Single-particle effects in the properties of heavy and superheavy nuclei

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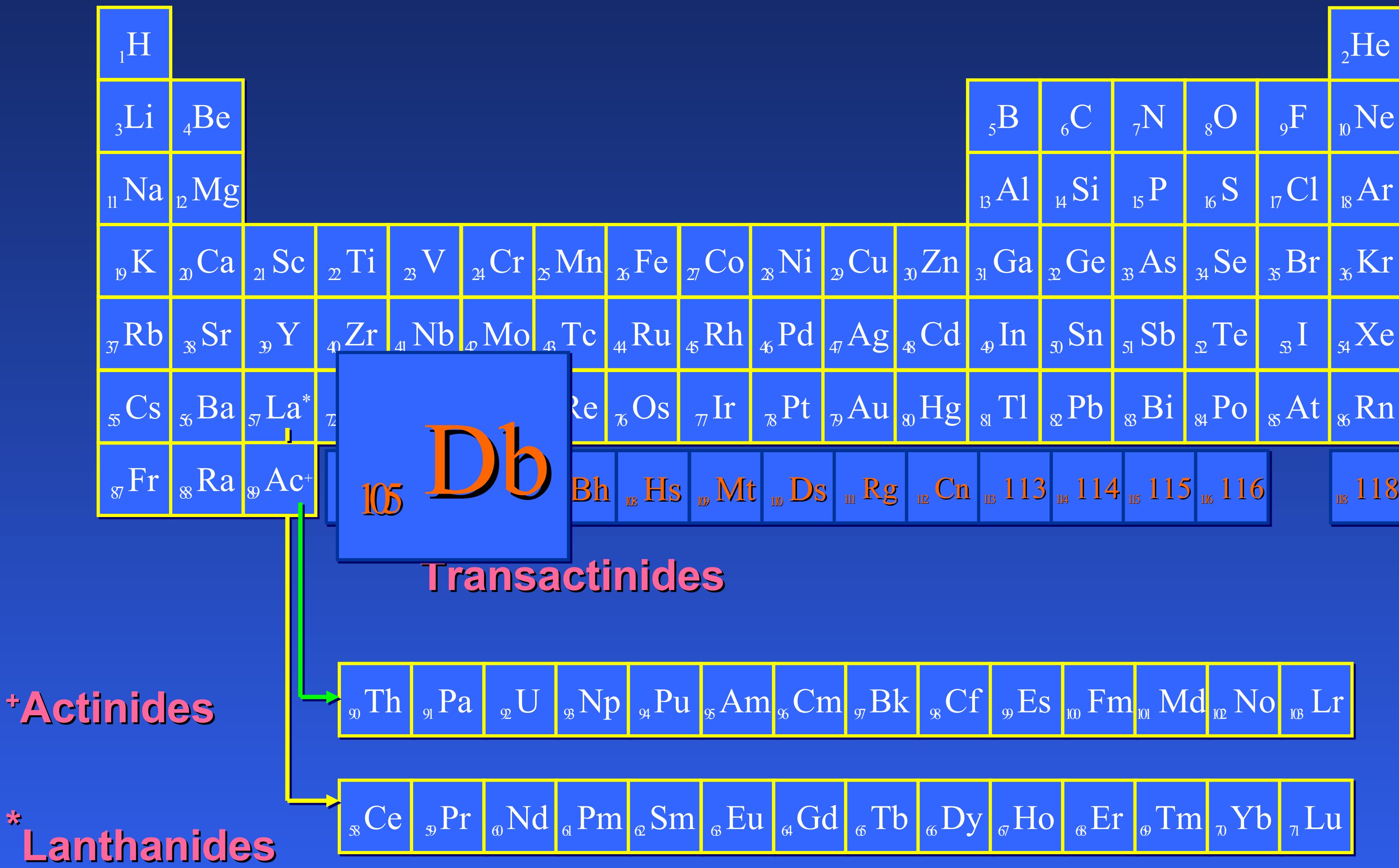
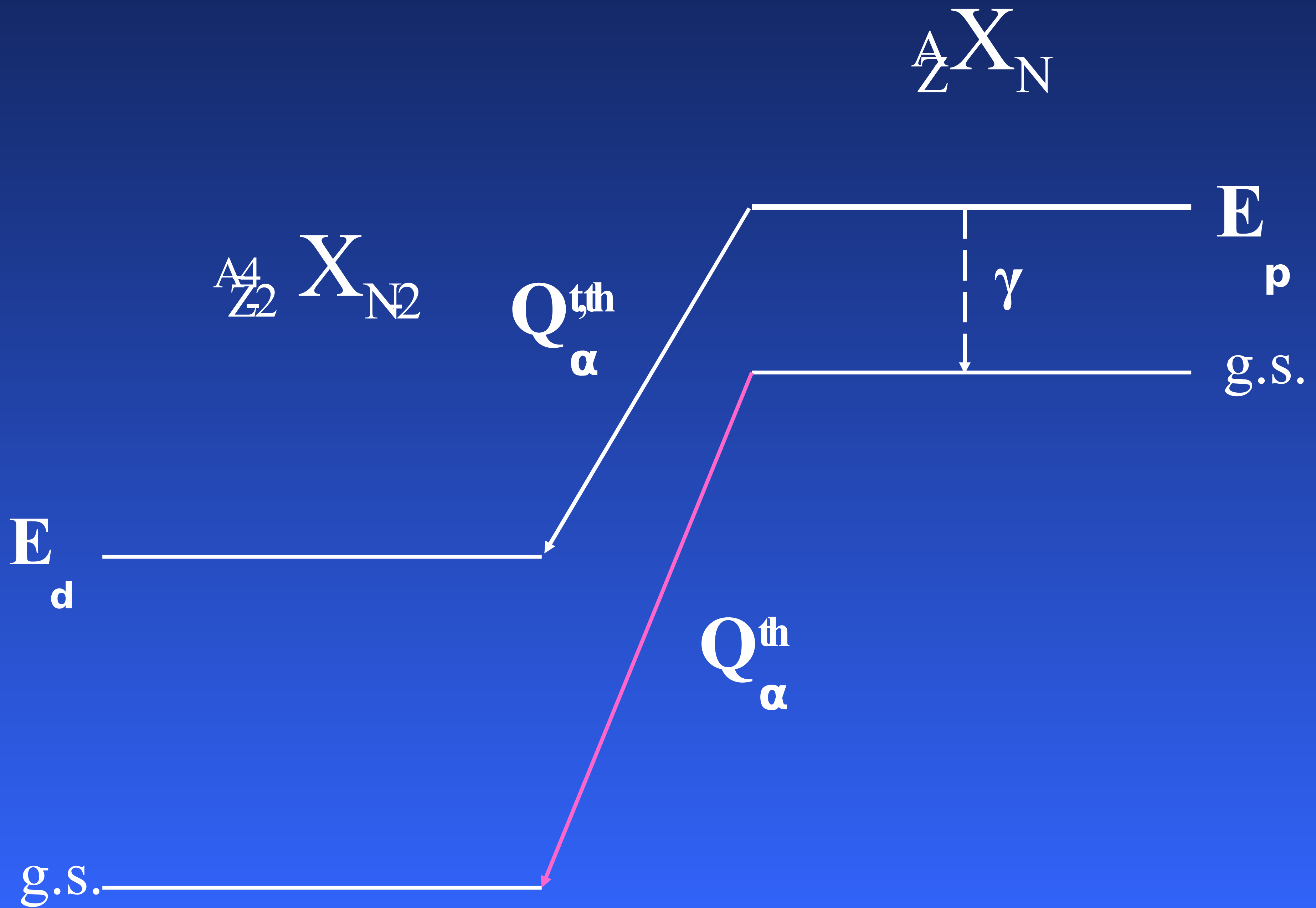
Plan

- Intoduction
- Metod of calculations
- Phenomenological formula for α-decay half-lives
- Results
  a) One-quasiparticle excitations
  b) Systematic
  c) α-decay chains
- Conclusions

MENDELEYEV PERIODIC TABLE OF THE ELEMENTS




$^{A}_{Z}X_{N}$
$^{A-4}_{Z-2}X_{N-2}$
$Q_{\alpha}^{t,th}$
E_p
γ
g.s.
E_d
Q_{α}^{th}
g.s.

Method of the calculations

Macroscopic

Yukawa-plus-exponetial model

Microscopic

Strutinski shell correction

BCS pairing approximation

Woods-Saxon potential

The shape of a nucleus

$$R(\theta,\phi)=R_0 C(\beta_{\lambda\mu})\left(1+\sum_{\lambda\mu}\beta_{\lambda\mu}Y_{\lambda\mu}(\theta,\phi)\right)$$

