0_6	β^0_8	$E_{\rm def}$ MeV	$E_{\rm sh}$ MeV	$\Delta_{\rm p}$ MeV	(th) g.s.	(exp) g.s.	Ref.
					$Z=93$						
136	229	0.188	0.117	0.035	-0.013	6.2	-1.2	0.56	5[642]		
138	231	0.197	0.116	0.027	-0.018	7.6	-1.6	0.56	5[642]	(5)	[25]
140	233	0.206	0.113	0.019	-0.021	8.7	-2.0	0.59	5[642]	(5+)	[25]
142	235	0.213	0.108	0.009	-0.023	9.5	-2.3	0.63	5[642]	5+	[25]
144	237	0.220	0.101	0.000	-0.026	9.9	-2.4	0.69	5[642]	5+	[25]
146	239	0.228	0.093	-0.010	-0.028	10.1	-2.4	0.77	5[642]	5+	[25]
148	241	0.230	0.079	-0.018	-0.021	9.9	-2.3	0.86	5[642]	(5+)	[25]
150	243	0.233	0.058	-0.026	-0.009	9.4	-2.1	0.96	5[642]	(5–)	[25]
					$Z=95$						
140	235	0.212	0.100	0.009	-0.017	9.4	-1.7	0.65	5[523]		
142	237	0.220	0.096	0.000	-0.019	10.4	-2.2	0.66	5[523]	5(–)	[25]
144	239	0.227	0.090	-0.009	-0.023	10.9	-2.6	0.68	5[523]	(5)–	[25]
146	241	0.234	0.084	-0.017	-0.026	11.2	-2.8	0.72	5[523]	5–	[25]
148	243	0.235	0.074	-0.022	-0.021	11.1	-2.8	0.77	5[523]	5–	[25]
150	245	0.235	0.055	-0.029	-0.005	10.7	-2.7	0.85	5[642]	(5+)	[25]
152	247	0.241	0.037	-0.039	0.002	10.2	-2.7	0.93	3[521]	(5)	[25]
154	249	0.239	0.028	-0.039	0.007	9.3	-2.4	0.97	3[521]		
					$Z=97$						
140	237	0.218	0.086	-0.004	-0.012	9.8	-1.5	0.61	3[521]		
142	239	0.224	0.083	-0.010	-0.012	11.0	-2.2	0.62	3[521]	(7+)	[25]
144	241	0.231	0.078	-0.018	-0.016	11.7	-2.7	0.64	3[521]	(7+)	[25]
146	243	0.238	0.073	-0.024	-0.017	12.2	-3.1	0.66	3[521]	(3–)	[25]
148	245	0.239	0.063	-0.031	-0.013	12.2	-3.2	0.70	3[521]	3–	[25]
150	247	0.241	0.049	-0.035	-0.006	11.9	-3.3	0.75	3[521]	(3–)	[25]
152	249	0.244	0.036	-0.042	0.000	11.5	-3.4	0.81	3[521]	7+	[25]
154	251	0.242	0.027	-0.041	0.004	10.5	-3.0	0.85	3[521]	(3–)	[25]
					$Z=99$						
144	243	0.238	0.067	-0.030	-0.013	12.2	-2.6	0.59	7[633]	(7+)	[5]
146	245	0.243	0.063	-0.037	-0.015	12.7	-3.2	0.59	7[633]	(7+)	[5]
148	247	0.245	0.053	-0.041	-0.010	12.9	-3.5	0.61	7[633]	(7+)	[5]
150	249	0.246	0.040	-0.044	-0.003	12.8	-3.8	0.65	7[633]	7(+)	[25]
152	251	0.249	0.028	-0.050	0.002	12.5	-4.0	0.70	7[633]	(3–)	[3,25]
154	253	0.247	0.020	-0.049	0.008	11.5	-3.7	0.75	7[633]	7+	[25]
156	255	0.246	0.009	-0.047	0.013	10.3	-3.3	0.81	7[633]	(7+)	[25]

TABLE I cont.

N	A	β_2^0	β_4^0	β_6^0	β_8^0	$E_{\rm def}$ MeV	$E_{\rm sh}$ MeV	$\Delta_{\rm p}$ MeV	(th) g.s.	(exp) g.s.	Ref.
					$Z = 101$						
142	243	0.247	0.057	-0.036	-0.008	11.1	-1.6	0.54	1[521]		
144	245	0.246	0.055	-0.042	-0.011	12.1	-2.4	0.54	1[521]	(7)	[25]
146	247	0.249	0.052	-0.047	-0.012	12.8	-3.0	0.54	1[521]	(7−)	[5]
148	249	0.251	0.043	-0.051	-0.006	13.2	-3.5	0.55	1[521]	(7−)	[4, 5]
150	251	0.252	0.030	-0.054	0.001	13.3	-4.1	0.57	1[521]	(7−)	[5]
152	253	0.254	0.020	-0.059	0.005	13.2	-4.5	0.60	1[521]		
154	255	0.253	0.011	-0.057	0.012	12.2	-4.2	0.65	1[521]	(7−)	[25]
156	257	0.252	0.000	-0.055	0.018	11.0	-3.9	0.72	1[521]	(7−)	[25]
158	259	0.248	-0.013	-0.050	0.022	9.8	-3.6	0.79	1[521]	(7−)	[25]
160	261	0.237	-0.027	-0.035	0.019	8.7	-3.5	0.88	7[514]		
					$Z = 103$						
146	249	0.246	0.036	-0.041	-0.010	12.3	-2.5	0.62	7[514]		
148	251	0.248	0.026	-0.046	-0.004	12.8	-3.2	0.61	7[514]		
150	253	0.250	0.016	-0.050	0.003	13.1	-3.9	0.61	7[514]	(7−)	[4, 5]
152	255	0.253	0.008	-0.056	0.008	13.2	-4.6	0.61	7[514]	(7−)	[5]
154	257	0.252	-0.002	-0.055	0.015	12.3	-4.4	0.64	7[514]	(9+)	[25]
156	259	0.252	-0.013	-0.054	0.022	11.3	-4.3	0.67	7[514]		
158	261	0.249	-0.024	-0.050	0.026	10.3	-4.2	0.72	7[514]		
					$Z = 105$						
148	253	0.246	0.008	-0.042	0.002	12.2	-3.0	0.55	9[624]		
150	255	0.247	0.000	-0.046	0.007	12.8	-3.9	0.54	9[624]		
152	257	0.249	-0.006	-0.051	0.010	13.1	-4.7	0.54	9[624]	(9+)	[4, 5]
154	259	0.249	-0.016	-0.050	0.017	12.4	-4.7	0.54	9[624]		
156	261	0.249	-0.026	-0.049	0.024	11.5	-4.8	0.55	9[624]		
158	263	0.247	-0.036	-0.046	0.028	10.6	-4.9	0.58	9[624]		
					$Z = 107$						
152	259	0.246	-0.019	-0.046	0.014	12.5	-4.7	0.41	5[512]		
154	261	0.248	-0.030	-0.045	0.019	12.1	-5.0	0.40	5[512]		
156	263	0.246	-0.040	-0.044	0.027	11.4	-5.2	0.39	5[512]		
158	265	0.246	-0.048	-0.043	0.032	10.7	-5.5	0.39	5[512]		
160	267	0.240	-0.056	-0.034	0.031	10.0	-5.9	0.43	5[512]		
162	269	0.235	-0.065	-0.026	0.029	9.4	-6.4	0.47	5[512]		
164	271	0.228	-0.067	-0.018	0.023	7.5	-5.5	0.53	5[512]		
					$Z = 109$						
154	263	0.232	-0.029	-0.039	0.018	10.3	-4.0	0.53	9[505]		
156	265	0.238	-0.049	-0.030	0.022	9.8	-4.4	0.50	11[615]		
158	267	0.236	-0.059	-0.027	0.025	9.3	-4.9	0.49	11[615]		
160	269	0.233	-0.067	-0.021	0.026	8.9	-5.5	0.49	11[615]		
162	271	0.229	-0.075	-0.015	0.026	8.6	-6.3	0.49	11[615]		
164	273	0.222	-0.079	-0.007	0.020	6.9	-5.7	0.51	11[615]		
166	275	0.215	-0.082	0.000	0.016	5.4	-5.0	0.55	11[615]		

TABLE I cont.

N	A	β_2^0	β_4^0	β_6^0	β_8^0	$E_{\rm def}$ MeV	$E_{\rm sh}$ MeV	$\Delta_{\rm p}$ MeV	(th) g.s.	(exp) g.s.	Ref.
					$Z = 111$						
160	271	0.222	-0.069	-0.013	0.021	7.0	-4.6	0.63	11[615]		
162	273	0.224	-0.084	-0.005	0.024	6.8	-5.6	0.60	3[512]		
164	275	0.216	-0.089	0.005	0.018	5.5	-5.3	0.60	3[512]		
166	277	0.210	-0.093	0.012	0.013	4.2	-4.8	0.62	3[512]		
168	279	0.202	-0.097	0.020	0.009	3.2	-4.3	0.64	3[512]		
170	281	0.147	-0.050	0.000	0.000	2.2	-3.9	0.73	11[615]		
172	283	0.126	-0.051	0.008	0.003	1.9	-4.2	0.79	1[521]		
					$Z = 113$						
164	277	0.210	-0.095	0.012	0.018	4.0	-5.0	0.61	1[510]		
166	279	0.203	-0.100	0.020	0.013	3.1	-4.7	0.61	1[510]		
168	281	0.200	-0.107	0.030	0.009	2.3	-4.4	0.60	1[510]		
170	283	0.149	-0.066	0.012	0.005	1.6	-4.2	0.67	3[512]		
172	285	0.132	-0.063	0.016	0.002	1.3	-4.5	0.72	3[512]		
174	287	0.095	-0.043	0.009	0.001	1.0	-4.8	0.81	7[503]		
176	289	0.091	-0.054	0.017	-0.001	0.7	-5.1	0.83	7[503]		
					$Z = 115$						
168	283	0.056	0.019	-0.005	-0.001	0.4	-3.6	0.56	1[541]		
170	285	0.065	0.009	-0.009	0.001	0.4	-4.1	0.61	1[541]		
172	287	0.066	-0.004	-0.005	0.001	0.4	-4.6	0.66	1[541]		
174	289	0.067	-0.022	0.003	0.001	0.3	-5.1	0.71	1[541]		
176	291	0.034	-0.002	-0.001	0.000	0.1	-5.4	0.64	1[541]		
178	293	0.018	0.006	-0.001	0.000	0.1	-5.9	0.65	1[541]		
					$Z = 117$						
170	287	0.079	-0.001	-0.011	0.002	0.8	-4.4	0.56	3[512]		
172	289	0.077	-0.013	-0.004	0.002	0.8	-4.8	0.60	3[512]		
174	291	0.074	-0.028	0.006	0.001	0.7	-5.3	0.65	3[512]		
176	293	0.063	-0.028	0.007	0.000	0.3	-5.5	0.66	3[512]		
178	295	0.032	-0.010	0.002	0.000	0.1	-5.7	0.69	3[512]		

