ALPHA EMITTERS IN THE REGION FROM Ce TO Os

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A survey is given of experimental information for alpha emitters in the range from Ce to Os. From experimentally known alpha decay energies some mass values of very neutron deficient nuclei were derived. The knowledge of these mass values makes possible the calculations of the electron capture and proton binding energies. In the range from Sm to Os the parameters of the Geiger-Nuttall type formula for calculation of the alpha decay half-lives are derived. The alpha decay barrier penetrabilities and reduced widths for 95 alpha emitters in the region from Ce to Os are calculated and discussed.

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1. Introduction

A great number of new alpha active neutron deficient rare-earth nuclei was identified recently by Darmstadt, CERN, Oak-Ridge, Orsay and Gatchina groups.

For nuclei with $50 < Z < 82$ almost nothing is known about fine structure in alpha decay and relatively little is known about the systematics of alpha reduced widths.

The aim of this paper is to review recent data reported on alpha emitters from Ce to Os and alpha reduced widths evaluation.

To calculate the reduced widths, two pieces of information are needed, namely alpha particle energy E_α and alpha partial half life $T^\alpha_{1/2}$ (or total half-life and branching ratio). For many of them, however in the range of the atomic numbers $58 \leqslant Z \leqslant 76$ the data on alpha decay branching ratio (partial half life for alpha decay) are lacking.

The dependence of alpha partial half-life $T^\alpha_{1/2}$ on decay energy Q_α is well established for even-even nuclei in trans-lead region [1]. For the lanthanides region the experimental data are scarcer, in the present stage of our knowledge however this dependence seems also to work satisfactorily.

The dependence mentioned above will be used for estimation of unknown alpha partial half-lives.

Calculations of nuclear masses away from the stability line where the mass terminating the alpha chain is known will be given.

The results of alpha decay data summarized in the present work will be used to test the quality of the mass formulae for nuclei with $\mathrm{Sm} \leqslant Z \leqslant \mathrm{Os}$.

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Summary of alpha decay measurements and comparison

	Isotope	E_α (keV)	$T_{1/2}$ (sec) exp.	b_α [c] exp.	b_α [g] calc.	$T^{\alpha}_{1/2}$ (sec) exp.
1	$^{142}_{58}Ce_{84}$	1276[b]	1.58×10^{24}	—	—	—
2	$^{144}_{60}Nd_{84}$	1849 ± 3	$(7.23\pm0.76)10^{22}$	1	—	$(7.23\pm0.76)10^{22}$
3	$^{145}_{61}Pm_{84}$	2240 ± 40	$(5.58\pm0.13)10^{18}$	$(2.8\pm0.6)10^{-9}$	$<10^{-9}$	$(1.99\pm0.43)10^{17}$
4	$^{146}_{62}Sm_{84}$	2550 ± 30	$(3.24\pm0.15)10^{15}$	1	—	$(3.24\pm0.15)10^{15}$
5	$^{147}_{62}Sm_{85}$	2233 ± 5	$(3.34\pm0.06)10^{18}$	1	—	$(3.34\pm0.06)10^{18}$
6	$^{148}_{62}Sm_{86}$	1960 ± 20	$(2.52\pm0.63)10^{23}$	1	—	$(2.52\pm0.63)10^{23}$
7	$^{149}_{62}Sm_{87}$	1840 ± 50	3.16×10^{23}	0.12 [e]	—	2.67×10^{24} [e]
8	$^{147}_{63}Eu_{84}$	2908 ± 5	$(1.86\pm0.04)10^{6}$	$(2.2\pm0.6)10^{-5}$	10^{-5}	$(8.44\pm2.31)10^{10}$
9	$^{148}_{63}Eu_{85}$	2630 ± 30	$(4.66\pm0.08)10^{6}$	$(9.4\pm2.8)10^{-9}$	2×10^{-8}	$(4.96\pm1.48)10^{14}$
10	$^{148}_{64}Gd_{84}$	3183 ± 1	$(3.08\pm0.20)10^{9}$	1	—	$(3.08\pm0.20)10^{9}$
11	$^{149}_{64}Gd_{85}$	3018 ± 5	$(7.99\pm0.08)10^{5}$	$(4.5\pm1.5)10^{-6}$	10^{-5}	$(1.74\pm0.57)10^{11}$
12	$^{150}_{64}Gd_{86}$	2730 ± 10	$(5.62\pm0.25)10^{13}$	1	—	$(5.62\pm0.25)10^{13}$
13	$^{151}_{64}Gd_{87}$	2600 ± 30	$(1.04\pm0.17)10^{7}$	8×10^{-9}	3×10^{-9}	$(1.3\pm0.2)10^{15}$
14	$^{152}_{64}Gd_{88}$	2140 ± 30	$(3.41\pm0.25)10^{21}$	1	—	$(3.41\pm0.25)10^{21}$
15	$^{149}_{65}Tb^{g}_{84}$ [a]	3966 ± 10 [d]	$(1.49\pm0.01)10^{4}$	(0.167 ± 0.014)	0.06	$(8.95\pm0.75)10^{4}$
16	$^{149}_{65}Tb^{m}_{84}$ [a]	3990 ± 30	$(2.50\pm0.02)10^{2}$	$(2\pm0.4)10^{-4}$	—	$(1.25\pm0.01)10^{6}$
17	$^{150}_{65}Tb_{85}$	3492 ± 5	$(1.25\pm0.06)10^{4}$	7×10^{-5} [e]	10^{-4}	1.7×10^{8} [e]
18	$^{151}_{65}Tb_{86}$	3409 ± 5	$(6.34\pm0.36)10^{4}$	$(9.5\pm1.5)10^{-5}$	3×10^{-4}	$(6.67\pm1.05)10^{8}$
19	$^{150}_{66}Dy_{84}$	4232 ± 5	430.2 ± 1.2	0.31 ± 0.03	0.37	$(1.39\pm0.13)10^{3}$
20	$^{151}_{66}Dy_{85}$	4067 ± 3	1014 ± 30	0.055 ± 0.008	0.056	$(1.84\pm0.27)10^{4}$
21	$^{152}_{66}Dy_{86}$	3630 ± 5	$(8.53\pm0.07)10^{3}$	$(9.4\pm0.9)10^{-4}$	6×10^{-4}	$(9.08\pm0.87)10^{6}$
22	$^{153}_{66}Dy_{87}$	3464 ± 5	$(2.26\pm0.04)10^{4}$	$(1\pm0.1)10^{-4}$	0.3×10^{-4}	$(2.26\pm0.23)10^{8}$
23	$^{154}_{66}Dy_{88}$	2872 ± 5	$\sim3.15\times10^{14}$	—	—	3.26×10^{13} [e]
24	$^{151}_{67}Ho^{ls}_{84}$ [a]	4607 ± 3	48 ± 9 [d]	0.10 ± 0.03	0.80	480 ± 170
25	$^{151}_{67}Ho^{hs}_{84}$ [a]	4517 ± 3	39 ± 4 [d]	0.20 ± 0.05	0.57	195 ± 52
26	$^{152}_{67}Ho^{ls}_{85}$ [a]	4387 ± 3	154 ± 5 [d]	$(1.7\pm0.3)10^{-2}$	0.16	$(9.06\pm1.62)10^{3}$
27	$^{152}_{67}Ho^{hs}_{85}$ [a]	4453 ± 10 [d]	49.5 ± 0.3 [d]	$(5.2\pm1.5)10^{-2}$ [d]	0.28	952 ± 275
28	$^{153}_{67}Ho^{ls}_{86}$ [a]	4008 ± 10 [d]	558 ± 30	$(0.12\pm0.07)10^{-2}$	3.8 ± 10^{-3}	$(4.65\pm2.72)10^{5}$
29	$^{153}_{67}Ho^{hs}_{86}$ [a]	3905 ± 10 [d]	120 ± 6	$(0.04\pm0.02)10^{-2}$	8×10^{-4}	$(3\pm0.15)10^{5}$
30	$^{154}_{67}Ho^{ls}_{87}$ [a]	3941 ± 10 [d]	708 ± 30	$(1.7\pm0.4)10^{-4}$	1.8×10^{-3}	$(4.16\pm0.99)10^{6}$
31	$^{154}_{67}Ho^{hs}_{87}$ [a]	3724 ± 5 [d]	195 ± 6	4.9×10^{-5} [e]	5.5×10^{-5}	3.95×10^{6} [e]
32	$^{152}_{68}Er_{84}$	4799 ± 3	10.3 ± 0.1 [d]	0.89 ± 0.07 [d]	0.86	11.57 ± 0.92
33	$^{153}_{68}Er_{85}$	4671 ± 3	35.6 ± 0.2 [d]	0.44 ± 0.06 [d]	0.57	80.9 ± 11
34	$^{154}_{68}Er_{86}$	4172 ± 10 [d]	225 ± 7.2	$(0.47\pm0.13)10^{-2}$	4.6×10^{-3}	$(4.79\pm1.33)10^{4}$
35	$^{155}_{68}Er_{87}$	4015 ± 10 [d]	318 ± 18	6×10^{-4} [e]	6.5×10^{-4}	5.3×10^{5} [e]
36	$^{153}_{69}Tm_{84}$	5106 ± 10 [d]	1.7 ± 0.1 [d]	0.8 ± 0.1 [d]	0.94	2.1 ± 0.3
37	$^{154}_{69}Tm_{85}$	4957 ± 10 [d]	8 ± 0.2 [d]	0.59 ± 0.10 [d]	0.73	13.56 ± 2.32
38	$^{154}_{69}Tm_{85}$	5033 ± 10 [d]	3.2 ± 0.1 [d]	0.59 [e]	0.86	5.44 [e]