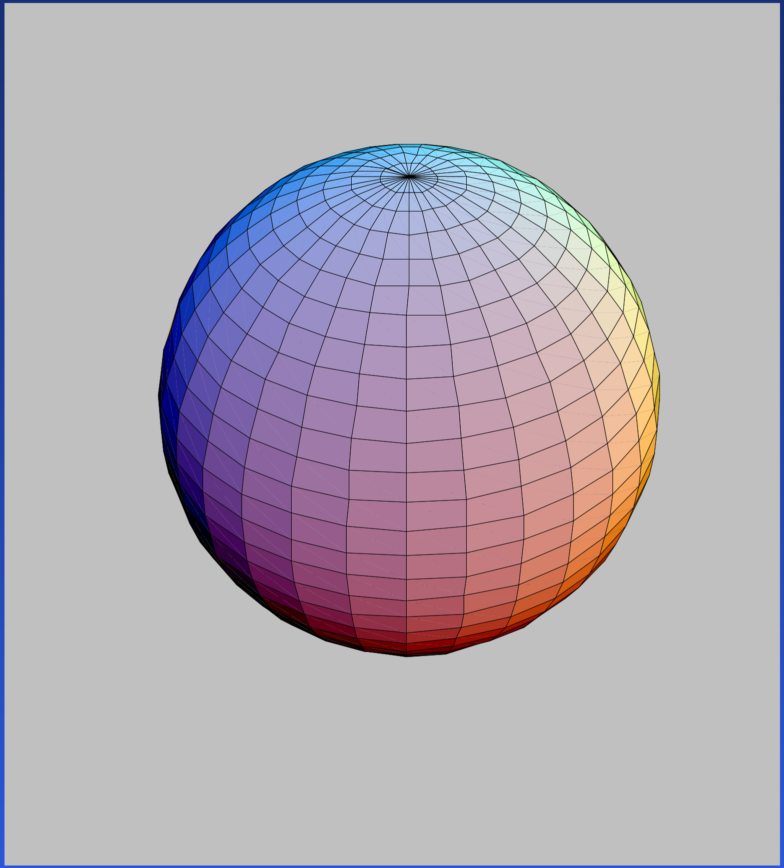
Axial symmetric nuclei:

$$\mu=0 \Rightarrow$$

$$\beta_{\lambda 0}\equiv\beta_{\lambda}$$

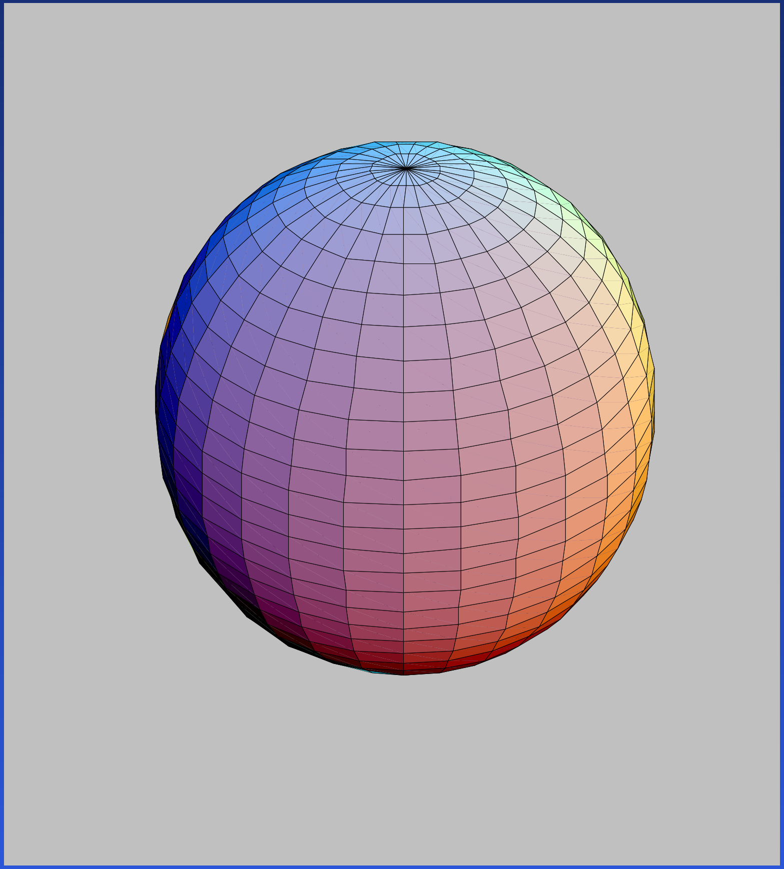
$$R(\theta)=R_0 C(\beta_{\lambda})\left(1+\sum_{\lambda=2}^{8}\beta_{\lambda}Y_{\lambda 0}(\theta)\right)$$

$\beta_2 = 0$



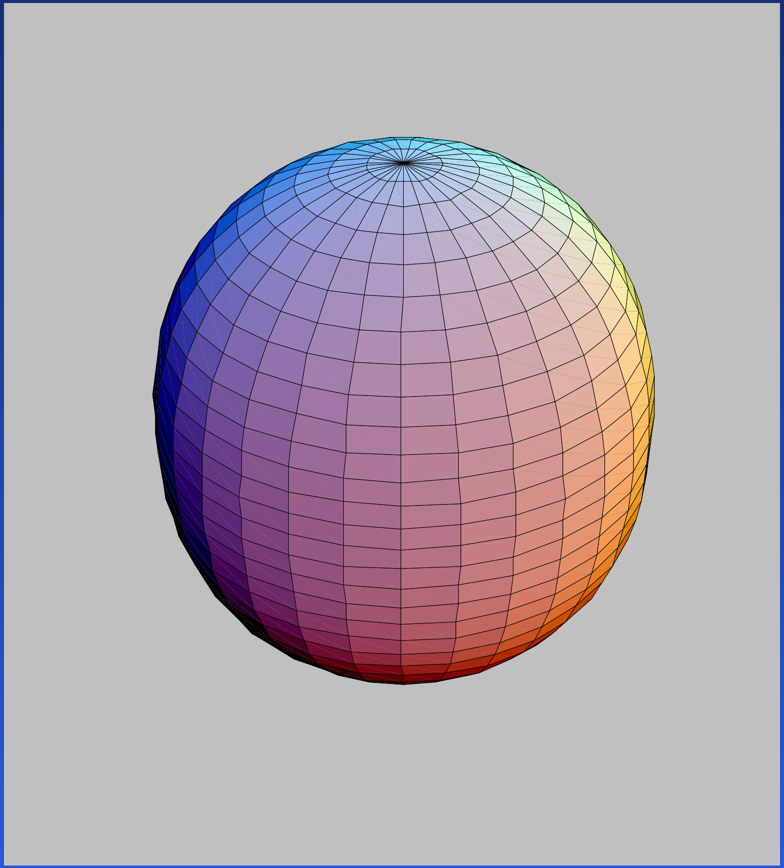
$\beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0.$

$\beta_2 = 0.2$



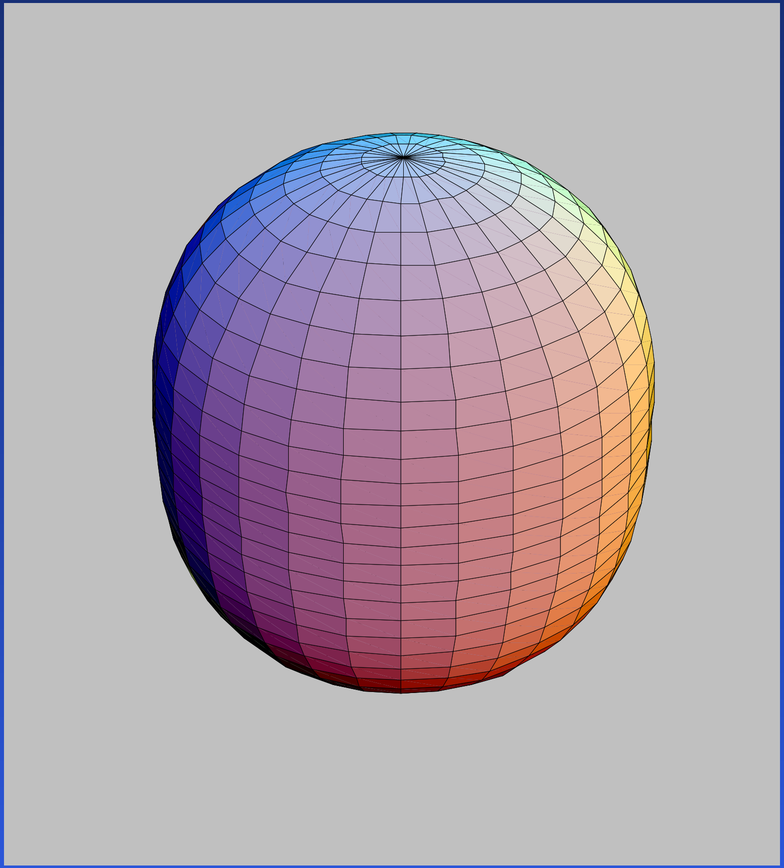
$\beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0.$