One can see in Table I that most of the considered nuclei are well deformed (as such ones, we consider nuclei with $E_{\rm def} > 2$ MeV [23]). Only one nucleus with $Z = 111$, four nuclei with $Z = 113$ and all nuclei with $Z = 115$ and 117 have $E_{\rm def} < 2$ MeV and, thus, are transitional or almost spherical.

Concerning shell correction energy $E_{\rm sh}$, it reflects a general tendency discussed *e.g.* in [13, 14, 24]. For nuclei considered in this paper, $E_{\rm sh}$ takes its maximum (about 6.5 MeV in absolute value) for nuclei with closed neutron deformed shell at $N = 162$. It becomes also large for nuclei with N approaching closed spherical shell at $N = 184$.

3.3. One-quasiparticle states

In this subsection, we present quantum characteristics and excitation energies of 6 lowest proton states: the ground state and 5 excited states. The quantum characteristics are: projection of the total spin of a state on the symmetry axis Ω and the Nilsson ("asymptotic") quantum numbers $[N\, n_z \Lambda]$, where N is the total number of the oscillator quanta, n_z is the number of quanta along the symmetry axis Oz and Λ is projection of the orbital angular momentum on the symmetry axis. For a shorter notation, we give 2Ω instead of Ω, and do not show explicitly parity π of a state, as it is the same as parity of the number N ($\pi = (-1)^N$). (In the figures, however, we explicitly show also π).

Characteristics of the ground state (g.s.) of considered nuclei are given in Table I. They are compared with available experimental data, taken from references given in the last column. As usual, data, which are not certain, are put into round brackets. One can see that in most cases, calculated Ω and parity agree with experimental ones. More particularly, of 38 cases, in which experimental indications of the values of Ω and π are given, the agreement appears in 24 cases. In the rest ones, a calculated state with proper Ω and π is close (first exited state as a rule) or even very close to the ground state, as can be seen in Figs. 3 to 8.

Table II gives quantum characteristics and excitation energies of the lowest five proton one-quasiparticle states of considered nuclei. One can see that their energies fill up, generally, the interval of up to about 1 MeV.

To get an orientation, how well the calculated spectra reproduce experimental ones, we show Figs. 1 and 2. One can see that usually the discrepancy in energy of the lowest states does not exceed about 300 keV, although in some cases it may be larger (1-[530] state in the figures). Average discrepancy (rms) for the three exited states of ^{237}Np (without the 1-[530] state), shown in Fig. 1, is 302 keV, and four exited states of ^{241}Am is also 302 keV.

Figs. 3 to 15 illustrate the dependence of the proton spectra on neutron number N (or mass number A) for the elements with $Z = 93$ to $Z = 117$. Behavior (systematics) of each level with changing N is shown. Generally, larger the excitation energy, stronger is the dependence. In particular, the ground state remains usually the same for a rather long chain of isotopes.

TABLE II

Characteristics $2\Omega[Nn_z\Lambda]$ and excitation energies of the lowest 5 exited states of odd-Z and odd-A nuclei with Z=93–117.

N	A	1	2	3	4	5
				$Z = 93$		
136	229	5[523] 0.19	3[521] 0.38	3[651] 0.58	1[530] 1.01	7[514] 1.05
138	231	5[523] 0.25	3[521] 0.46	3[651] 0.60	1[530] 1.02	1[400] 1.13
140	233	5[523] 0.26	3[521] 0.52	3[651] 0.59	1[400] 0.97	1[530] 1.01
142	235	5[523] 0.23	3[651] 0.54	3[521] 0.55	1[400] 0.78	1[530] 0.98
144	237	5[523] 0.19	3[651] 0.49	3[521] 0.55	1[400] 0.60	3[402] 0.92
146	239	5[523] 0.13	1[400] 0.41	3[651] 0.43	3[521] 0.52	3[402] 0.73
148	241	5[523] 0.03	1[400] 0.27	3[651] 0.32	3[521] 0.43	3[402] 0.62
150	243	5[523] 0.01	1[400] 0.14	3[651] 0.18	3[521] 0.29	3[402] 0.50
				$Z = 95$		
140	235	5[642] 0.09	3[521] 0.17	7[633] 0.72	3[651] 0.94	7[514] 0.97
142	237	5[642] 0.10	3[521] 0.18	7[633] 0.66	3[651] 0.91	1[400] 0.98
144	239	5[642] 0.12	3[521] 0.19	7[633] 0.59	1[400] 0.80	3[651] 0.84
146	241	5[642] 0.14	3[521] 0.19	7[633] 0.50	1[400] 0.62	3[651] 0.76
148	243	5[642] 0.07	3[521] 0.14	7[633] 0.42	1[400] 0.45	3[651] 0.59
150	245	3[521] 0.05	5[523] 0.13	1[400] 0.27	7[633] 0.32	3[651] 0.36
152	247	5[642] 0.01	1[400] 0.13	7[633] 0.22	3[402] 0.22	5[523] 0.30
154	249	5[642] 0.02	1[400] 0.12	3[651] 0.19	7[633] 0.20	5[523] 0.41
				$Z = 97$		
140	237	7[633] 0.26	5[523] 0.27	5[642] 0.38	7[514] 0.69	1[521] 0.85
142	239	7[633] 0.23	5[523] 0.30	5[642] 0.40	7[514] 0.76	1[521] 0.83
144	241	7[633] 0.18	5[523] 0.31	5[642] 0.43	1[521] 0.81	7[514] 0.84
146	243	7[633] 0.14	5[523] 0.34	5[642] 0.45	1[521] 0.79	1[400] 0.87
148	245	7[633] 0.12	5[642] 0.38	5[523] 0.43	1[400] 0.71	1[521] 0.74
150	247	7[633] 0.09	5[642] 0.31	1[400] 0.53	5[523] 0.54	1[521] 0.66
152	249	7[633] 0.05	5[642] 0.25	1[400] 0.35	3[402] 0.51	1[521] 0.54
154	251	7[633] 0.03	5[642] 0.20	1[400] 0.30	3[402] 0.44	1[521] 0.47
				$Z = 99$		
144	243	3[521] 0.15	1[521] 0.39	7[514] 0.58	5[523] 0.84	5[642] 0.85
146	245	3[521] 0.14	1[521] 0.37	7[514] 0.66	5[642] 0.85	5[523] 0.86
148	247	3[521] 0.15	1[521] 0.34	7[514] 0.65	5[642] 0.77	1[400] 0.93
150	249	3[521] 0.17	1[521] 0.28	7[514] 0.61	5[642] 0.67	1[400] 0.75
152	251	3[521] 0.20	1[521] 0.20	1[400] 0.55	5[642] 0.58	7[514] 0.60
154	253	1[521] 0.16	3[521] 0.22	1[400] 0.48	7[514] 0.50	5[642] 0.51
156	255	1[521] 0.12	3[521] 0.25	7[514] 0.38	1[400] 0.40	5[642] 0.43

TABLE II cont.