TABLE I

with calculated alpha and beta partial half-lives

$T^{\alpha}_{1/2}$ (sec) calc [17] [h]	[23] [i]	[f]	$T^{\beta}_{1/2}$ (sec) exp	$T^{\beta}_{1/2}$ (sec) theor [5]	Ref.
7.07×10^{34}	1.44×10^{35}	6.3×10^{34}	—	—	[2]
1.41×10^{23}	4.67×10^{23}	1.9×10^{23}	—	—	[6]
4.65×10^{17}	5.91×10^{17}	6.15×10^{17}	$(5.58\pm0.13)10^{8}$	$>10^{7}$	[2]
1.51×10^{15}	2.00×10^{15}	2.13×10^{15}	—	—	[2]
3.71×10^{18}	5.73×10^{18}	5.47×10^{18}	—	—	[2]
8.41×10^{22}	1.66×10^{23}	1.34×10^{23}	—	—	[2]
1.38×10^{25}	3.16×10^{25}	2.26×10^{25}	—	—	[7]
1.75×10^{11}	2.30×10^{11}	2.58×10^{11}	$(1.86\pm0.04)10^{6}$	2×10^{6}	[2]
1.62×10^{15}	2.37×10^{14}	2.44×10^{14}	$(4.66\pm0.08)10^{6}$	5×10^{6}	[2]
2.13×10^{9}	3.05×10^{9}	3.45×10^{9}	—	—	[2]
6.89×10^{10}	1.02×10^{11}	1.10×10^{11}	$(7.99\pm0.08)10^{5}$	10^{6}	[2]
6.21×10^{13}	1.03×10^{14}	1.00×10^{14}	—	—	[2]
1.93×10^{15}	3.43×10^{15}	3.11×10^{15}	1.04×10^{7}	10^{7}	[2]
4.12×10^{21}	1.05×10^{22}	7.52×10^{21}	—	—	[8]
1.10×10^{4}	1.65×10^{4}	1.95×10^{4}	$(1.79\pm0.23)10^{4}$	1.3×10^{3}	[2, 9, 10]
—	—	—	$(2.50\pm0.02)10^{2}$	1.3×10^{3}	[2, 11]
2.44×10^{7}	3.78×10^{7}	0.42×10^{8}	1.25×10^{4}	5×10^{3}	[2]
1.13×10^{8}	1.73×10^{8}	1.85×10^{8}	$(6.34\times0.36)10^{4}$	6×10^{4}	[2]
8.45×10^{2}	1.45×10^{3}	1.71×10^{3}	623.4 ± 27.1	10^{3}	[2]
8.57×10^{4}	1.45×10^{4}	1.66×10^{4}	1073 ± 33	10^{3}	[2]
8.34×10^{6}	1.45×10^{7}	1.55×10^{7}	$(8.53\pm0.07)10^{3}$	9×10^{3}	[2]
1.59×10^{8}	2.84×10^{8}	2.89×10^{8}	$(2.26\pm0.04)10^{4}$	10^{4}	[2]
4.37×10^{13}	9.59×10^{13}	0.83×10^{14}	—	—	[2]
21.3	42.1	50	53 ± 10	200	[2]
64.8	127	150	48.7 ± 5.8	200	[2]
3.43×10^{2}	6.61×10^{2}	752	156 ± 5	150	[2]
1.46×10^{2}	2.81×10^{2}	390	52.2 ± 0.9	150	
7.00×10^{4}	1.34×10^{5}	1.46×10^{5}	558 ± 30	560	[2]
3.4×10^{5}	6.57×10^{5}	7.07×10^{5}	120 ± 6	560	[2]
1.94×10^{5}	3.70×10^{5}	3.89×10^{5}	708 ± 30	700	[2]
6.33×10^{6}	1.25×10^{7}	1.28×10^{7}	195	700	[2]
6.48	14.7	17.16	93.6 ± 59.5	110	[2]
29.6	65.5	74.7	63.6 ± 6.8	100	[2]
2.13×10^{4}	4.66×10^{4}	5.02×10^{4}	226.1 ± 7.2	230	[2]
2.45×10^{5}	4.75×10^{5}	4.91×10^{5}	318	320	[2]
0.6	1.58	1.84	8.5 ± 4.3	32	
3.1	7.88	8.94	19.51 ± 4.78	25	
1.33	3.4	3.88	7.8	25	