$\beta_2 = 0.3$



$\beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0.$

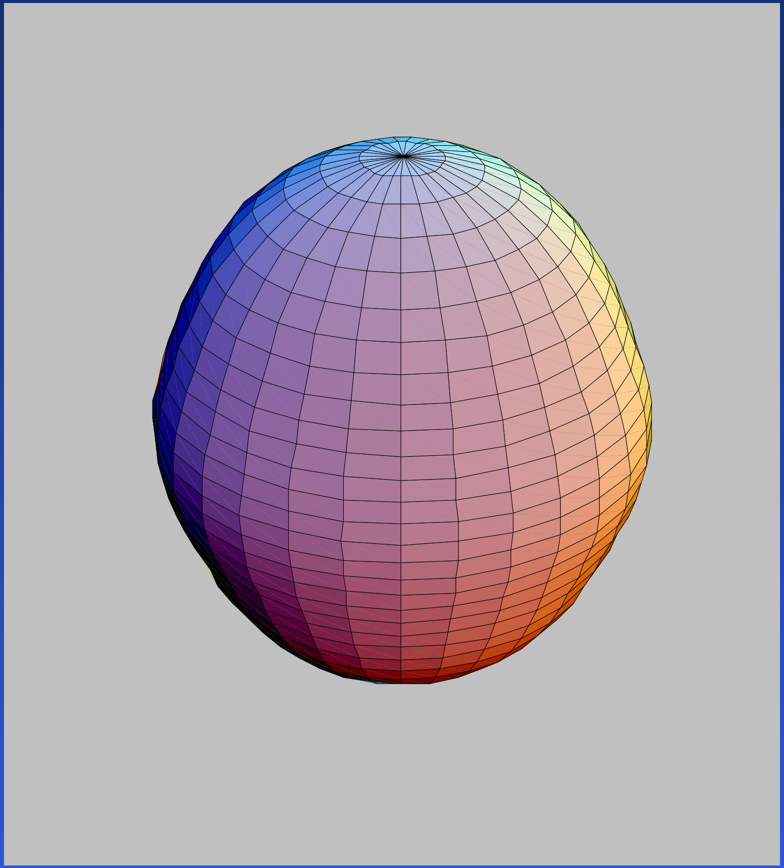
$\beta_2 = 0.4$



$\beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0.$

$\beta_2 = 0.4$

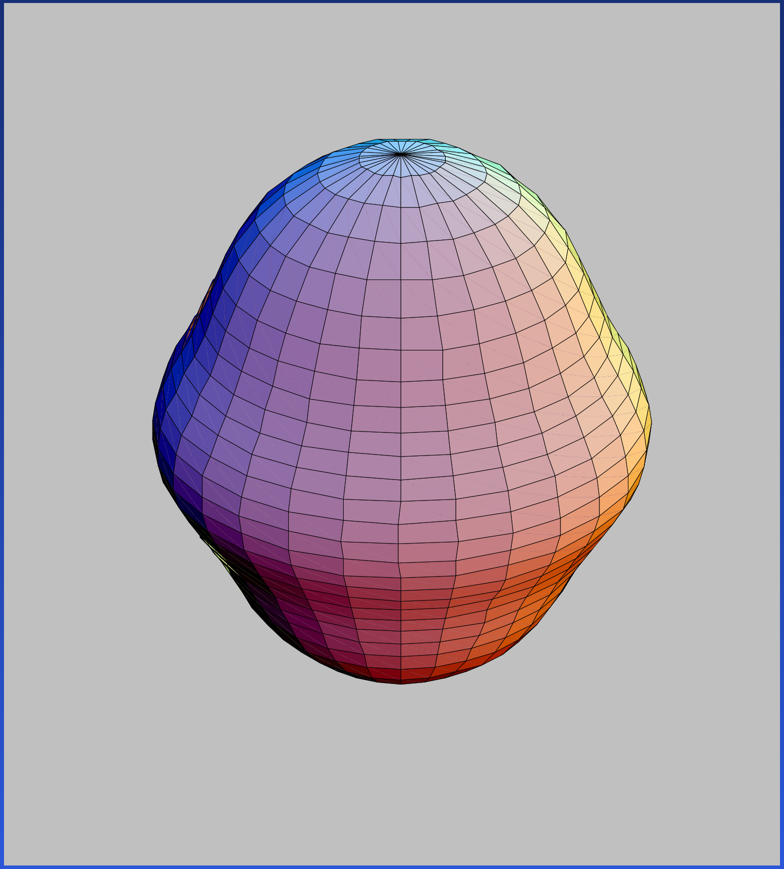
$\beta_4 = 0.1$



$\beta_3 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0.$

$\beta_2 = 0.4$

$\beta_4 = 0.2$

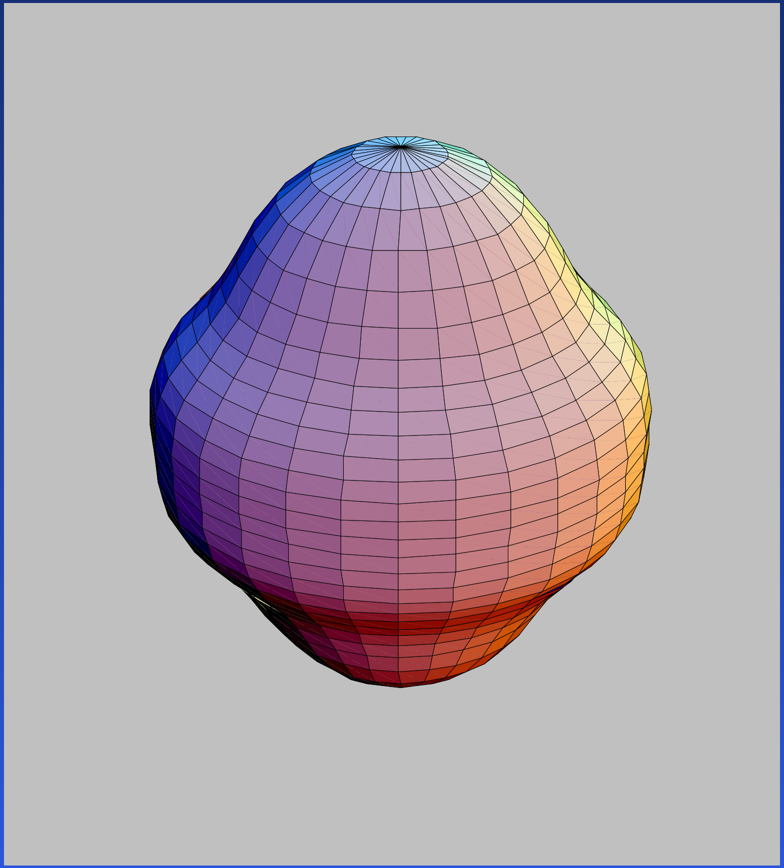


$\beta_3 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0.$

$\beta_2 = 0.4$

$\beta_4 = 0.2$

$\beta_6 = 0.1$



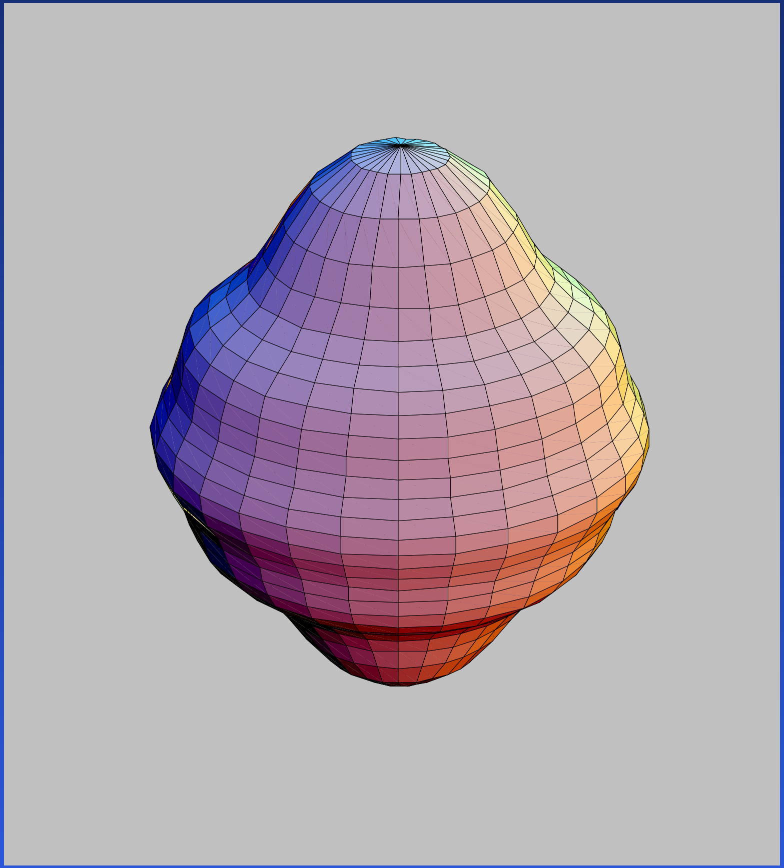
$\beta_3 = \beta_5 = \beta_7 = \beta_8 = 0.$