N	A	1	2	3	4	5
				$Z = 101$		
142	243	7[514] 0.22	7[633] 0.33	9[624] 0.61	3[521] 0.64	5[512] 0.78
144	245	7[514] 0.24	7[633] 0.36	9[624] 0.62	3[521] 0.64	5[512] 0.81
146	247	7[514] 0.27	7[633] 0.39	9[624] 0.62	3[521] 0.65	5[512] 0.87
148	249	7[514] 0.30	7[633] 0.39	9[624] 0.57	3[521] 0.68	5[512] 0.96
150	251	7[514] 0.30	7[633] 0.37	9[624] 0.49	3[521] 0.70	5[512] 1.03
152	253	7[514] 0.32	7[633] 0.36	9[624] 0.43	3[521] 0.72	1[400] 0.88
154	255	7[514] 0.26	7[633] 0.31	9[624] 0.35	3[521] 0.71	1[400] 0.76
156	257	7[514] 0.19	7[633] 0.27	9[624] 0.27	1[400] 0.62	3[521] 0.70
158	259	7[514] 0.09	9[624] 0.20	7[633] 0.22	1[400] 0.53	5[642] 0.67
160	261	1[521] 0.01	7[633] 0.14	9[624] 0.16	5[642] 0.49	1[400] 0.55
				$Z = 103$		
146	249	1[521] 0.06	9[624] 0.18	5[512] 0.44	7[633] 0.70	1[651] 0.88
148	251	1[521] 0.08	9[624] 0.13	5[512] 0.50	7[633] 0.72	3[521] 1.04
150	253	9[624] 0.09	1[521] 0.10	5[512] 0.56	7[633] 0.71	3[521] 1.08
152	255	9[624] 0.05	1[521] 0.13	5[512] 0.61	7[633] 0.72	3[521] 1.13
154	257	9[624] 0.04	1[521] 0.13	5[512] 0.62	7[633] 0.65	1[400] 1.02
156	259	9[624] 0.02	1[521] 0.13	7[633] 0.58	5[512] 0.62	1[400] 0.86
158	261	9[624] 0.01	1[521] 0.10	7[633] 0.50	5[512] 0.56	1[400] 0.74
				$Z = 105$		
148	253	7[514] 0.16	5[512] 0.21	1[521] 0.33	1[651] 1.03	9[505] 1.04
150	255	7[514] 0.14	5[512] 0.24	1[521] 0.35	7[633] 1.03	9[505] 1.15
152	257	7[514] 0.11	5[512] 0.27	1[521] 0.38	7[633] 1.04	9[505] 1.23
154	259	7[514] 0.11	5[512] 0.27	1[521] 0.35	7[633] 0.96	1[400] 1.28
156	261	7[514] 0.10	5[512] 0.26	1[521] 0.32	7[633] 0.88	1[400] 1.12
158	263	7[514] 0.14	5[512] 0.22	1[521] 0.27	7[633] 0.79	1[400] 0.99
				$Z = 107$		
152	259	9[624] 0.48	7[514] 0.75	9[505] 0.92	1[521] 0.94	11[615] 1.02
154	261	9[624] 0.54	7[514] 0.80	1[521] 0.96	11[615] 1.04	9[505] 1.11
156	263	9[624] 0.59	7[514] 0.85	1[521] 0.95	11[615] 1.05	9[505] 1.23
158	265	9[624] 0.62	7[514] 0.88	1[521] 0.92	11[615] 1.05	9[505] 1.33
160	267	9[624] 0.53	1[521] 0.72	7[514] 0.94	11[615] 0.96	7[633] 1.33
162	269	9[624] 0.44	1[521] 0.54	11[615] 0.84	7[514] 1.01	7[633] 1.16
164	271	9[624] 0.35	1[521] 0.38	11[615] 0.67	7[633] 1.02	7[514] 1.08

TABLE II cont.

N	A	1	2	3	4	5
				$Z = 109$		
154	263	11[615] 0.04	5[512] 0.27	1[651] 0.45	3[512] 0.54	3[642] 0.55
156	265	9[505] 0.28	3[512] 0.41	5[512] 0.52	1[510] 0.59	1[651] 0.61
158	267	3[512] 0.37	9[505] 0.37	1[510] 0.56	5[512] 0.60	1[651] 0.81
160	269	3[512] 0.34	9[505] 0.46	1[510] 0.55	5[512] 0.66	1[651] 0.98
162	271	3[512] 0.32	1[510] 0.53	9[505] 0.54	5[512] 0.69	1[521] 1.15
164	273	3[512] 0.32	1[510] 0.55	9[505] 0.55	5[512] 0.67	1[521] 0.92
166	275	3[512] 0.31	9[505] 0.53	1[510] 0.55	5[512] 0.65	1[521] 0.71
				$Z = 111$		
160	271	3[512] 0.04	9[505] 0.07	1[510] 0.18	1[651] 0.75	3[642] 0.86
162	273	11[615] 0.04	1[510] 0.12	9[505] 0.22	1[651] 0.95	5[512] 1.05
164	275	11[615] 0.08	1[510] 0.13	9[505] 0.23	1[521] 1.02	5[512] 1.07
166	277	11[615] 0.11	1[510] 0.13	9[505] 0.22	1[521] 0.84	5[512] 1.08
168	279	1[510] 0.12	11[615] 0.14	9[505] 0.20	1[521] 0.63	5[512] 1.08
170	281	1[521] 0.08	9[505] 0.16	3[512] 0.20	7[503] 0.39	1[510] 0.47
172	283	11[615] 0.11	3[512] 0.19	7[503] 0.26	9[505] 0.39	1[510] 0.46
				$Z = 113$		
164	277	3[512] 0.04	9[505] 0.04	11[615] 0.40	7[503] 0.83	1[631] 1.00
166	279	9[505] 0.04	3[512] 0.06	11[615] 0.45	7[503] 0.84	1[550] 0.99
168	281	9[505] 0.06	3[512] 0.08	11[615] 0.50	1[550] 0.83	7[503] 0.87
170	283	1[510] 0.13	7[503] 0.28	1[550] 0.35	9[505] 0.37	11[615] 0.39
172	285	1[510] 0.15	7[503] 0.15	1[550] 0.15	11[615] 0.45	13[606] 0.54
174	287	1[550] 0.02	3[512] 0.06	13[606] 0.08	1[510] 0.32	11[615] 0.46
176	289	1[550] 0.01	3[512] 0.02	13[606] 0.10	1[510] 0.26	11[615] 0.57
				$Z = 115$		
168	283	3[512] 0.35	13[606] 0.59	7[503] 0.62	11[615] 0.65	1[510] 0.71
170	285	3[512] 0.27	13[606] 0.39	7[503] 0.45	11[615] 0.56	1[510] 0.61
172	287	3[512] 0.16	13[606] 0.29	7[503] 0.38	1[510] 0.49	11[615] 0.63
174	289	3[512] 0.06	13[606] 0.16	7[503] 0.29	1[510] 0.36	11[615] 0.75
176	291	3[512] 0.11	5[503] 0.43	1[510] 0.53	13[606] 0.69	7[503] 0.71
178	293	3[512] 0.11	5[503] 0.22	1[510] 0.58	3[501] 0.78	7[503] 0.88
				$Z = 117$		
170	287	1[510] 0.18	1[541] 0.36	13[606] 0.61	5[503] 0.62	7[503] 0.72
172	289	1[510] 0.15	1[541] 0.23	13[606] 0.46	7[503] 0.60	5[503] 0.68
174	291	1[510] 0.09	1[541] 0.11	13[606] 0.31	7[503] 0.47	5[503] 0.72
176	293	1[541] 0.05	1[510] 0.11	13[606] 0.43	5[503] 0.57	7[503] 0.58
178	295	1[541] 0.01	5[503] 0.16	1[510] 0.23	3[501] 0.64	13[606] 1.03

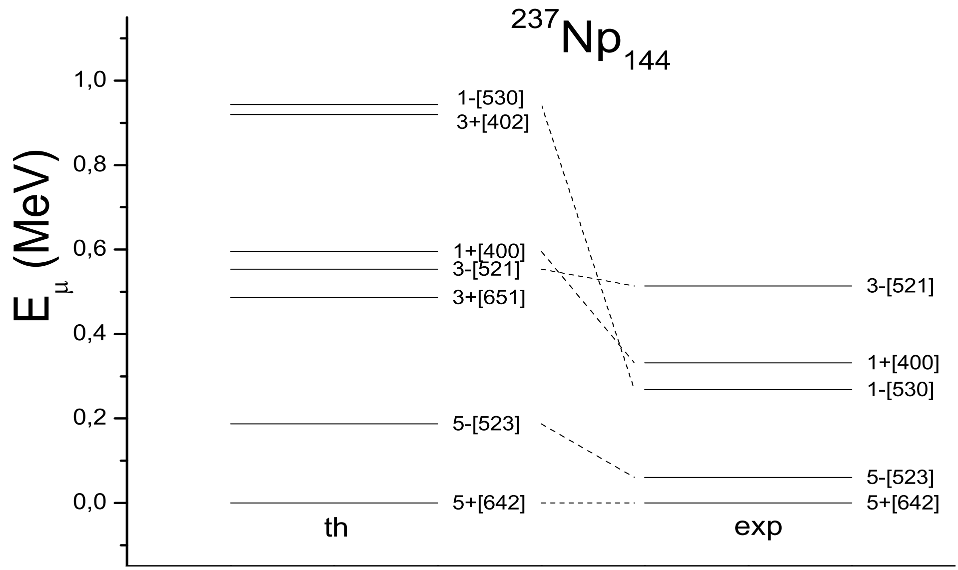

Fig. 1. Comparison between theoretical and experimental single-proton spectra for the nucleus ^{237}Np.

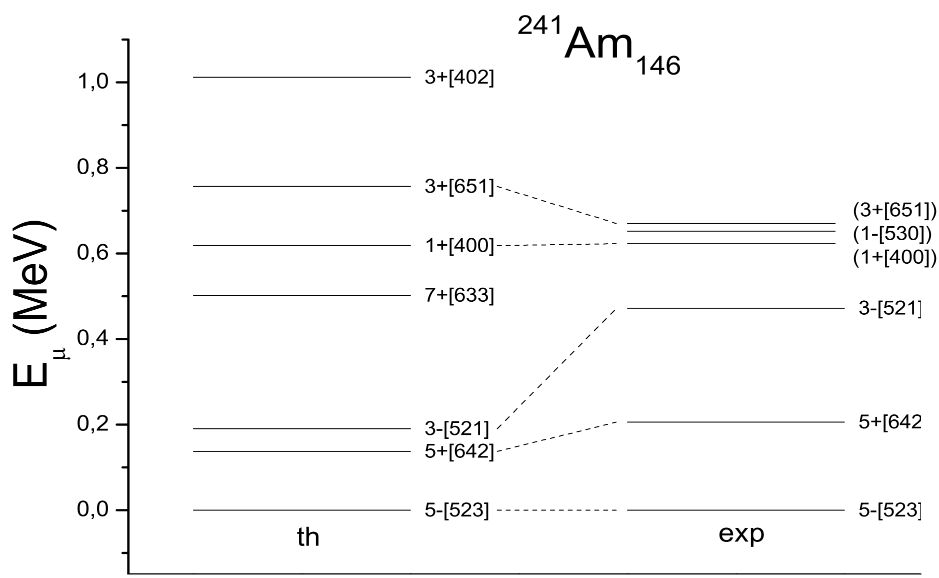

Fig. 2. Same as in Fig. 1, but for ^{241}Am.