	Isotope	E_α (keV)	$T_{1/2}$ (sec) exp.	b_α [c] exp.	b_α [g] calc.	$T^{\alpha}_{1/2}$ (sec) exp.
39	$^{155}_{69}\mathrm{Tm}_{86}$	4462 ± 10 [d]	29.2 ± 0.8 [d]	5.3×10^{-3} [e]	0.01	5.53×10^{3} [e]
40	$^{156}_{69}\mathrm{Tm}_{87}$	4234 ± 10 [d]	86 ± 4 [d]	$(6.4 \pm 1.0)10^{-4}$ [d]	10^{-3}	$(1.35 \pm 0.22)10^{5}$
41	$^{156}_{69}\mathrm{Tm}_{87}$	4460 ± 10	19 ± 3	3.3×10^{-3} [e]	0.02	5.8×10^{3} [e]
42	$^{154}_{70}\mathrm{Yb}_{84}$	5334 ± 10 [d]	0.44 ± 0.04 [d]	0.93 ± 0.02	0.97	0.473 ± 0.044
43	$^{155}_{70}\mathrm{Yb}_{85}$	5209 ± 10 [d]	1.8 ± 0.1 [d]	0.84 ± 0.10	0.90	2.14 ± 0.28
44	$^{156}_{70}\mathrm{Yb}_{86}$	4688 ± 10 [d]	26.7 ± 0.6 [d]	0.21 ± 0.06	0.04	127.1 ± 36.4
45	$^{157}_{70}\mathrm{Yb}_{87}$	4504 ± 10 [d]	36.7 ± 1.0 [d]	4×10^{-3} [e]	4.8×10^{-3}	9.15×10^{3} [e]
46	$^{158}_{70}\mathrm{Yb}_{88}$	4069 ± 10 [d]	93 ± 6	2×10^{-5} [e]	3.2×10^{-5}	4.5×10^{6} [e]
47	$^{155}_{71}\mathrm{Lu}_{84}$	5656 ± 6	$(70 \pm 6)10^{-3}$	0.79	0.99	$(8.8 \pm 0.8)10^{-2}$
48	$^{156}_{71}\mathrm{Lu}_{85}$	5568 ± 5	0.18 ± 0.02	1 ± 0.25	0.98	0.18 ± 0.05
49	$^{156}_{71}\mathrm{Lu}_{85}$	5450 ± 10	~0.5	0.7	0.94	~0.7
50	$^{157}_{71}\mathrm{Lu}_{86}$	4995 ± 10 [d]	5.5 ± 0.3 [d]	0.06 ± 0.02	0.13	91.7 ± 31.5
51	$^{158}_{71}\mathrm{Lu}_{87}$	4665 ± 10 [d]	10 ± 1 [d]	2×10^{-3} [e]	3×10^{-3}	5×10^{3} [e]
52	$^{159}_{71}\mathrm{Lu}_{88}$	4420 ± 10 [d]	12.3 ± 1.0 [d]	9.1×10^{-5} [e]	3×10^{-4}	1.35×10^{5} [e]
53	$^{156}_{72}\mathrm{Hf}_{84}$	5878 ± 10	$(25 \pm 4)10^{-3}$	1 ± 0.19	0.99	$(25 \pm 6)10^{-3}$
54	$^{157}_{72}\mathrm{Hf}_{85}$	5735 ± 5	0.110 ± 0.006	0.91 ± 0.07	0.98	0.121 ± 0.011
55	$^{158}_{72}\mathrm{Hf}_{86}$	5268 ± 5	3.2 ± 0.6	0.46 ± 0.03	0.41	6.95 ± 1.38
56	$^{159}_{72}\mathrm{Hf}_{87}$	5095 ± 5	5.6 ± 0.5	0.12 ± 0.01	0.12	46.7 ± 5.7
57	$^{160}_{72}\mathrm{Hf}_{88}$	4777 ± 5	29 [e]	0.023 ± 0.006	5.5×10^{-3}	1.26×10^{3} [e]
58	$^{161}_{72}\mathrm{Hf}_{89}$	4600 ± 10	17 ± 2	1.9×10^{-3} [e]	8×10^{-4}	8.8×10^{3} [e]
59	$^{162}_{72}\mathrm{Hf}_{90}$	4308 ± 10	35.5 ± 2	$(1 \pm 0.25)10^{-5}$ [e]	2.4×10^{-5}	$(3.6 \pm 0.9)10^{5}$ [e]
60	$^{174}_{72}\mathrm{Hf}_{102}$	2500 ± 30	$(6.31 \pm 1.26)10^{22}$	1	—	$(6.31 \pm 1.26)10^{22}$
61	$^{157}_{73}\mathrm{Ta}_{84}$	6219 ± 10	$(5.3 \pm 2.2)10^{-3}$	1 ± 0.23	0.997	$(5.3 \pm 2.2)10^{-3}$
62	$^{158}_{73}\mathrm{Ta}_{85}$	6051 ± 6	$(36.8 \pm 1.6)10^{-3}$	0.93 ± 0.06	0.99	$(39 \pm 4)10^{-3}$
63	$^{159}_{73}\mathrm{Ta}_{86}$	5601 ± 6	0.570 ± 0.180	0.80 ± 0.05	0.78	0.712 ± 0.183
64	$^{160}_{73}\mathrm{Ta}_{87}$	5413 ± 5	—	—	0.35	3.42 [e]
65	$^{161}_{73}\mathrm{Ta}_{88}$	5148 ± 5	—	—	0.05	34.6 [e]
66	$^{158}_{74}\mathrm{W}_{84}$	6450 ± 30	—	—	0.998	2.2×10^{-3} [e]
67	$^{159}_{74}\mathrm{W}_{85}$	6299 ± 6	$(7.3 \pm 2.7)10^{-3}$	2 ± 1.2	0.995	$(3.6 \pm 2.5)10^{-3}$
68	$^{160}_{74}\mathrm{W}_{86}$	5920 ± 10	$(81 \pm 15)10^{-2}$	0.94 ± 0.40	0.95	$(86 \pm 40)10^{-3}$
69	$^{161}_{74}\mathrm{W}_{87}$	5777 ± 5	0.410 ± 0.040	0.82 ± 0.26	0.81	0.50 ± 0.16
70	$^{162}_{74}\mathrm{W}_{88}$	5538 ± 5	1.39 ± 0.04	0.46 ± 0.04	0.46	3.02 ± 0.28
71	$^{163}_{74}\mathrm{W}_{89}$	5384 ± 5	3.0 ± 0.2	0.41 ± 0.05	0.15	7.3 ± 1.0
72	$^{164}_{74}\mathrm{W}_{90}$	5148 ± 5	6.4 ± 0.8	$(26 \pm 17)10^{-3}$	27×10^{-3}	246 ± 164
73	$^{165}_{74}\mathrm{W}_{91}$	4902 ± 5	5.1 ± 0.5	$(5.1 \pm 0.9)10^{-3}$	1.6 ± 10^{-3}	$(1 \pm 0.14)10^{3}$
74	$^{166}_{74}\mathrm{W}_{92}$	4739 ± 5	16 ± 3	$(6 \pm 2)10^{-3}$	5.5 ± 10^{-4}	$(2.7 \pm 1.8)10^{3}$
75	$^{161}_{75}\mathrm{Re}_{86}$	6279 ± 10	$\left(10^{+15}_{-\ 5}\right)10^{-3}$	0.50 [e]	0.986	20×10^{-3} [e]
76	$^{162}_{75}\mathrm{Re}_{87}$	6119 ± 6	$(100 \pm 30)10^{-3}$	1.4 [e]	0.945	70×10^{-3} [e]
77	$^{163}_{75}\mathrm{Re}_{88}$	5918 ± 6	0.260 ± 0.040	0.64 ± 0.18	0.81	0.41 ± 0.13
78	$^{164}_{75}\mathrm{Re}_{89}$	5778 ± 10	0.88 ± 0.24	0.60 [e]	0.62	1.46 [e]