$\beta_2 = 0.4$

$\beta_4 = 0.2$

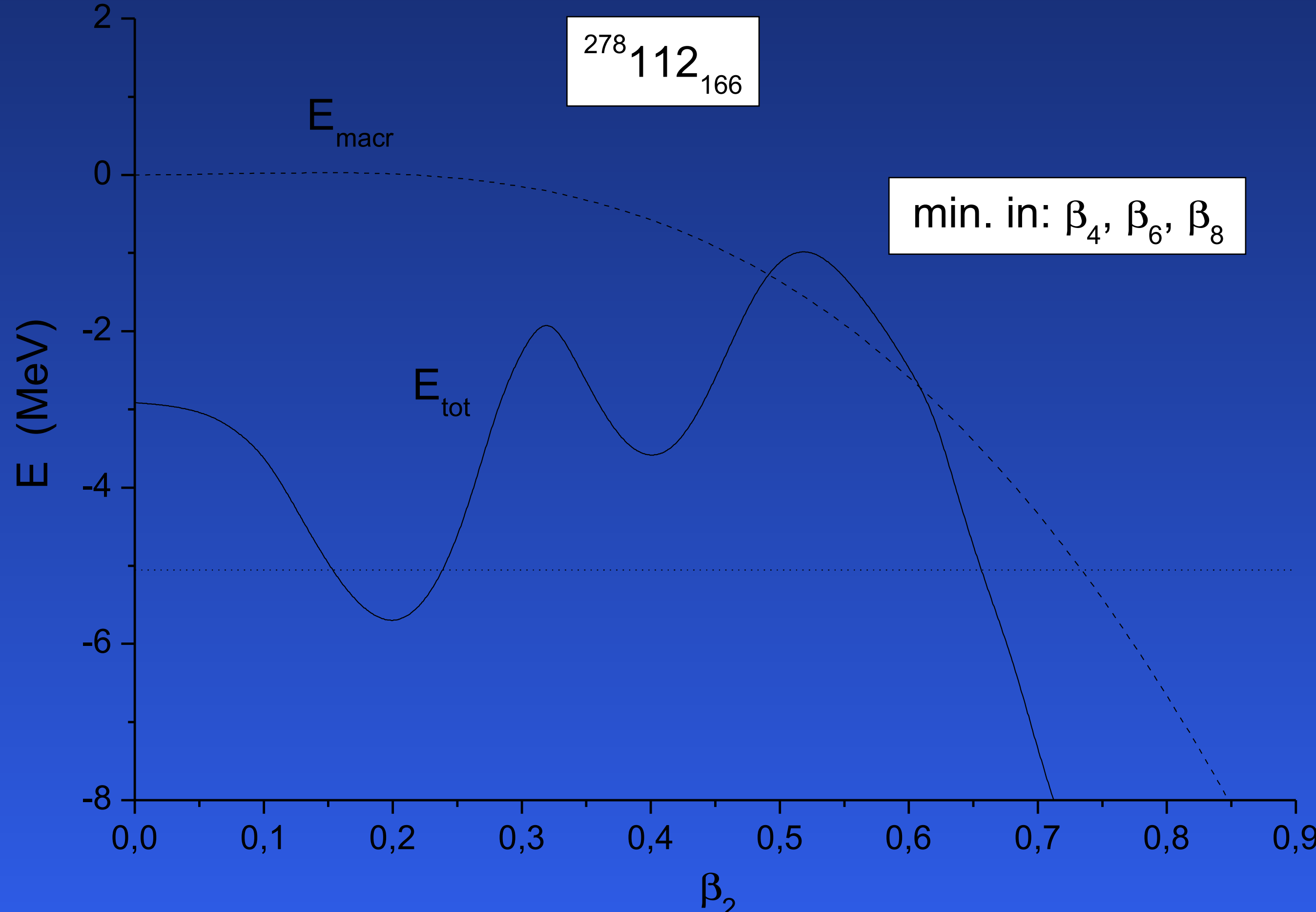
$\beta_6 = 0.1$

$\beta_8 = 0.1$

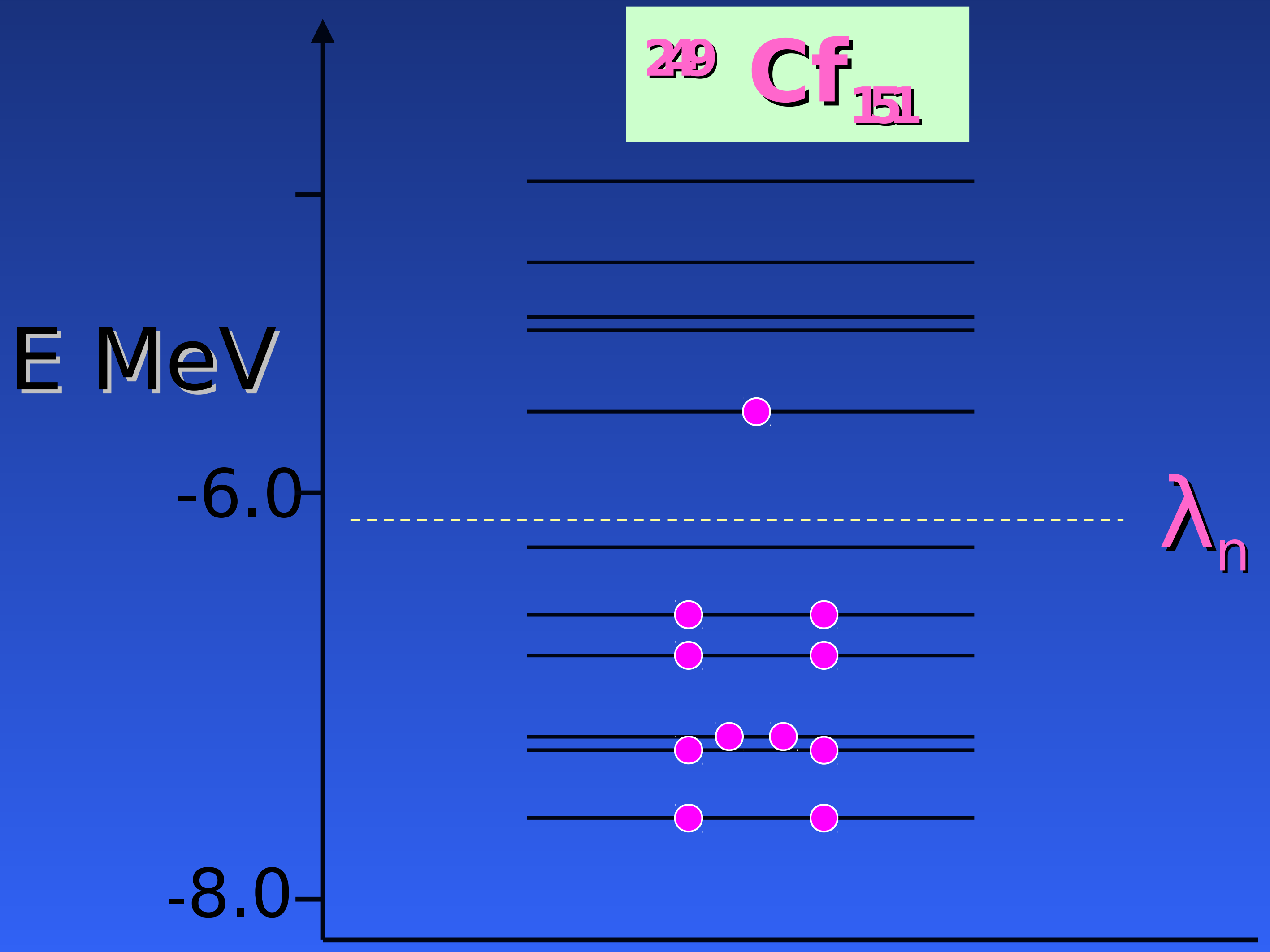


$\beta_3 = \beta_5 = \beta_7 = 0.$

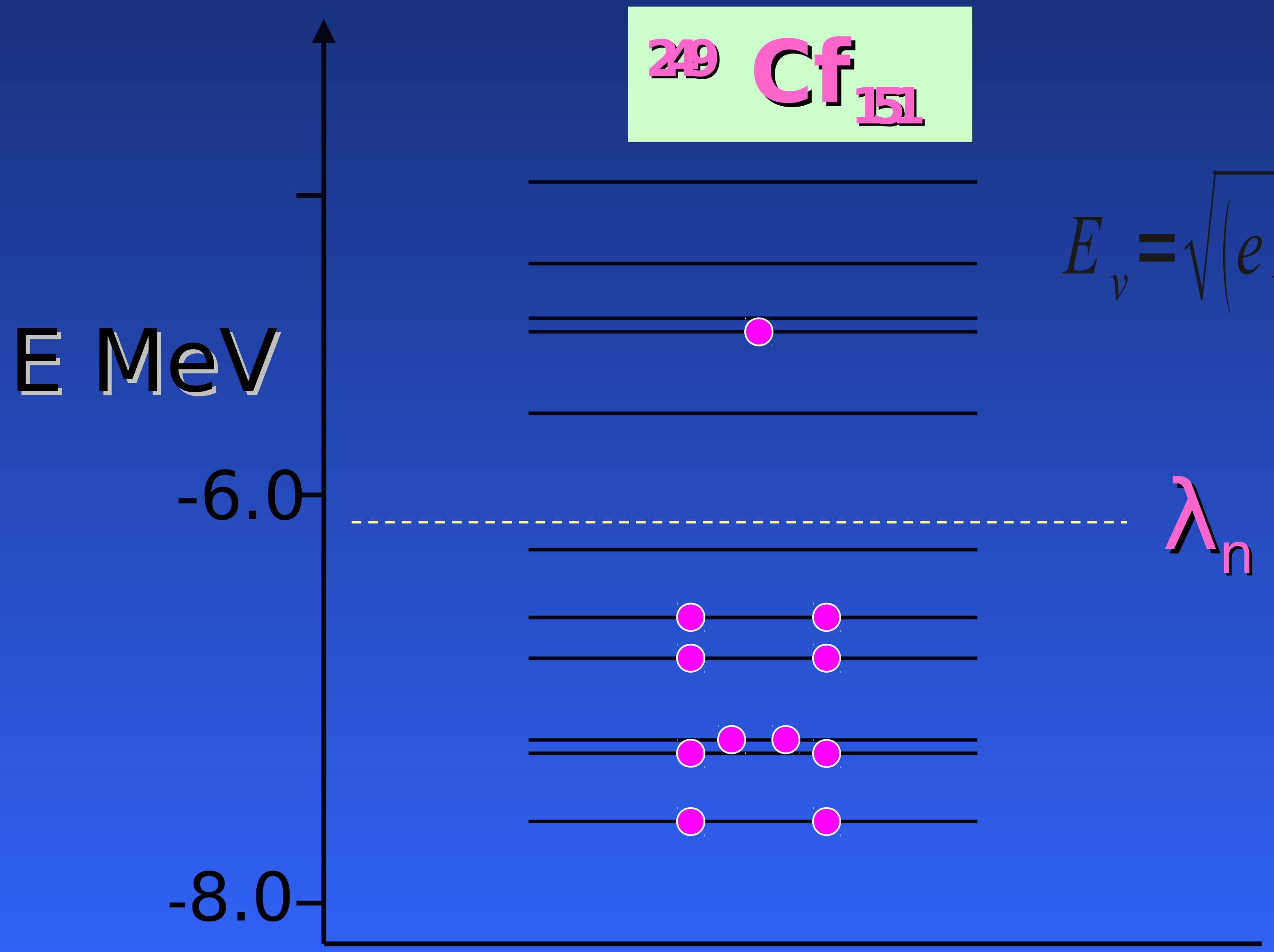
Shell efects



One-quasiparticle excitations



One-quasiparticle excitations



$$E_\nu = \sqrt{(e_\nu - \lambda)^2 + \Delta^2}.$$

Phenomenological formula for α-decay half-lives

Viola-Seaborg formula：

$$\log_{10} T_\alpha(Z,N) = a Z (Q_\alpha)^{-1/2} + b Z + c$$ for e-e

$$\log_{10} T_\alpha(Z,N) = a Z (Q_\alpha - E_p)^{-1/2} + b Z + c$$ for o-e

$$\log_{10} T_\alpha(Z,N) = a Z (Q_\alpha - E_n)^{-1/2} + b Z + c$$ for e-o

$$\log_{10} T_\alpha(Z,N) = a Z (Q_\alpha - E_{np})^{-1/2} + b Z + c$$ for o-o

$$E_{np} = E_n + E_p$$

Results

$$\left(\left|\lg T_{\alpha}^{th}(Q_{\alpha}^{\exp}) - \lg T_{\alpha}^{\exp}\right|\right) \qquad \bar{f} = 10^{|\bar{\delta}|}$$