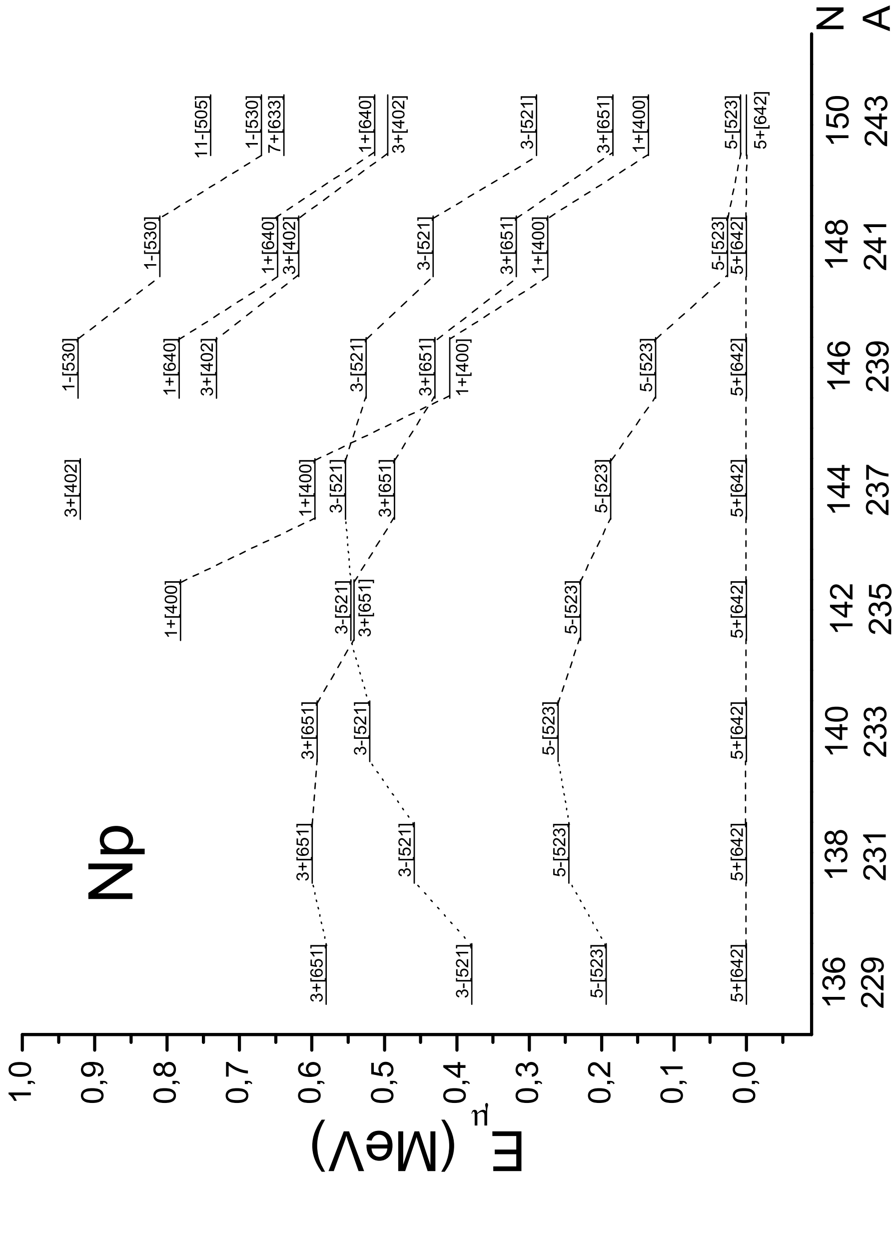

Fig. 3. Systematics of one-quasiparticle proton states calculated for odd-A isotopes of neptunium ($Z = 93$).

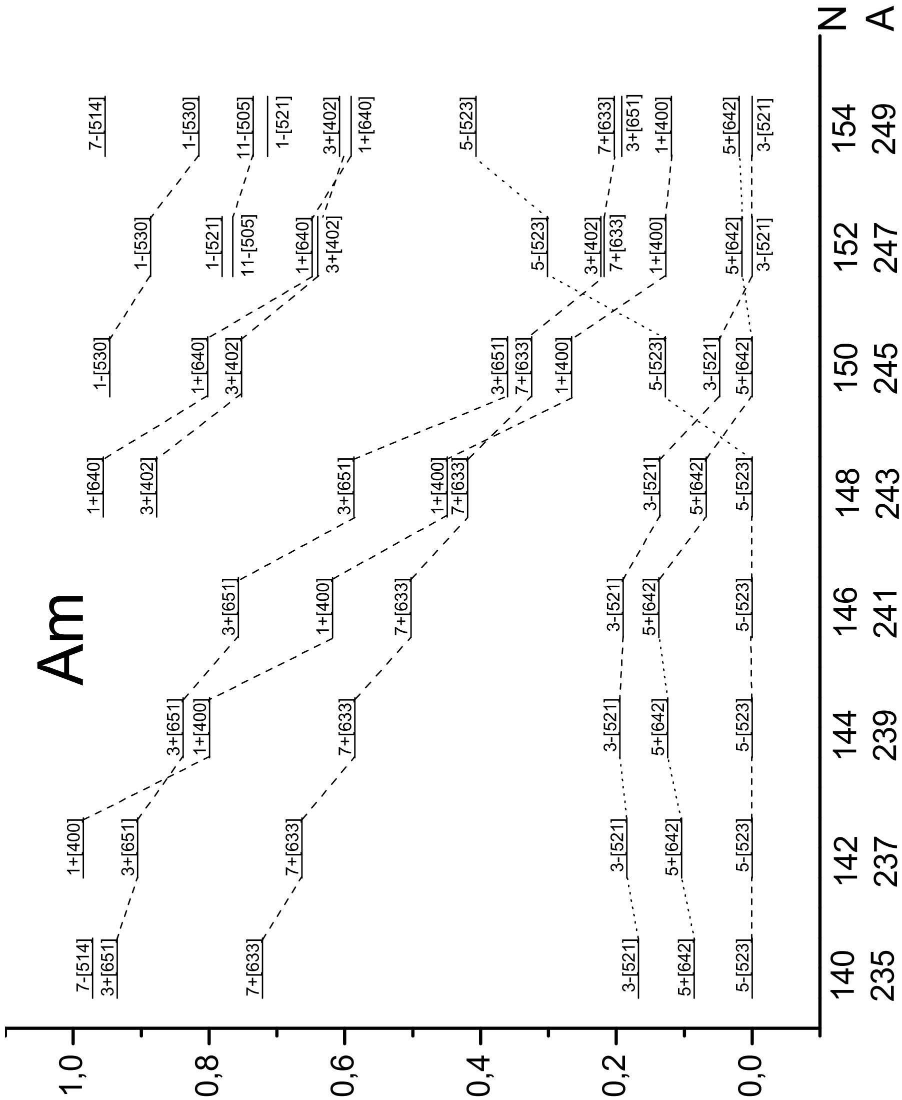

Fig. 4. Same as in Fig. 3, but for americium ($Z = 95$).

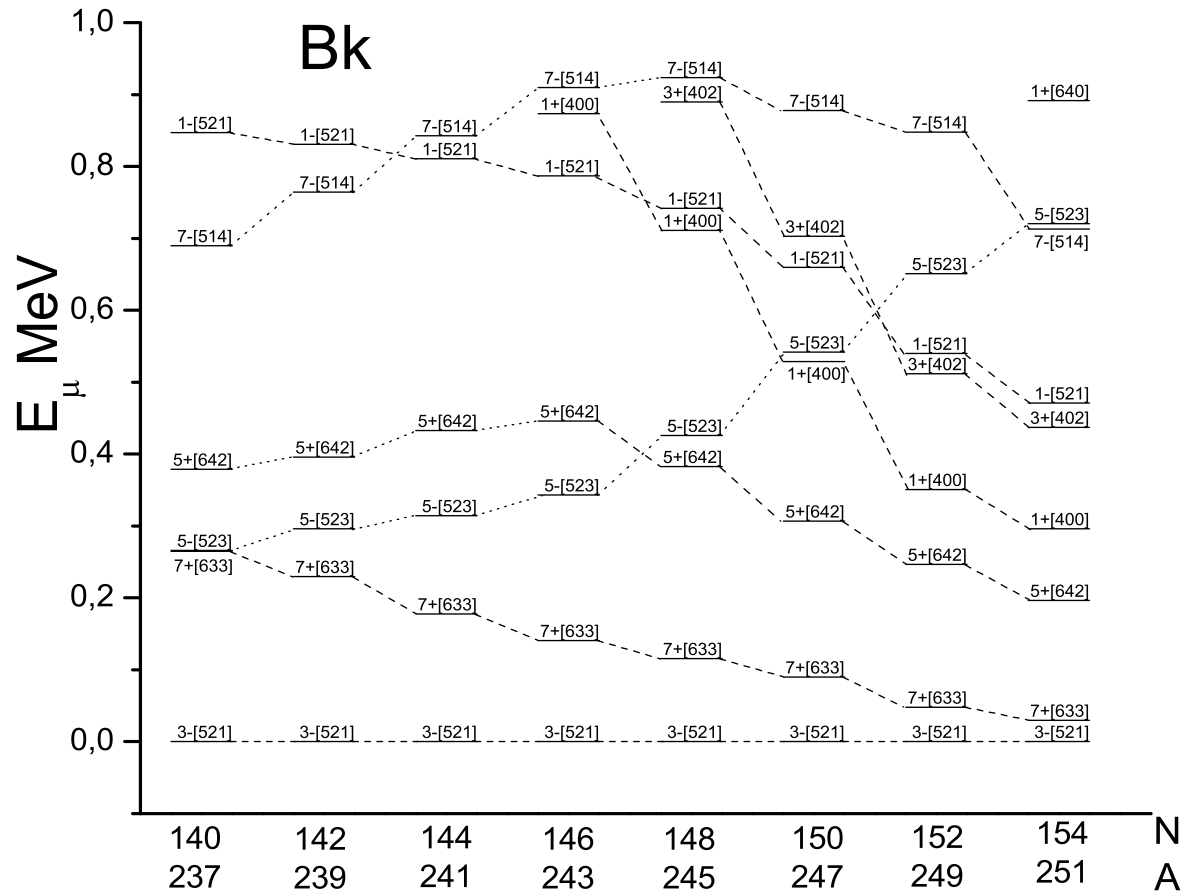

Fig. 5. Same as in Fig. 3, but for berkelium ($Z = 97$).