TABLE I (continued)

$T^{\alpha}_{1/2}$ (sec) calc			$T^{\beta}_{1/2}$ (sec) exp	$T^{\beta}_{1/2}$ (sec) theor [5]	Ref.
[17] h	[23] i	f			
1.28×10^{3}	3.16×10^{3}	3.42×10^{3}	29.2	39	
2.9×10^{4}	7.18×10^{4}	0.74×10^{5}	86 ± 4	80	
1.3×10^{3}	3.2×10^{3}	3.4×10^{3}	19	80	[2]
0.15	0.46	0.538	6.28 ± 1.80	20	[9, 10]
0.56	1.64	1.85	11.25 ± 7.06	18	[9, 10]
2.2×10^{2}	6.18×10^{2}	667	33.8 ± 2.7	32	[9, 10]
2.31×10^{3}	6.43×10^{3}	6.67×10^{3}	36.7 ± 1.0	32	
1.12×10^{6}	3.23×10^{6}	3.1×10^{6}	93 ± 6	100	
1.7×10^{-2}	6×10^{-2}	6.9×10^{-2}	$(33.3\pm6.9)10^{-2}$	6.2	[9, 10]
3.9×10^{-2}	0.13	0.15	0.5	8	[9, 10]
0.12	0.43	0.5	1.7	8	[9, 10]
16.6	53.6	64.4	5.85 ± 0.50	10	[9, 10]
8.89×10^{2}	2.8×10^{3}	2.9×10^{3}	—	10	
2.26×10^{4}	7.19×10^{4}	0.7×10^{5}	—	20	
5.5×10^{-3}	22.6×10^{-3}	26×10^{-3}	>0.1	3.2	[9, 10]
0.02	0.08	0.092	1.22 ± 0.95	5	[9, 10]
2.27	8.4	9.1	5.9 ± 1.1	6.2	[9, 10]
15.2	55.0	57.6	6.4 ± 0.6	8	[9, 10]
6.58×10^{2}	2.34×10^{3}	2.33×10^{3}	—	13	
6.3×10^{3}	2.24×10^{4}	2.13×10^{4}	—	17	[2]
3.5×10^{5}	1.3×10^{6}	1.22×10^{6}	—	30	[12]
1.22×10^{26}	4.84×10^{23}	9.9×10^{22}	—	—	[3]
6.8×10^{-4}	3.3×10^{-3}	3.8×10^{-3}	$>15\times10^{-3}$	1.3	[9, 10]
2.9×10^{-3}	13.5×10^{-3}	15×10^{-3}	0.5 ± 0.95	2.3	[9, 10]
0.20	0.84	0.92	2.85 ± 1.14	3.2	[9, 10]
1.34	5.55	5.84	—	3.2	[9, 10]
23.7	95.8	96.7	—	5.5	[9, 10]
2.4×10^{-4}	1.4×10^{-3}	1.5×10^{-3}	—	0.8	[9]
8.4×10^{-4}	4.51×10^{-3}	5×10^{-3}	$>5\times10^{-3}$	1.2	[9]
2.4×10^{-3}	119×10^{-3}	129×10^{-3}	>1.3	2.5	[9, 10]
9.2×10^{-2}	0.44	0.47	>2	2	[9, 10]
0.98	4.59	4.68	2.57 ± 0.31	4	[9, 10]
4.9	22.4	22.12	5.1 ± 0.5	4	[9, 10]
67.0	300	281.8	6.6 ± 0.8	8	[9, 10]
1.2×10^{3}	5.54×10^{3}	4.91×10^{3}	5.1 ± 0.5	8	[4, 9, 10]
9.6×10^{3}	4.4×10^{4}	3.66×10^{4}	16 ± 3	20	[4, 9, 10]
2.41×10^{-3}	14×10^{-3}	15×10^{-3}	—	1.1	[9, 10]
9.8×10^{-3}	55×10^{-3}	58×10^{-3}	—	—	[9, 10]
6.2×10^{-2}	0.33	0.34	0.72 ± 0.19	1.5	[9, 10]
0.23	1.24	1.23	—	2	[9, 10]