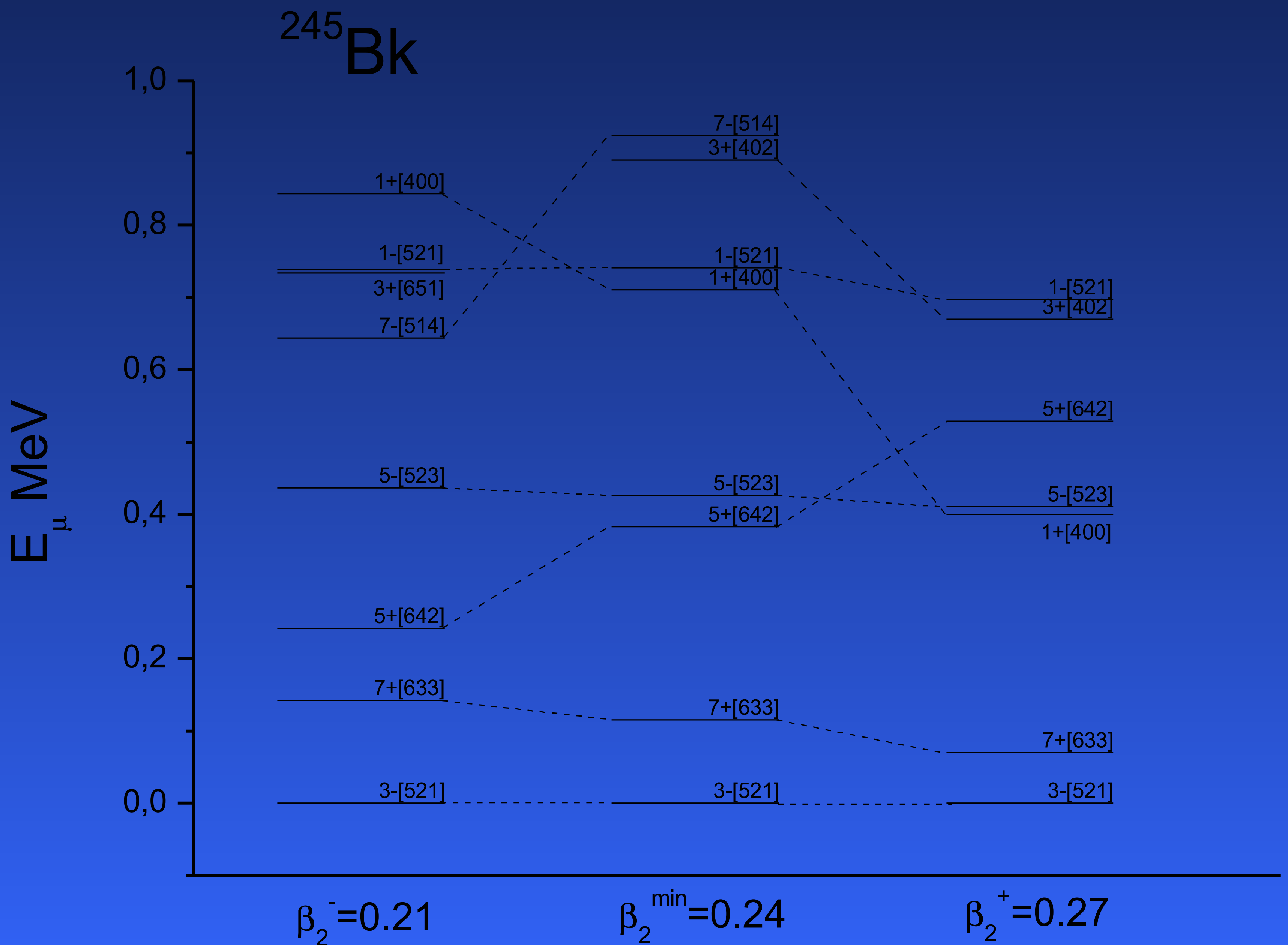
Z = 84 -110 N = 128 -171

Nuclei	n	$\lvert\bar{\delta}\rvert$	rms	$\bar{f}$	np	$\bar{E}$
e-e	61	0.13	0.16	1.3	3	0
o-e	45	0.32	0.41	2.1	1	0.113
e-o	56	0.50	0.60	3.2	1	0.170
o-o	40	0.60	0.72	4.0	0	0.28

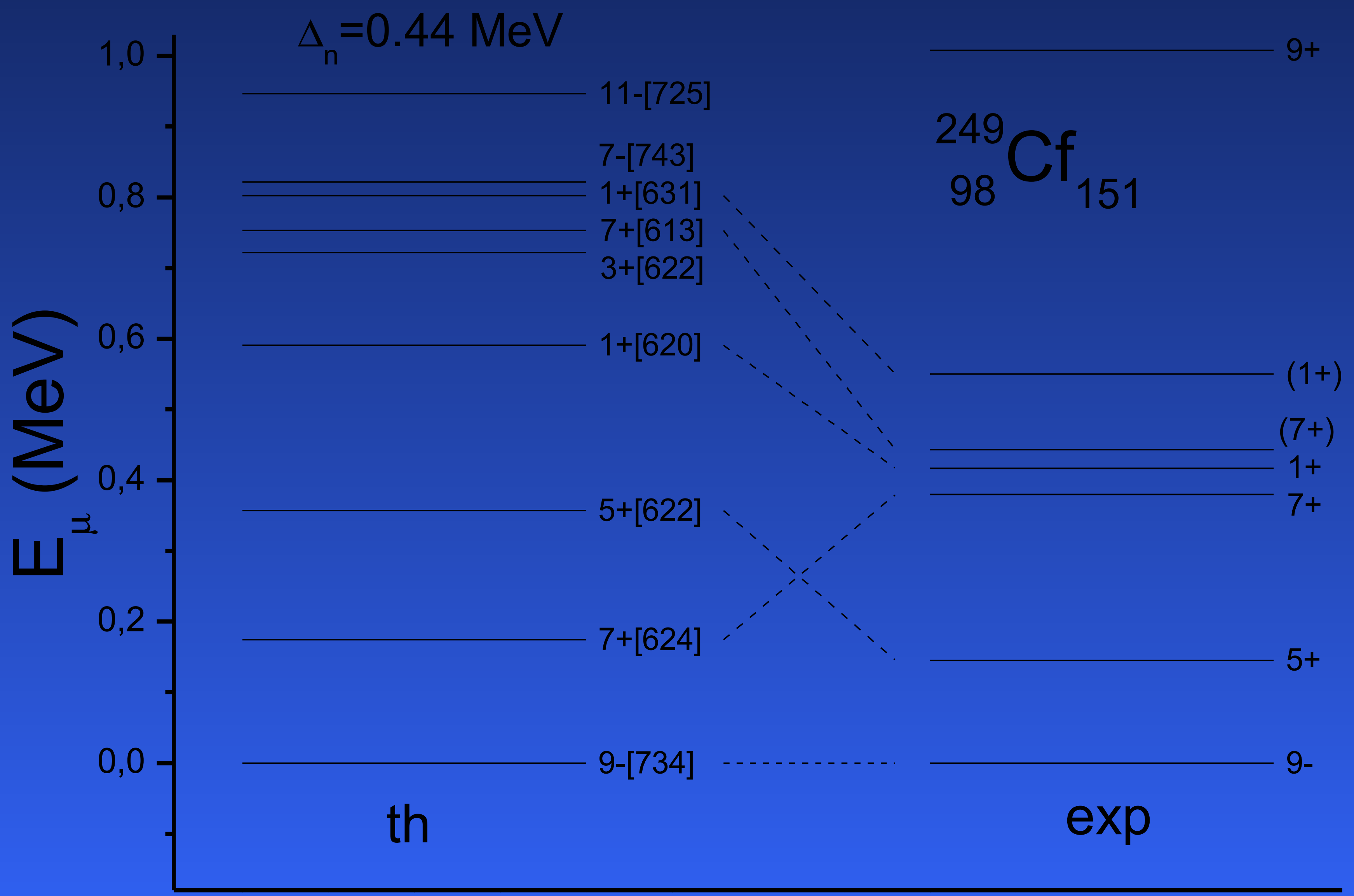
$$\left(\left|\lg T_\alpha^{th}(Q_\alpha^{th}) - \lg T_\alpha^{\exp}\right|\right)$$