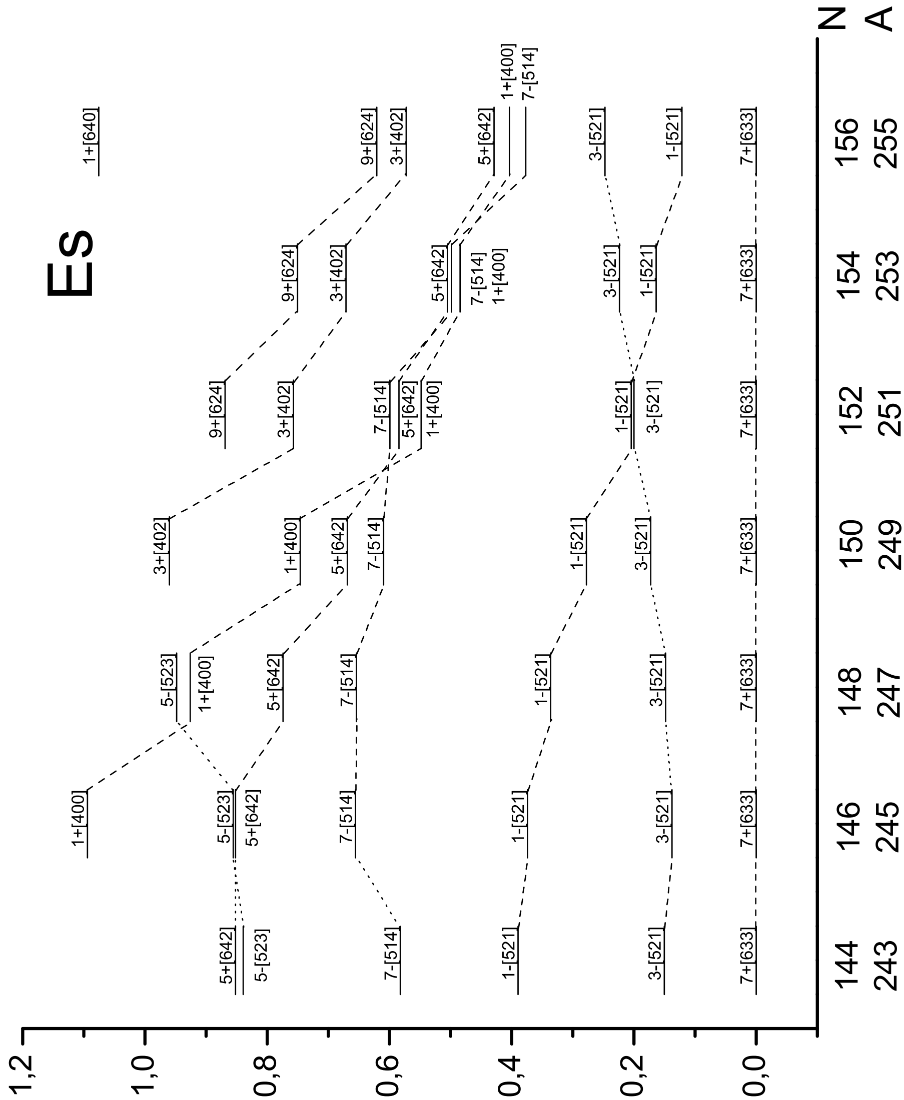

Fig. 6. Same as in Fig. 3, but for einsteinium ($Z = 99$).

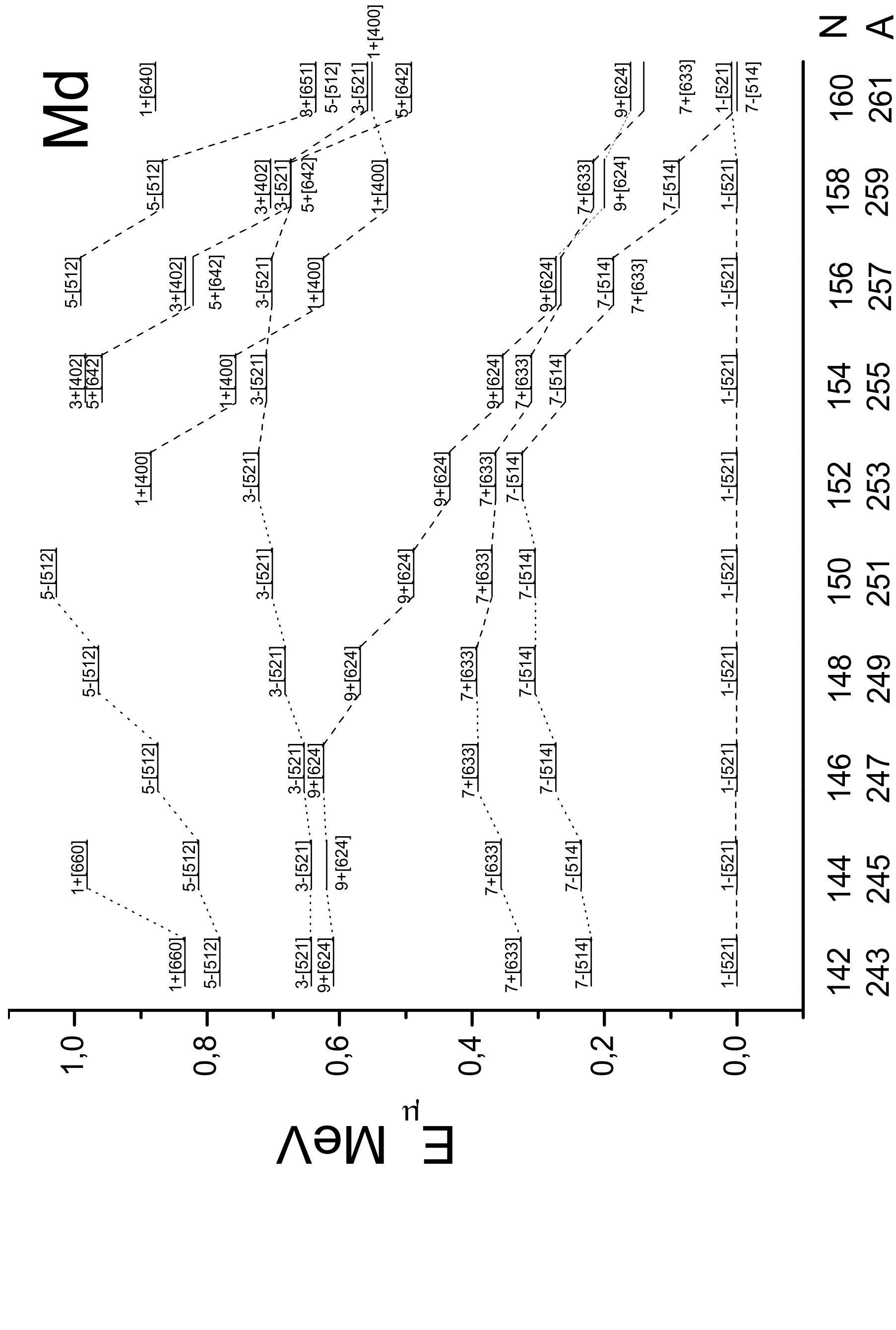

Fig. 7. Same as in Fig. 3, but for mendelevium ($Z = 101$).