	Isotope	E_α (keV)	$T_{1/2}$ (sec) exp.	b_α exp. [c]	b_α calc. [g]	$T^\alpha_{1/2}$ (sec) exp.
79	$^{165}_{75}Re_{90}$	5506±10	2.4±0.6	0.13±0.03	0.14	18.5±6.3
80	$^{166}_{75}Re_{91}$	5495±10	2.2±0.4	0.10 [e]	0.21	22 [e]
81	$^{167}_{75}Re_{92}$	5330±10	2.0±0.3	17×10^{-3} [e]	5×10^{-3}	114 [e]
82	$^{168}_{75}Re_{93}$	5140±10	2.9±0.3	3×10^{-3} [e]	3×10^{-2}	850 [e]
83	$^{169}_{75}Re_{94}$	5050±10	—	—	4×10^{-3}	2.1×10^{3} [e]
84	$^{163}_{76}Os_{87}$	6510±30	—	—	0.993	7×10^{-3} [e]
85	$^{164}_{76}Os_{88}$	6320±20	$(41\pm20)10^{-3}$	1±0.7	0.98	$(41\pm35)10^{-3}$
86	$^{165}_{76}Os_{89}$	6164±10	$\left(65^{+70}_{-30}\right)10^{-3}$	1±0.4	0.92	$(65\pm40)10^{-3}$
87	$^{166}_{76}Os_{90}$	5981±6	0.181±0.038	0.72±0.13	0.83	0.25±0.07
88	$^{167}_{76}Os_{91}$	5836±5	1.05±0.35	0.58±0.12	0.57	1.81±0.71
89	$^{168}_{76}Os_{92}$	5660±10	2.4±0.2	0.47 [c]	0.28	5.1 [e]
90	$^{169}_{76}Os_{93}$	5560±10	3.2±0.2	0.25 [e]	0.21	13 [e]
91	$^{170}_{76}Os_{94}$	5400±10	4.0±0.2	0.08 [e]	0.05	52 [e]
92	$^{171}_{76}Os_{95}$	5240±10	8.2±0.8	33×10^{-3} [e]	10^{-2}	250 [e]
93	$^{172}_{76}Os_{96}$	5105±10	19±2	22×10^{-3} [e]	5×10^{-3}	865 [e]
94	$^{173}_{76}Os_{97}$	4940±10	16±5	2×10^{-4} [e]	6×10^{-4}	8×10^{4} [e]
95	$^{174}_{76}Os_{98}$	4760±10	45±5	2.1×10^{-4} [e]	2×10^{-4}	$\left(2.14^{+1.34}_{-0.56}\right)10^{5}$

[a] m, g, ls, hs — these letters mean respectively isomeric, low spin, high spin states; [b] value taken intensities α/kx and β^+/kx or from intensity ratios b_α, exp $= I_{\alpha\ \text{daughter}}/I_{\alpha\ \text{parent}}$; [d] measured by author coefficients defined in present work by fitting to the experimental points; [f] calculated assuming a reduced on the formula derived from the alpha decay theory by Taagepera and Nurmia [17]; [i] based on the

2. *Characteristics of alpha activities for nuclei with $58 \leqslant Z \leqslant 76$*

In Table I are presented all reported alpha decay measurements from cerium to osmium. These results have been extracted from many recent publications. In addition to publications many useful data and references have been found in Table of Isotopes [2] and in two compilations [3, 4]. Table I contains results published up to April 1982.

In the first column of Table I, the symbols for the alpha radioactive parent nuclei with Ce $\leqslant Z \leqslant$ Os are listed. The second column gives alpha particle energies. The third column gives the experimentally measured half-lives. The fourth column gives values of branching ratios. The estimated values of branching ratios are indexed by letter *e*. They are obtained from the relationship $T^\alpha_{1/2} = f(Q_\alpha)$ with a set of parameters established by the author. The experimental values are shown without any label.

Assuming a reduced alpha width equal 1, we have calculated partial alpha half lives (column seven) which may be compared with the experimental alpha half-lives in column six.

Experimental and theoretical beta half-lives are compared in the two last columns.

TABLE I (continued)

$T^{\alpha}_{1/2}$ (sec) calc			$T^{\beta}_{1/2}$ (sec) exp	$T^{\beta}_{1/2}$ (sec) theor [5]	Ref.
[17] h	[23] i	f			
1.16	18.8	17.9	2.7±0.7	3	[9]
4.1	20.8	19.3	—	4	[14]
24.3	121	107	—	6	[14]
210	1.03×10^{3}	223	—	7	[13, 14]
6×10^{2}	2.99×10^{3}	2.4×10^{3}	—	10	[13]
8×10^{-4}	5.5×10^{-3}	5.8×10^{-3}	—	0.8	[9]
4.1×10^{-3}	26×10^{-3}	27×10^{-3}	$>6\times10^{-2}$	1.6	[9]
16×10^{-3}	9.88×10^{-3}	0.1	$>5\times10^{-2}$	1.2	[9, 13]
8.6×10^{-2}	0.51	0.498	0.64±0.33	2.5	[9, 13]
0.34	1.99	1.88	2.5±1.1	2.5	[9, 13]
1.99	11.3	10.16	—	4	[13]
5.6	31.3	11.4	—	3	[13]
31	173	142	—	7.1	[3]
185	1.04×10^{3}	806	—	8.2	[3]
894	5.06×10^{3}	3.7×10^{3}	—	19	[3]
6.7×10^{3}	3.86×10^{4}	2.6×10^{4}	16±5	16	[3]
6.7×10^{4}	4.04×10^{5}	2.5×10^{5}	45±5	45	[3]

from Wapstra and Bos tables [24]; [c] b_{α}, exp $= T_{1/2\,\mathrm{exp}}/T^{\alpha}_{1/2\,\mathrm{exp}}$ from measurements of the relative (of the present work) and colleagues in Gatchina [43–48]; [c] predicted from the formula for $T^{\alpha}_{1/2}$ with alpha width of one; [g] $b_{\alpha,\,\mathrm{calc.}} = T^{\beta}_{1/2}/(T^{\alpha}_{1/2}+T^{\beta}_{1/2})$ from theoretical alpha and beta half-lives; [h] based fission theory of the alpha emission by Poenaru, Ivascu and Mazilu [23].

The theoretical values are taken from calculations using the gross theory of beta decay of Takahashi et al. [5].

Therefore, the theoretical beta half-lives were used together with the theoretical alpha half-lives to calculate theoretical alpha branching ratios using the expression $b_{\alpha} = T^{\beta}_{1/2}/(T^{\alpha}_{1/2}+T^{\beta}_{1/2})$. These values are presented in the fifth column.

3. *Alpha decay partial half-lives for nucleides in the $62 \leqslant Z \leqslant 76$ range*

For calculations and discussion of the systematics of the alpha reduced widths the partial half-lives $T^{\alpha}_{1/2}$ are needed. The estimates of $T^{\alpha}_{1/2}$ can be performed using semi-empirical formulae published in [15–23] having only kinetic energy of the emitted alpha particle. The formulae in [15, 16, 18–22] were derived only for $Z \geqslant 82$ region. Extention of the estimates of $T^{\alpha}_{1/2}$ toward Z lower than 82 has been given in Refs. [17, 23].