Z = 84 -110 N = 128 -171

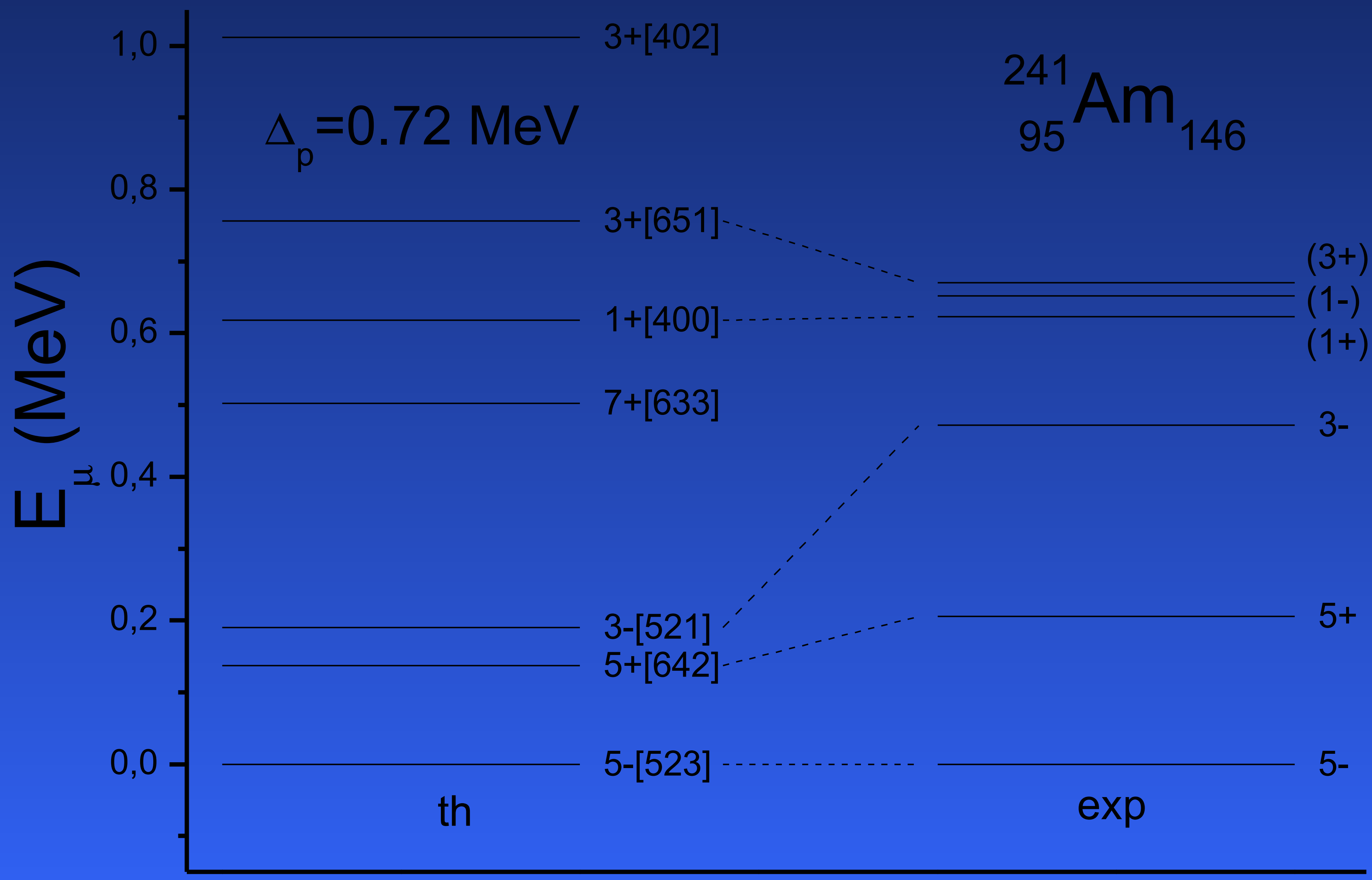
Nuclei	n	$\bar{\delta}$	rms	$\bar{f}$
e-e	67	0.71	0.93	5.1
o-e	48	1.08	1.44	12.0
e-o	68	1.20	1.58	15.8
o-o	43	1.26	1.57	18.0



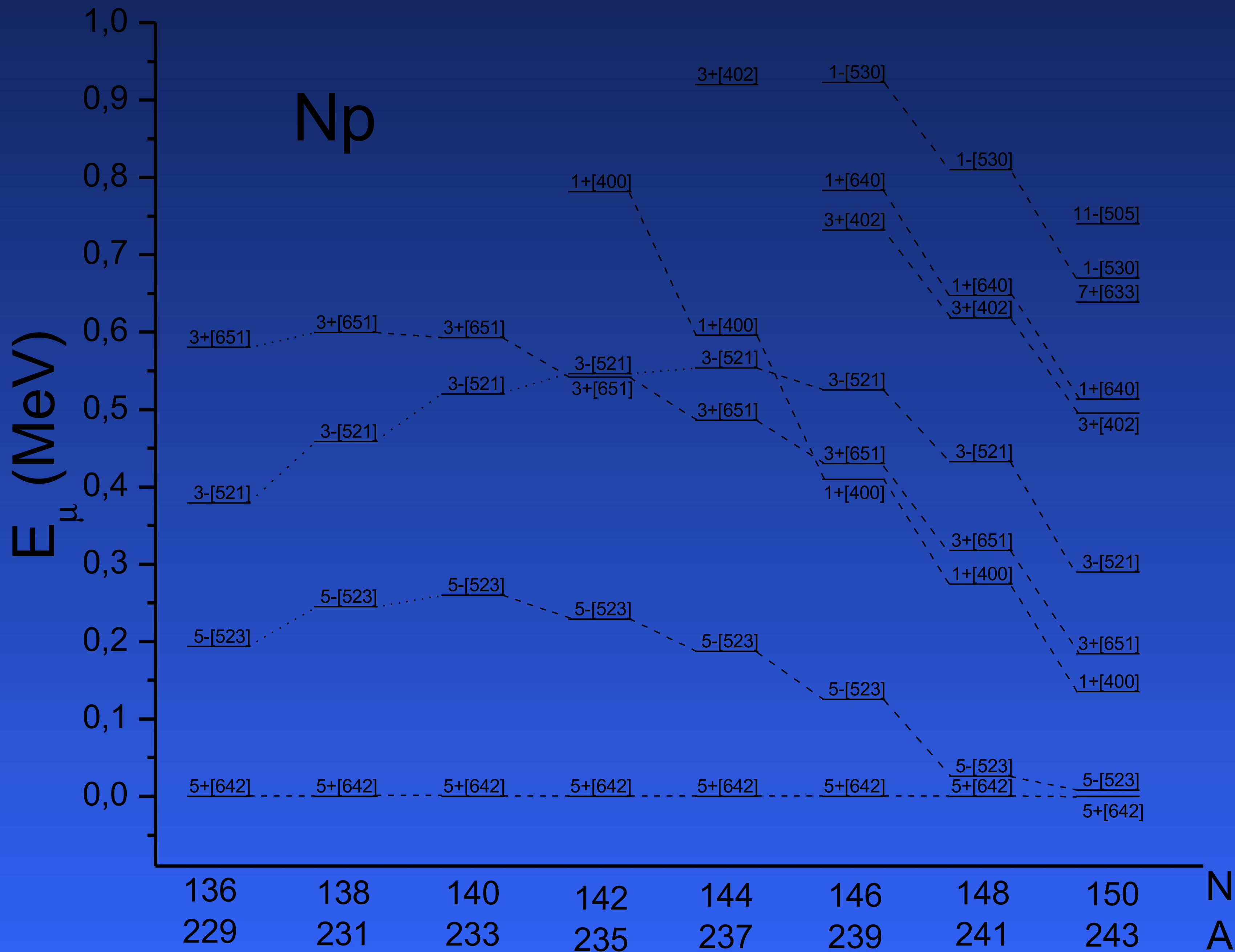
245Bk
1,0
0,8
0,6
0,4
0,2
0,0
Eμ MeV
1+[400]
1-[521]
3+[651]
7-[514]
5-[523]
5+[642]
7+[633]
3-[521]
7-[514]
3+[402]
1-[521]
1+[400]
5-[523]
5+[642]
7+[633]
3-[521]
1-[521]
3+[402]
5+[642]
5-[523]
1+[400]
7+[633]
3-[521]
β2-=0.21
β2min=0.24
β2+=0.27



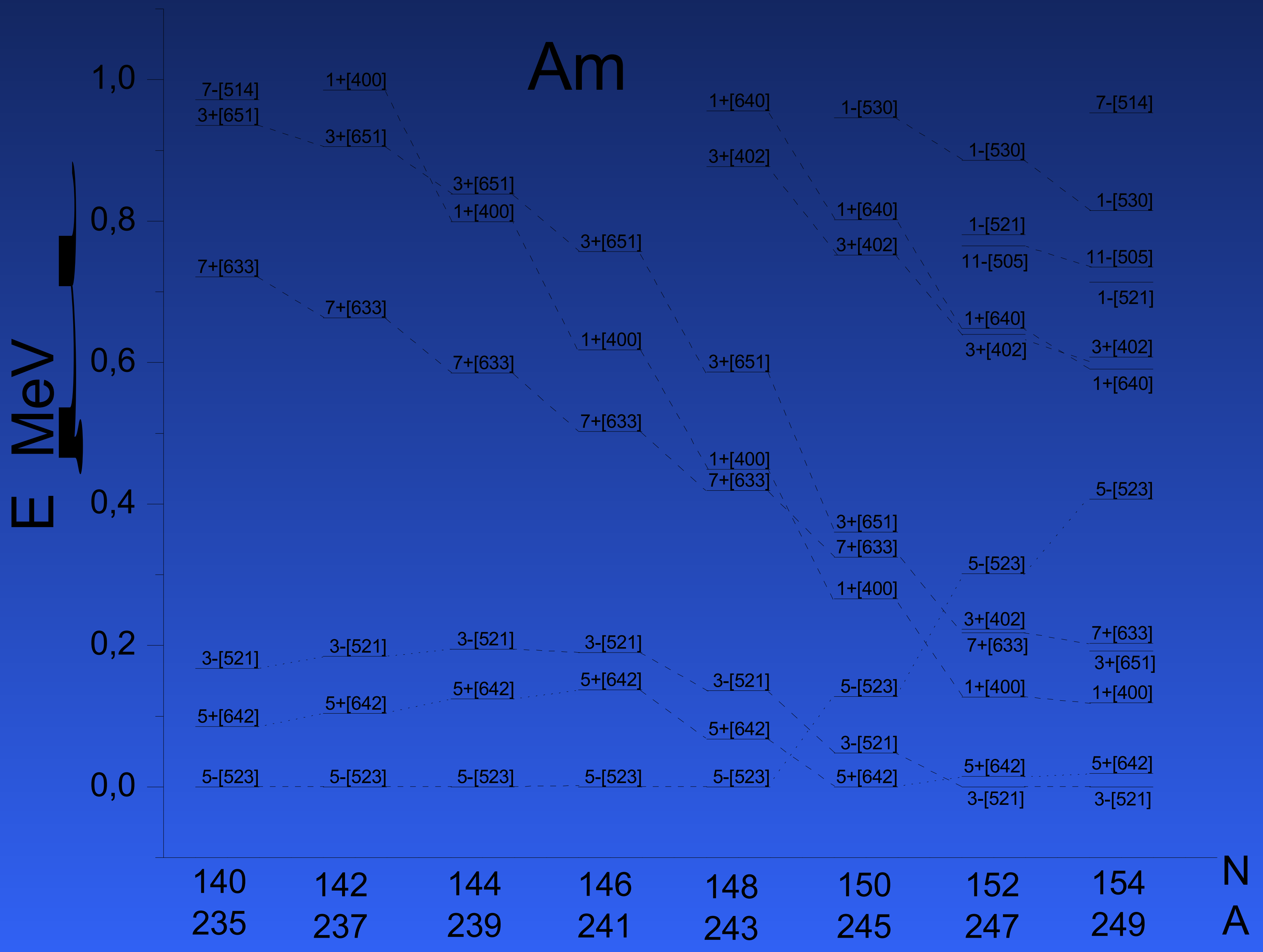
Δn=0.44 MeV
Eμ (MeV)
1,0
0,8
0,6
0,4
0,2
0,0
11-[725]
7-[743]
1+[631]
7+[613]
3+[622]
1+[620]
5+[622]
7+[624]
9-[734]
th
249 98 Cf 151
9+
(1+)
(7+)
1+
7+
5+
9-
exp