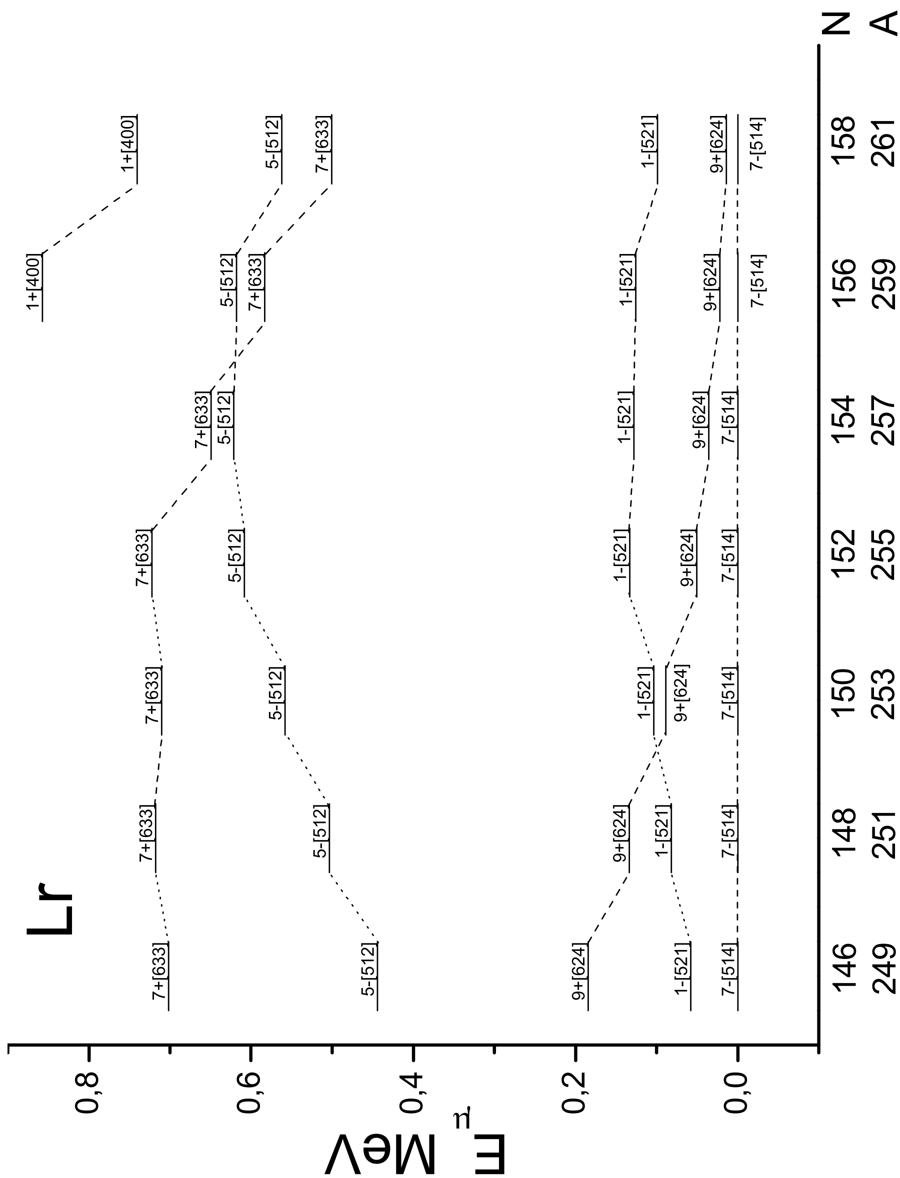

Fig. 8. Same as in Fig. 3, but for lawrencium ($Z = 103$).

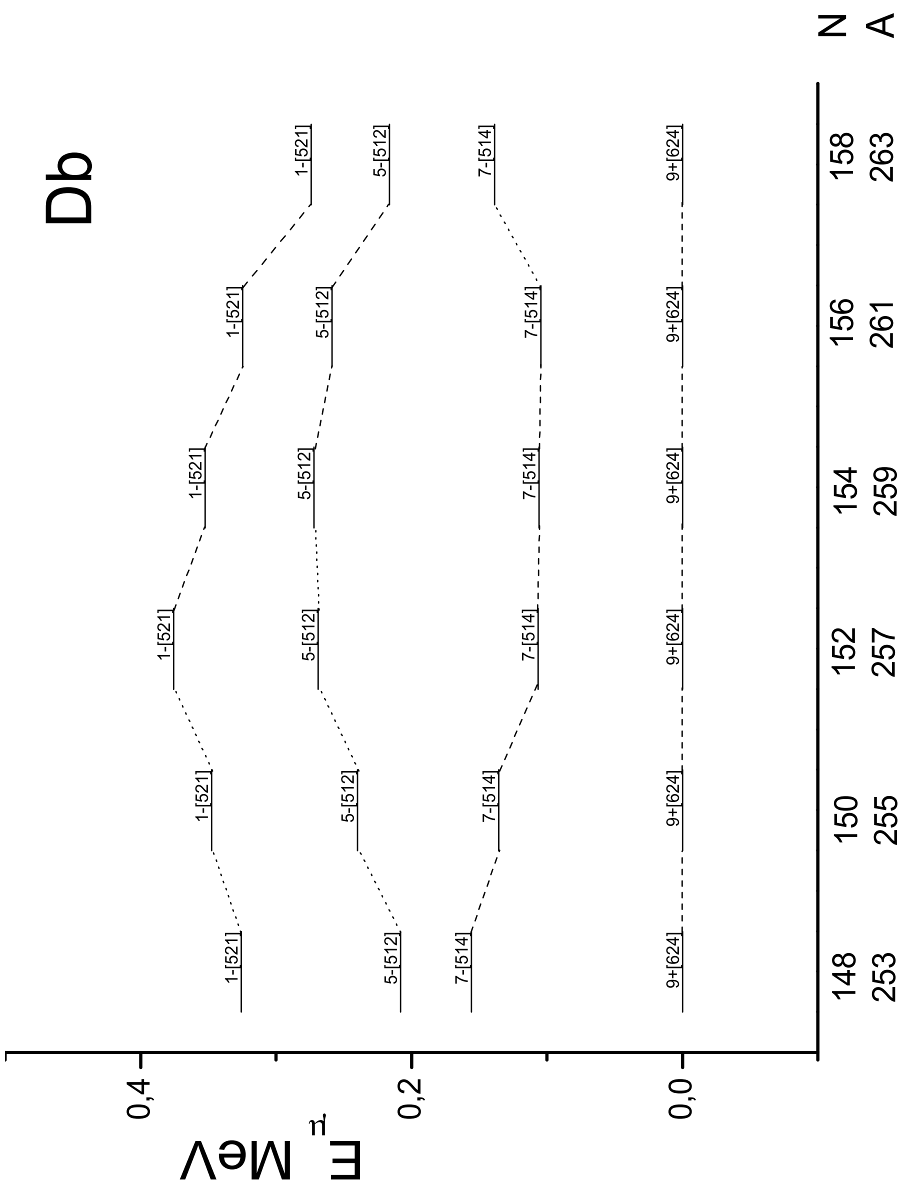

Fig. 9. Same as in Fig. 3, but for dubnium ($Z = 105$).

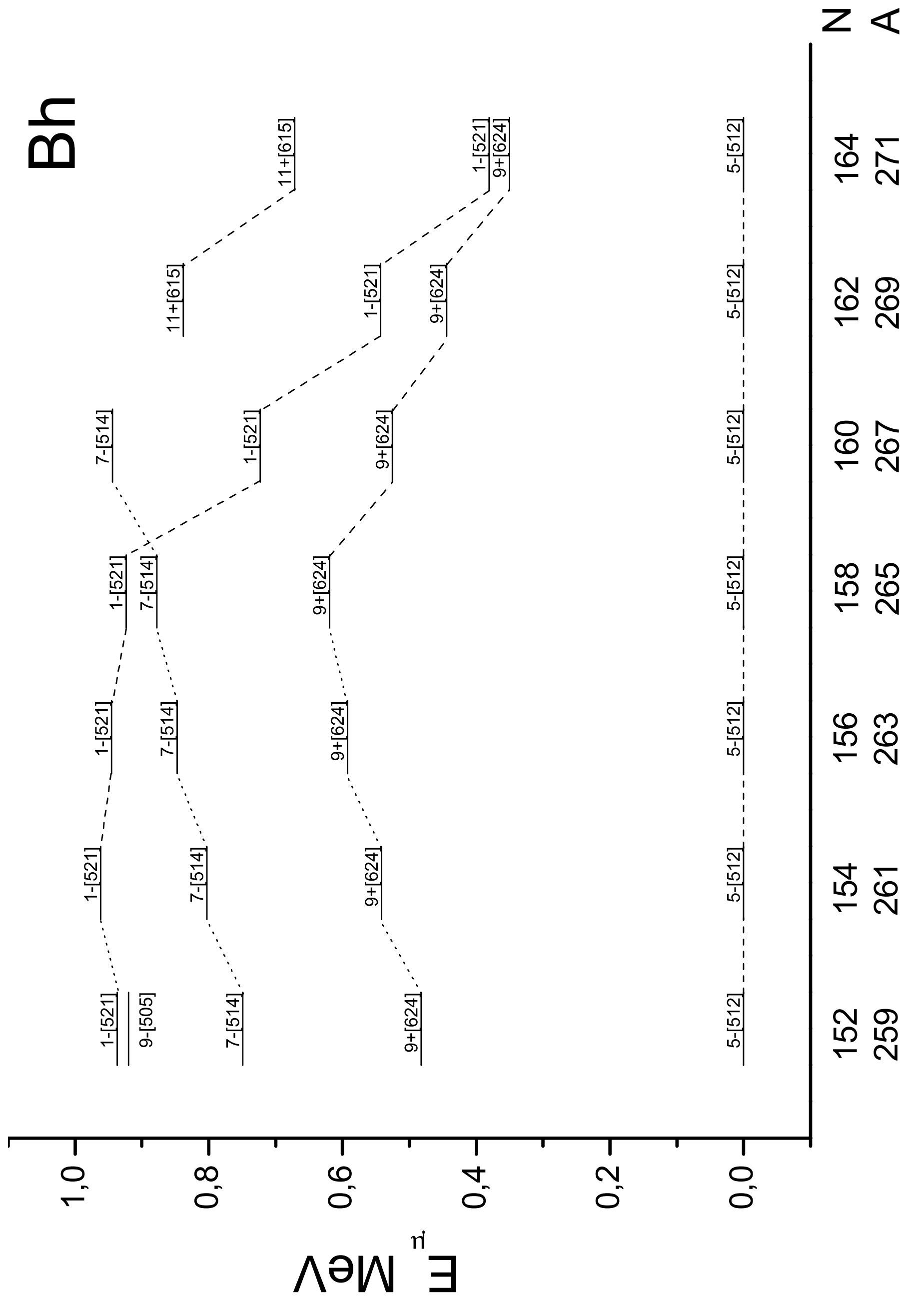

Fig. 10. Same as in Fig. 3, but for bohrium ($Z = 107$).