The present work prefers simplest and oldest [1] search for the connection between half life $T^{\alpha}_{1/2}$ and alpha decay energy which works well as we shall see below. For our purpose it is convenient to present $T^{\alpha}_{1/2} = f(Q_{\alpha})$ in manner illustrated by Figs. 1a–c.

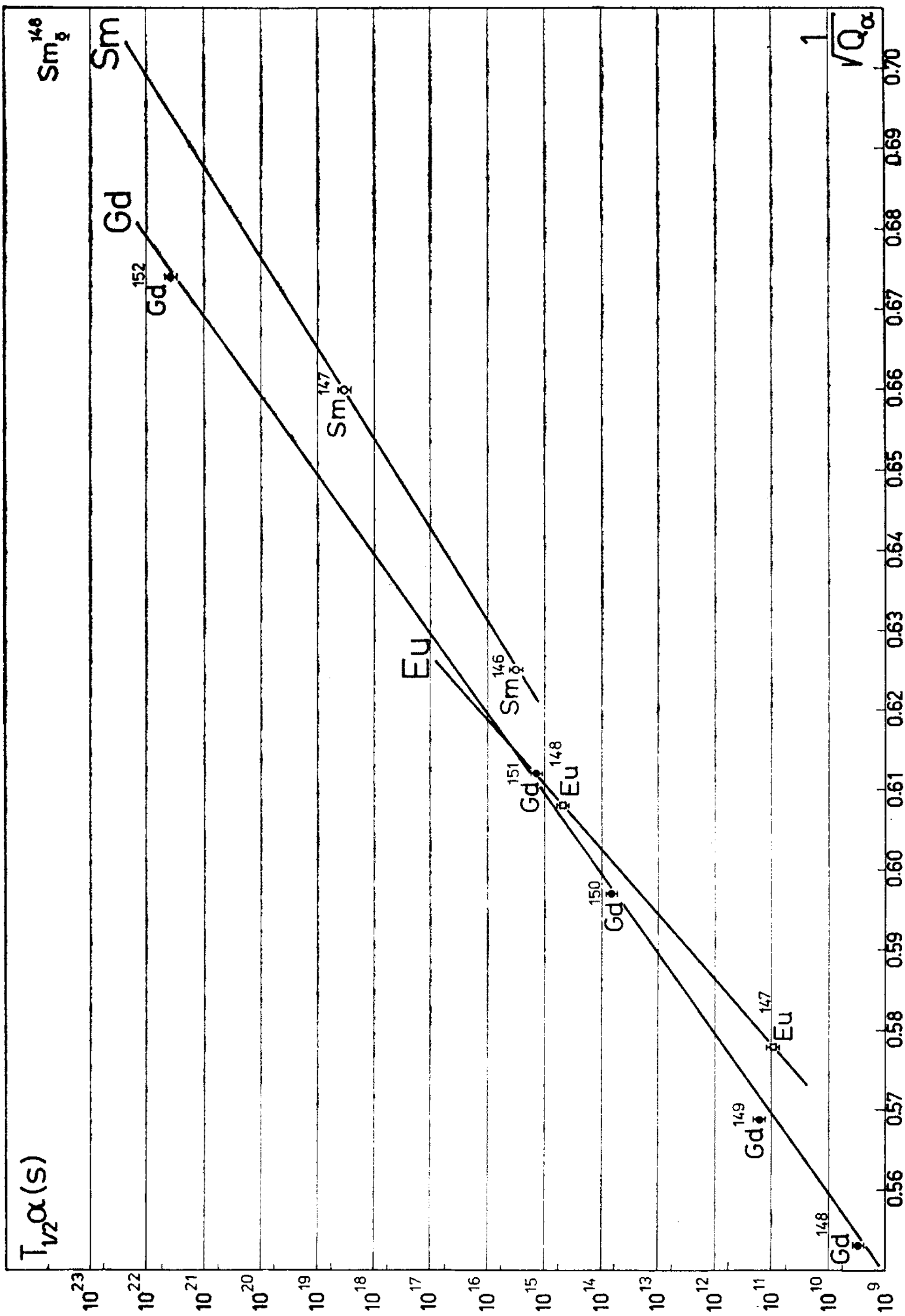

T1/2α(s)
1/√Qα
10^9
10^10
10^11
10^12
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
10^22
10^23
0.56
0.57
0.58
0.59
0.60
0.61
0.62
0.63
0.64
0.65
0.66
0.67
0.68
0.69
0.70
Sm
Gd
Eu
Sm 148
Gd 152
Sm 147
Sm 146
Gd 151
Eu 148
Gd 150
Eu 147
Gd 149
Gd 148