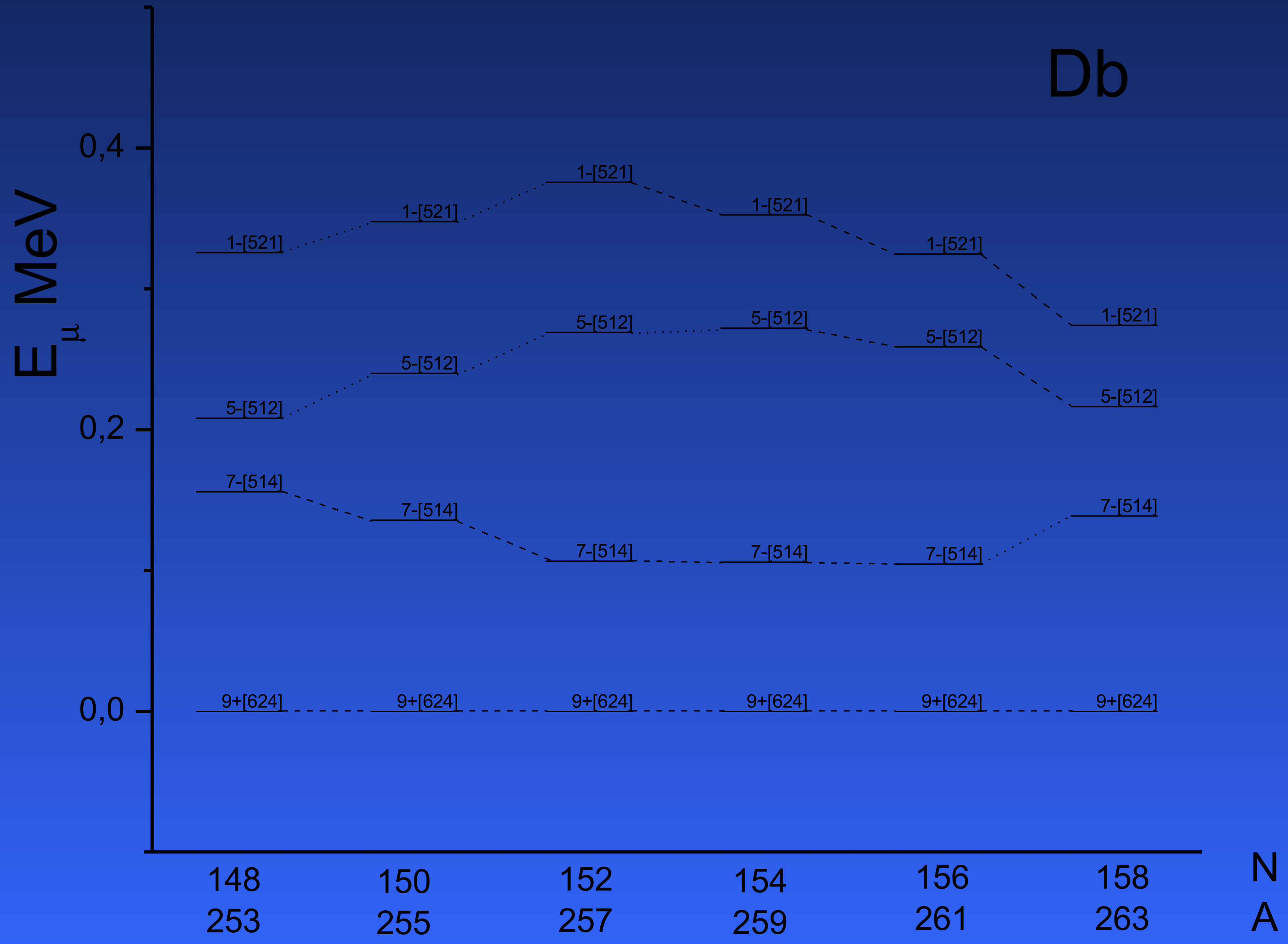
E_μ (MeV)
1,0
0,8
0,6
0,4
0,2
0,0
Δ_p=0.72 MeV
$^{241}_{95}Am_{146}$
3+[402]
3+[651]
1+[400]
7+[633]
3-[521]
5+[642]
5-[523]
(3+)
(1-)
(1+)
3-
5+
5-
th
exp



Np
E_μ (MeV)
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
N
A
136 229
138 231
140 233
142 235
144 237
146 239
148 241
150 243
3+[651]
3-[521]
5-[523]
5+[642]
1+[400]
3+[402]
1-[530]
1+[640]
11-[505]
7+[633]



Am
E MeV
1,0
0,8
0,6
0,4
0,2
0,0
7-[514]
3+[651]
7+[633]
3-[521]
5+[642]
5-[523]
1+[400]
3+[651]
7+[633]
3-[521]
5+[642]
5-[523]
3+[651]
1+[400]
7+[633]
3-[521]
5+[642]
5-[523]
3+[651]
1+[400]
7+[633]
3-[521]
5+[642]
5-[523]
1+[640]
3+[402]
3+[651]
1+[400]
7+[633]
3-[521]
5+[642]
5-[523]
1-[530]
1+[640]
3+[402]
3+[651]
7+[633]
1+[400]
5-[523]
3-[521]
5+[642]
1-[530]
1-[521]
11-[505]
1+[640]
3+[402]
5-[523]
3+[402]
7+[633]
1+[400]
5+[642]
3-[521]
7-[514]
1-[530]
11-[505]
1-[521]
3+[402]
1+[640]
5-[523]
7+[633]
3+[651]
1+[400]
5+[642]
3-[521]
140
235
142
237
144
239
146
241
148
243
150
245
152
247
154
249
N
A