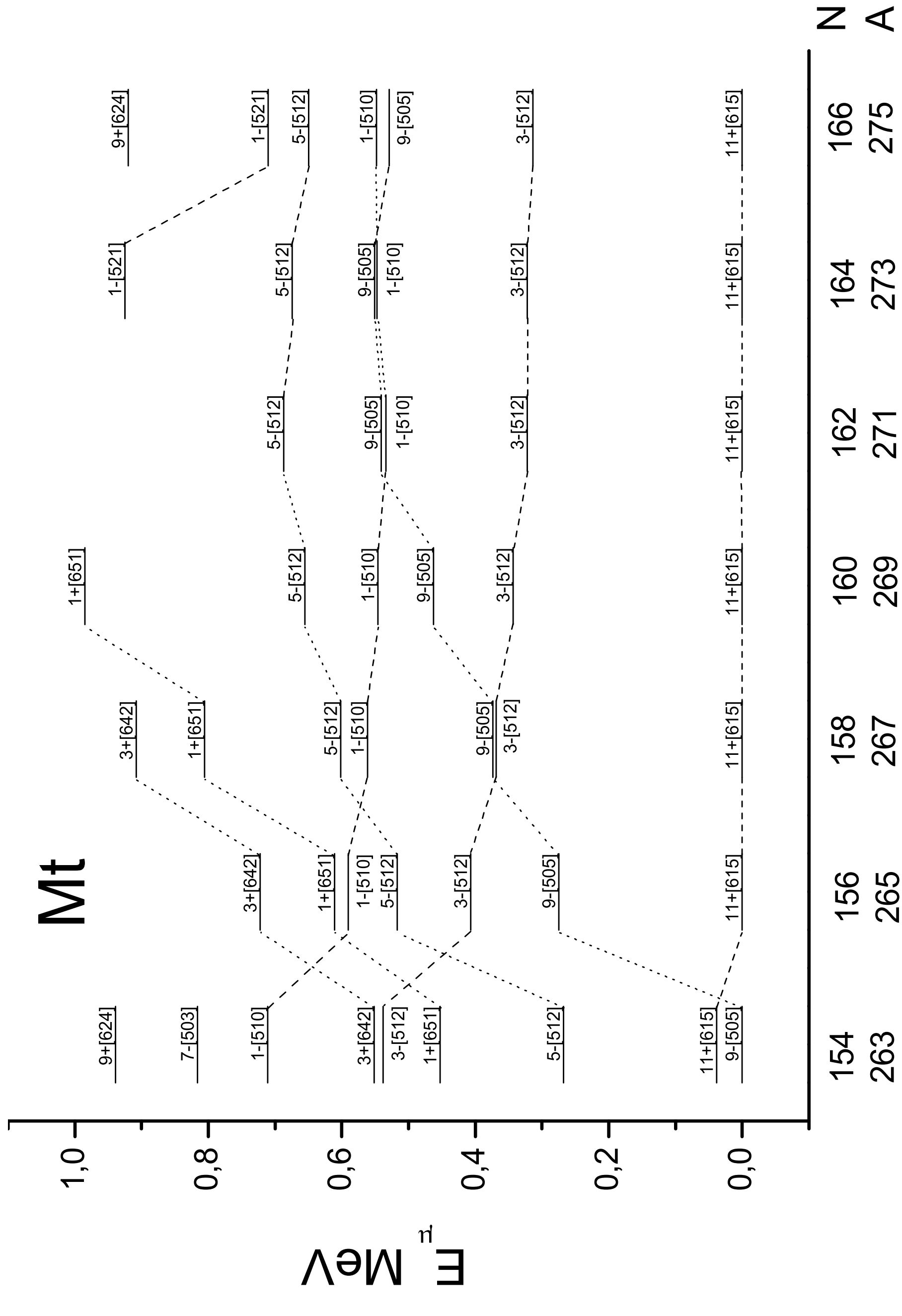

Fig. 11. Same as in Fig. 3, but for meitnerium ($Z = 109$).

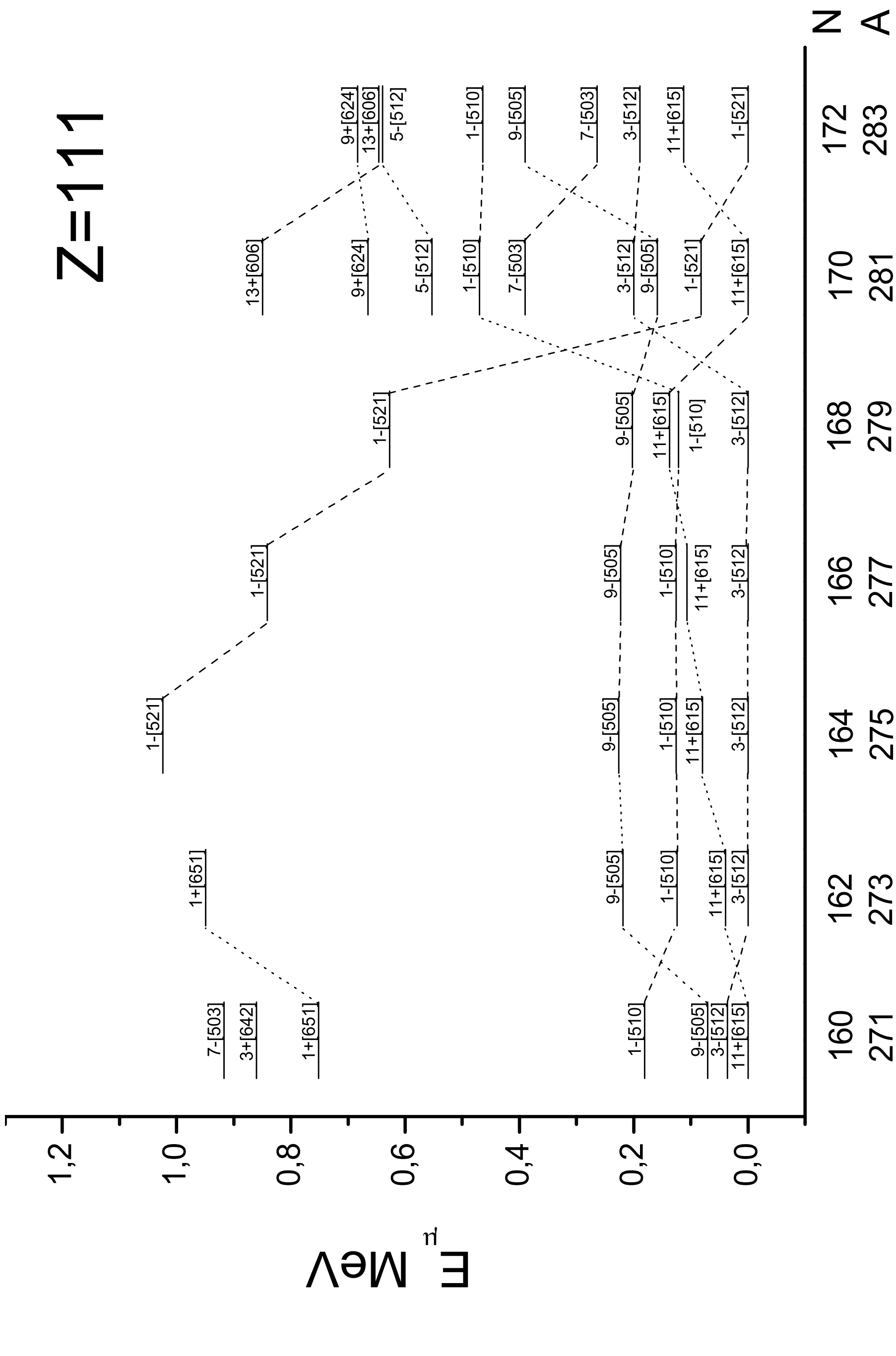

Fig. 12. Same as in Fig. 3, but for the element 111.