Fig. 1a

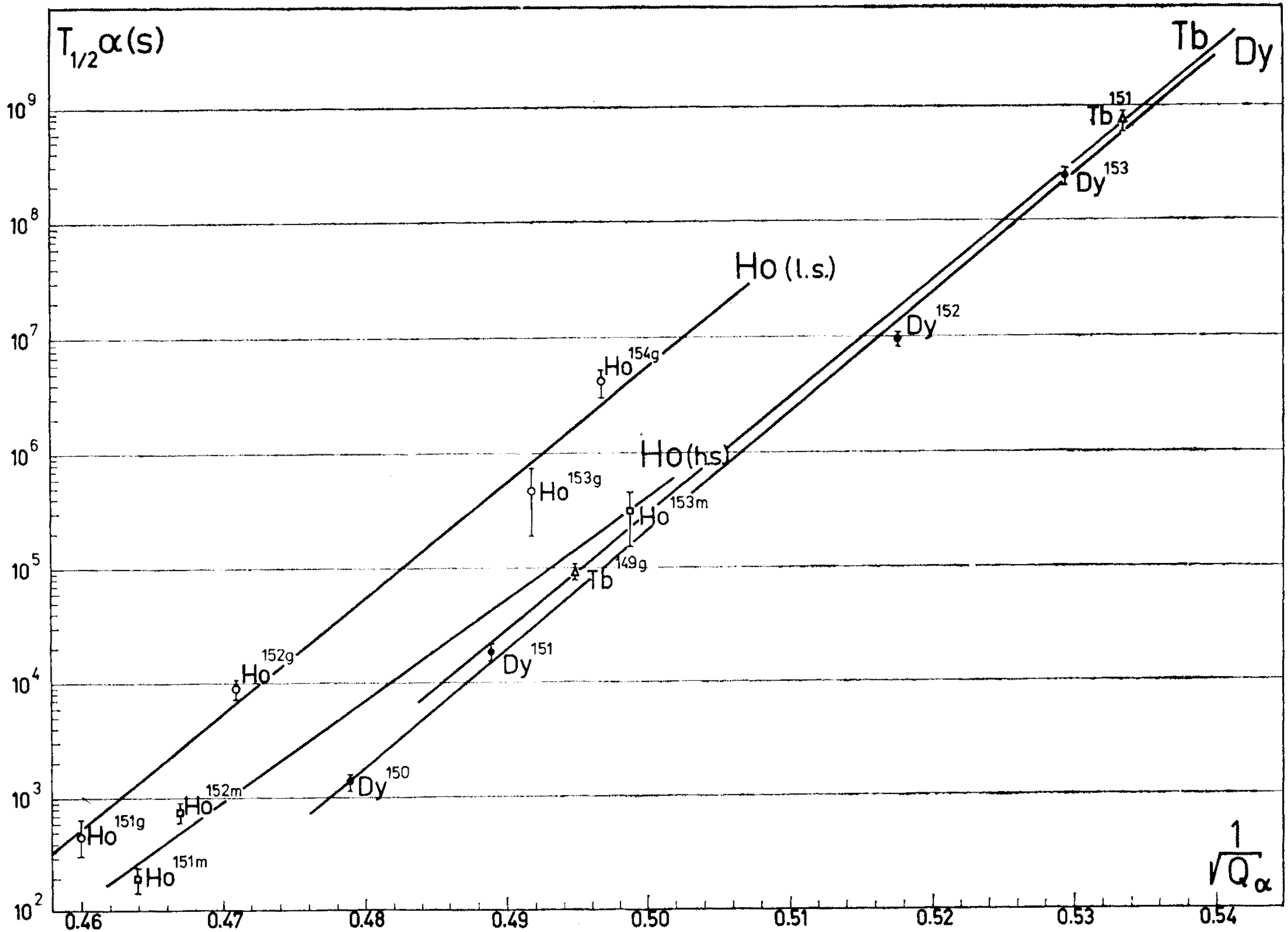

T1/2α(s)
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
0.46
0.47
0.48
0.49
0.50
0.51
0.52
0.53
0.54
1/√Qα
Tb
Dy
Tb151
Dy153
Dy152
Ho (l.s.)
Ho154g
Ho(h.s.)
Ho153g
Ho153m
Tb149g
Dy151
Ho152g
Dy150
Ho152m
Ho151g
Ho151m

Fig. 1b

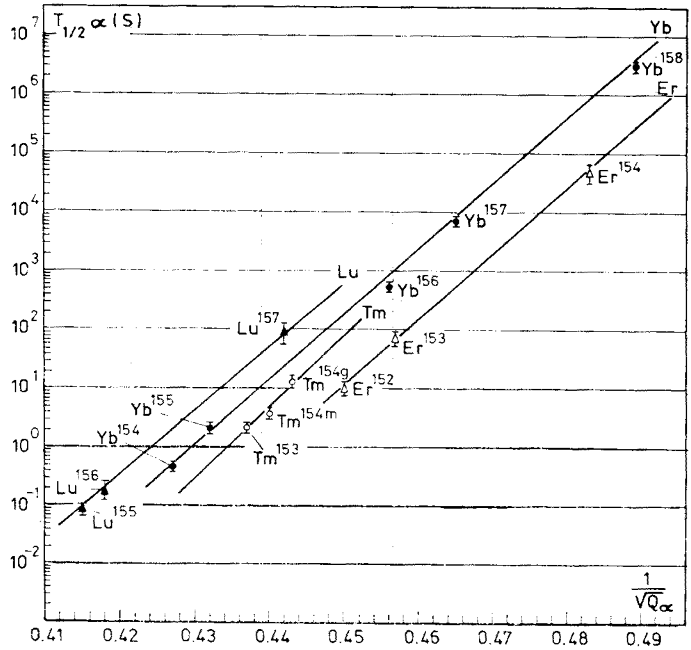


Fig. 1c

Here the $T^{\alpha}_{1/2}$ is plotted against the reciprocal square root of the total decay energy and the resulting family of straight lines is obtained. These lines were defined by least squares fitting using only those points for which accurate decay energies and alpha partial half-lives (branching ratios) are available. Each line in Fig. 1a–d representing a single element can be expressed analytically as follows:

$$T^{\alpha}_{1/2}(\mathrm{sec}) = 10^{\left(A + \frac{B}{\sqrt{Q_\alpha}}\right)} . \tag{1}$$

Here Q_α is the effective alpha decay energy (in MeV) which consists of the alpha particle energy plus the recoil energy (the correction for electron screening was not taken into account). The constants A and B depend on the element considered. By the employment of the available data for the elements in the range $62 \leqslant Z \leqslant 76$ presented in Table I one can calculate the constants A and B. Table II lists the values of A and B for each element. From formula (1) the unknown $T^{\alpha}_{1/2}$ values can be calculated if the Q_α are available.

It was interesting to compare our estimates of the $T^{\alpha}_{1/2}$ with the theoretical predictions of $T^{\alpha}_{1/2}$ derived from the alpha decay theory of quantum mechanics published by Taagepera and Nurmia [17] and fission theory of alpha emission, recently published by Poenaru et al. [23].

The well known formula of Taagepera and Nurmia is given in a very useful form

$$T^{\alpha}_{1/2} = [10^{\left(1.61\frac{Z_d}{\sqrt{E}} - Z_d^{2/3}\right) - 28.9}] \times 3.156 \times 10^7 \text{ (in seconds)}, \tag{2}$$