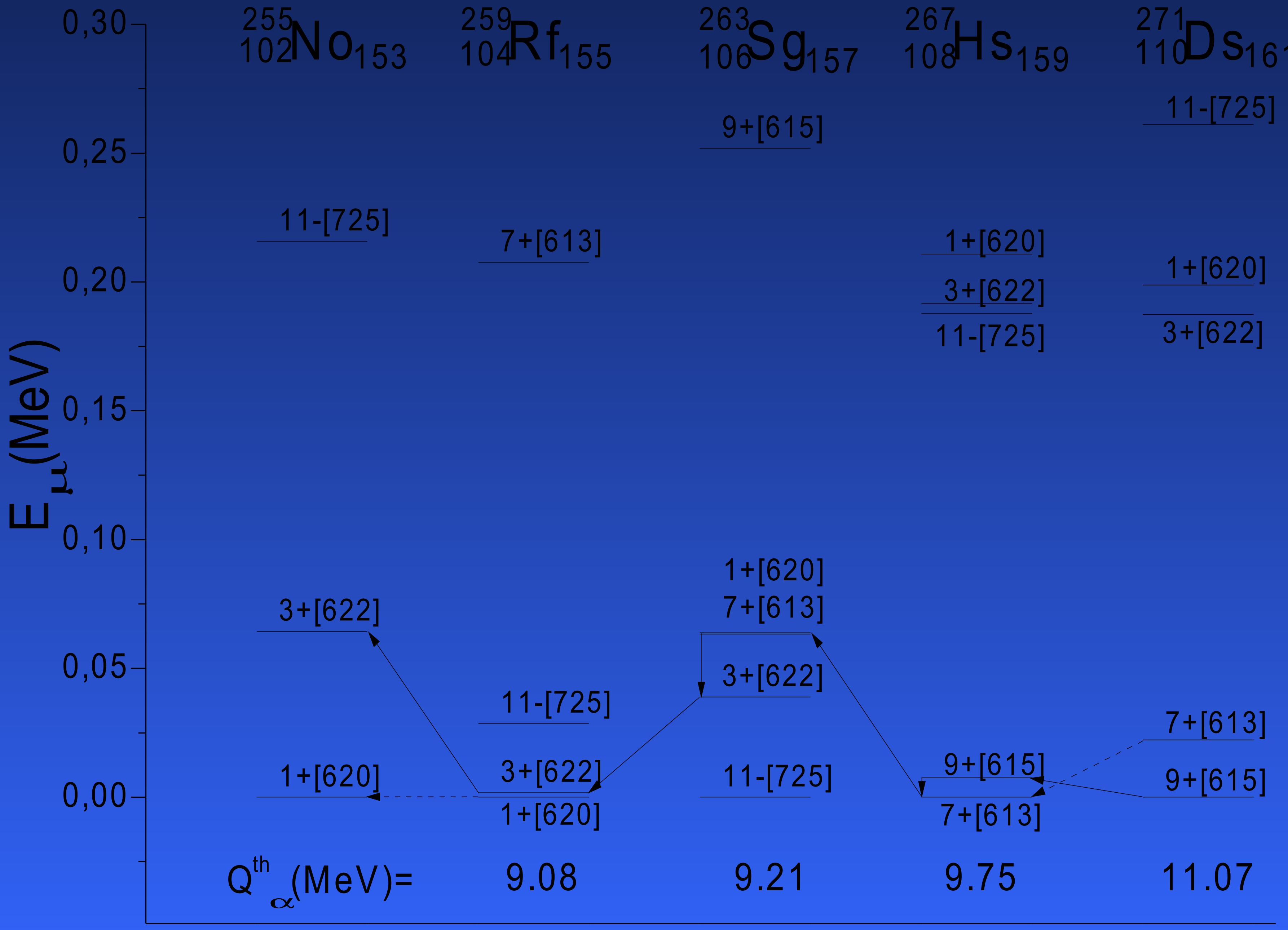

Db
E_μ MeV
0,4
0,2
0,0
1-[521]
5-[512]
7-[514]
9+[624]
N
A
148
253
150
255
152
257
154
259
156
261
158
263

Theoretical and experimental spins in a ground state

Z=93		
N	s.p. (teor)	s.p. (eksp)
138	5[642]	(5)
140	5[642]	(5+)
142	5[642]	5+
144	5[642]	5+
146	5[642]	5+
148	5[642]	(5+)
150	5[642]	(5-)

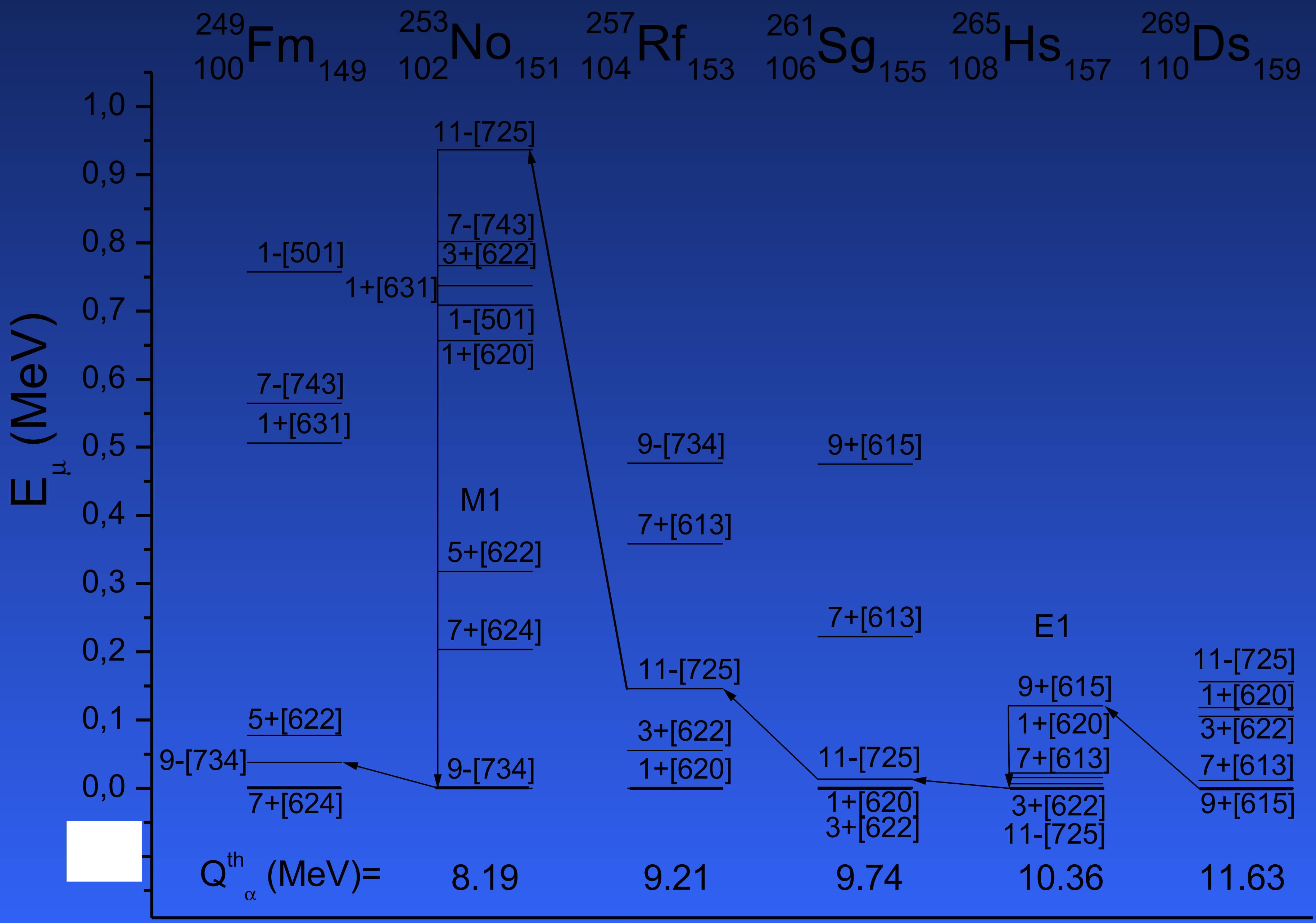
Z=95		
N	s.p. (teor)	s.p. (eksp)
142	5[523]	5(-)
144	5[523]	(5)-
146	5[523]	5-
148	5[523]	5-
150	5[642]	(5+)
152	3[521]	(5)

Z=105		
N	s.p. (teor)	s.p. (eksp)
152	9[624]	(9+)



$^{255}_{102}No_{153}$
$^{259}_{104}Rf_{155}$
$^{263}_{106}Sg_{157}$
$^{267}_{108}Hs_{159}$
$^{271}_{110}Ds_{161}$
E_{μ} (MeV)
0,30
0,25
0,20
0,15
0,10
0,05
0,00
11-[725]
3+[622]
1+[620]
7+[613]
11-[725]
3+[622]
1+[620]
9+[615]
1+[620]
7+[613]
3+[622]
11-[725]
1+[620]
3+[622]
11-[725]
9+[615]
7+[613]
11-[725]
1+[620]
3+[622]
7+[613]
9+[615]
Q^{th}_{α}(MeV)=
9.08
9.21
9.75
11.07

	T_α^{exp}	T_α^{th}	Q_α^{exp} MeV	Q_α^{th} MeV	Q_α^{trth} MeV
^{271}Ds	1.1 ms	0.39 ms	10.91	11.07	11.06
^{267}Hs	59 ms	0.25 s	10.03	9.75	9.69
^{263}Sg	0.31 s	0.93 s	9.39	9.21	9.25
^{259}Rf	3.1 s	0.59 s	9.03	9.08	9.08



249 100 Fm 149
253 102 No 151
257 104 Rf 153
261 106 Sg 155
265 108 Hs 157
269 110 Ds 159
E μ (MeV)
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
1-[501]
7-[743]
1+[631]
5+[622]
9-[734]
7+[624]
11-[725]
7-[743]
3+[622]
1+[631]
1-[501]
1+[620]
M1
5+[622]
7+[624]
9-[734]
9-[734]
7+[613]
11-[725]
3+[622]
1+[620]
9+[615]
7+[613]
11-[725]
1+[620]
3+[622]
E1
9+[615]
1+[620]
7+[613]
3+[622]
11-[725]
11-[725]
1+[620]
3+[622]
7+[613]
9+[615]
Q th α (MeV)=
8.19
9.21
9.74
10.36
11.63

	T_{α}^{exp}	T_{α}^{th}	Q_{α}^{exp} MeV	Q_{α}^{th} MeV	Q_{α}^{trth} MeV
^{269}Ds	179 μs	40 μs	11.28	11.63	11.51
^{265}Hs	701 μs	4.7 ms	10.35	10.68	10.36
^{261}Sg	61 ms	96 ms	9.68	9.74	9.60
^{257}Rf	9.4 s	64 s	8.80	9.21	8.42
^{253}No	92.4 s	90.8 s	8.21	8.19	8.15

Summary

- Quantum characteristics of most experimentally known ground states of analyzed here odd-A nuclei (in 24 of 38 cases for proton-odd and in 23 for 34 cases for neutron-odd nuclei) are reproduced by the calculations.
- Energy of known lowest nucleon excited states are reproduced by the applied model within an average accuracy of about 200 keV.
- Sensitivity of single-particle excitation energies to changes of such a quantity as the equilibrium deformation of a nucleus is rather large.
- A new, simple phenomenological formula for description of α-decay half-lives of heaviest e-e, o-e, e-o and o-o nuclei uses only 5 adjustable parameters. The formula allows one to describe *T*exp of 61 e-e nuclei roughly within a factor of 1.3, 45 o-e nuclei within a factor of 2.1, 55 e-o nuclei within a factor of 3.2 and 40 o-o nuclei within a factor of 4.0, on the average, when $\mathbf{Q}_{\alpha}^{exp}$ is taken.
- The accuracy of the mentioned above phenomenological formula decreases by a factor of about 4, when theoretical values of $\mathbf{Q}_{\alpha}^{th}$ are used.
- It is found that description of the ^{269}**Ds and** ^{271}**Ds** chains data is rather good.