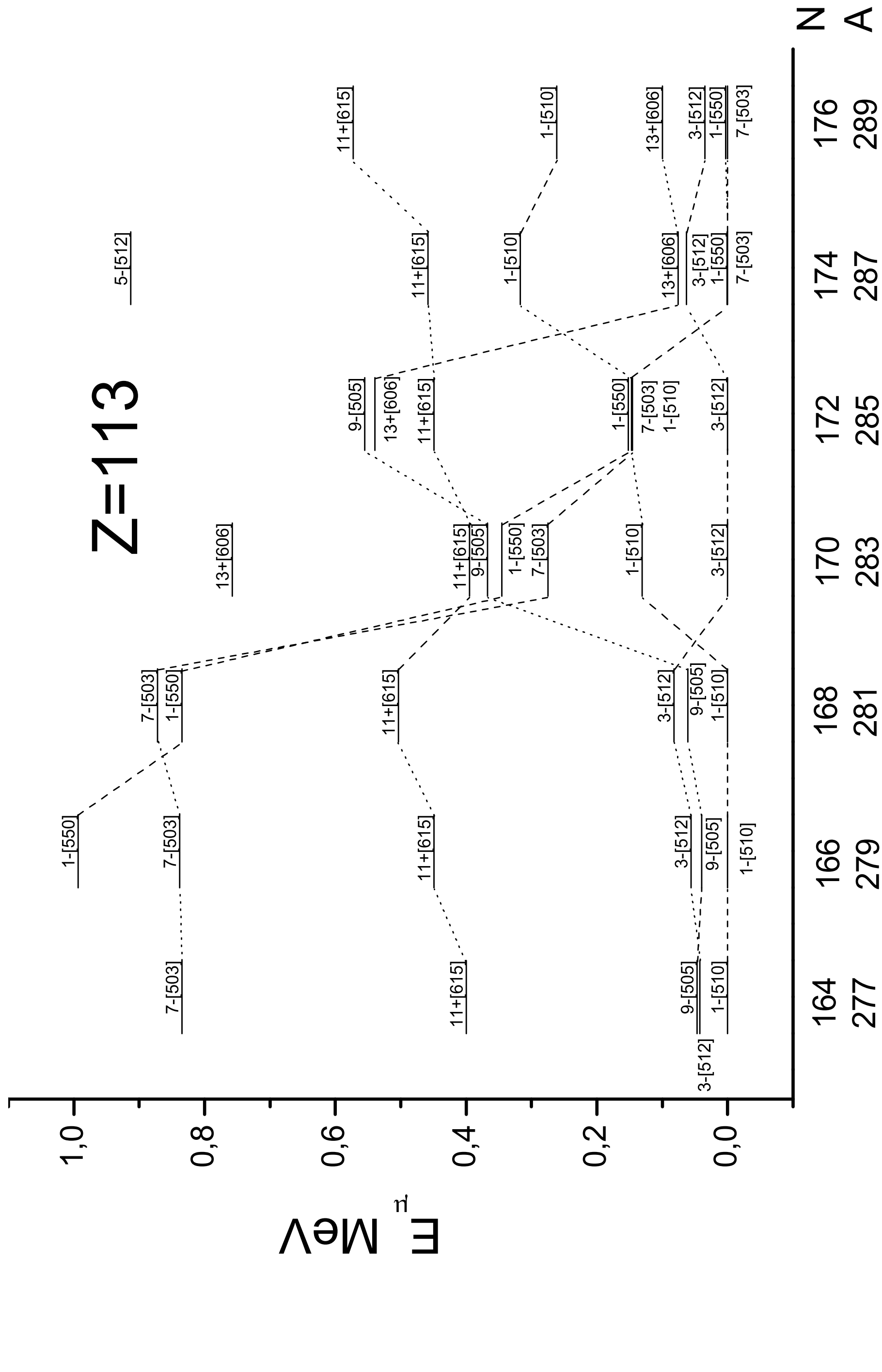

Fig. 13. Same as in Fig. 3, but for the element 113.

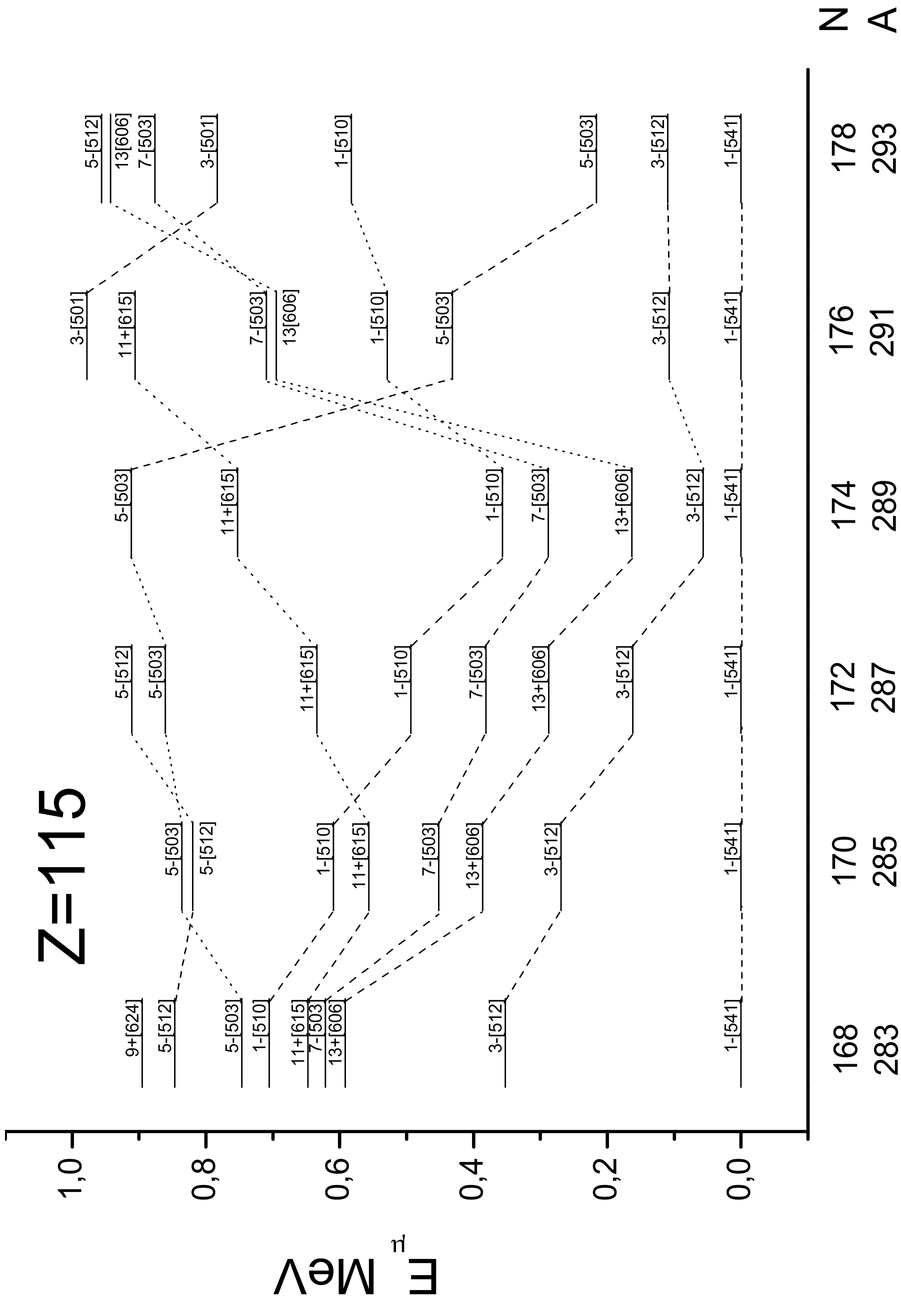

Fig. 14. Same as in Fig. 3, but for the element 115.

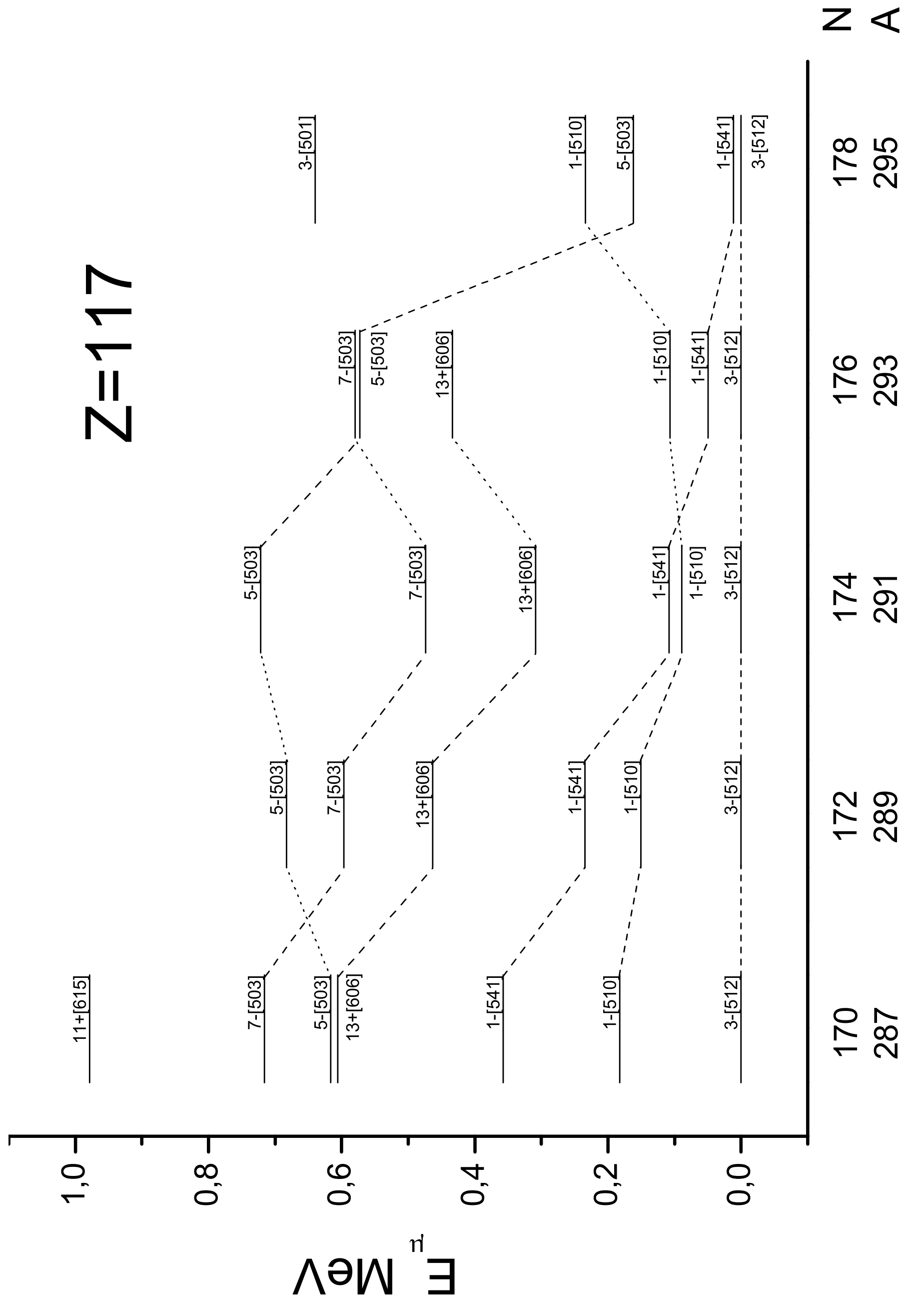

Fig. 15. Same as in Fig. 3, but for the element 117.

Concluding, one can say that the region of nuclei presently explored experimentally is rather fast shifting to heavier and heavier ones. The results of the present paper may give a help in a first orientation on the lowest single-proton states which may be observed in this very little yet explored region.

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