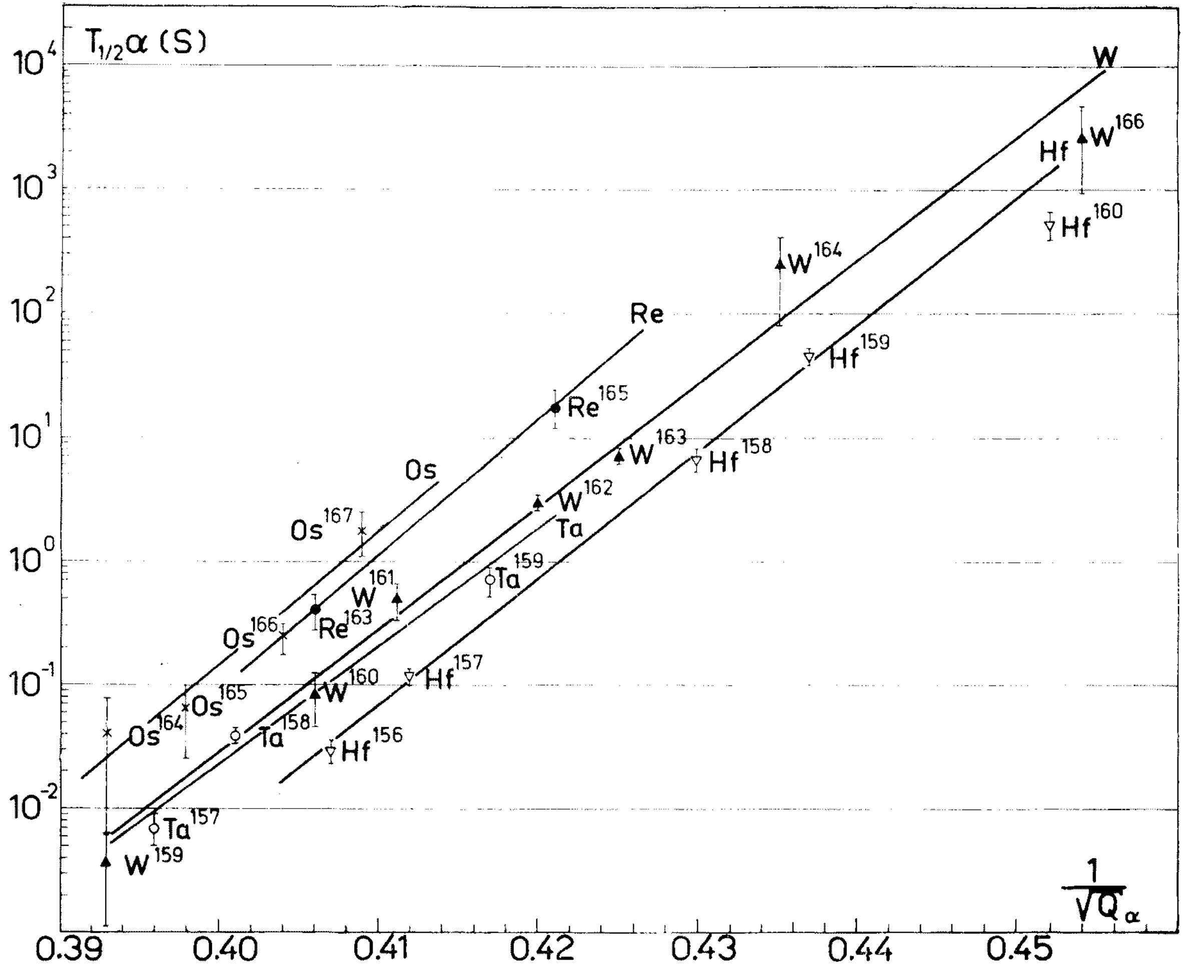


Fig. 1d

Fig. 1a–d. Plot of alpha partial half-lives for ground state transitions vs the inverse square root of the total alpha energy Q_α (= alpha particle energy + recoil energy). The points are experimental and the straight lines are based on leasts quare analysis

TABLE II

Semiempirical constants characteristic for each element in the range $Z = 62 \div 76$

Element	A	B
$_{62}$Sm	−39.27	87.58
$_{63}$Eu	−57.05	117.80
$_{64}$Gd	−45.91	100.01
$_{65}$Tb	−44.54	99.97
$_{66}$Dy	−45.07	100.66
$_{67}$Ho	−43.21	99.88
$_{67}$Ho^{m}	−38.87	86.85
$_{68}$Er	−47.79	108.66
$_{69}$Tm	−47.78	110.28
$_{70}$Yb	−48.16	112.09
$_{71}$Lu	−48.16	113.48
$_{72}$Hf	−42.95	101.95
$_{73}$Ta	−47.39	114.45
$_{74}$W	−41.21	99.17
$_{75}$Re	−45.14	110.23
$_{76}$Os	−41.37	101.39

where Z_d — atomic number of the daughter nucleus, E — kinetic energy of the alpha particle.

Poenaru et al. [23] suggested different approach to calculation of $T^{\alpha}_{1/2}$ based on the fission theory of alpha decay:

$$T^{\alpha}_{1/2} = 10^{(B_1+B_2y+B_3z+B_4y^2+B_5yz+B_6z^2)K_s/\ln 10-20.446} \text{ (in seconds)}, \tag{3}$$

where y and z are reduced variables expressing the relative distance of N and Z from the closest magic-plus-one number of neutrons and protons N_i, Z_i:

$$y = (N-N_i)/(N_{i+1}-N_i); \quad N_i < N \leqslant N_{i+1}; \quad N_i = 51,\ 83,\ 127,\ 185,\ \ldots$$

$$z = (Z-Z_i)/(Z_{i+1}-Z_i); \quad Z_i < Z \leqslant Z_{i+1}; \quad Z_i = 51,\ 83,\ 115,\ 121,\ \ldots$$

$$Q = E_\alpha A/A_d \text{ (in MeV)};$$

$$K_s = 2.52956Z_d(A_d/AQ)^{1/2}[\arccos\sqrt{x}-\sqrt{x(1-x)}];$$

$$x = 0.4253Q(1.5874+A^{1/3})/Z_d; \quad A_d = A-4; \quad Z_d = Z-2;$$

$$B_1 = 0.988662; \quad B_2 = 0.016314; \quad B_3 = 0.020433; \quad B_4 = 0.027896.$$

It was found that different set of parameters in comparison with original work of Poenaru et al. $B_5 = B_6 = -0.003033$ reproduces much better the experimental result.

In the first and second place of column seven of Table I the values of $T^{\alpha}_{1/2}$ computed on the basis of these two different approaches [17, 23] are given. It can be seen from comparison of the column six and seven that agreement with experiment is very good in the case of the work [23].

4. *Atomic masses*

In the calculations of the alpha reduced widths the Rasmussen formalism was applied. As input data besides alpha particle energy and alpha partial half-life one needs the masses of nuclei (in amu). They were obtained from experimentally well known atomic masses compiled by Wapstra and Bos [24] and from estimated values given by the same authors. For 20 cases the masses were estimated from chains of alpha decay ending at the nucleus of known mass excess.

There are, however, only few cases where such calculations can be made in the rare earth region. Recently, Pardo et al. [25] have measured the mass excess of ^{146}Gd to be (-76.096 ± 0.025) MeV. The alpha decay energies for the alpha transitions ^{178}Hg $\to$ ^{174}Pt $\to$ ^{170}Os $\to$ ^{166}W $\to$ ^{162}Hf $\to$ ^{158}Yb $\to$ ^{154}Er $\to$ ^{150}Dy $\to$ ^{146}Gd are already known. With the help of those known alpha decay energies the masses of ^{150}Dy, ^{154}Er, ^{158}Yb, ^{162}Hf, ^{166}W, ^{170}Os, ^{174}Pt and ^{178}Hg members of the alpha chain can be calculated.

In order to illustrate such situation, Figs. 2a–d show four decay chain families based on isobars 145–148. Because the masses of ^{146}Eu, ^{150}Tb and ^{154}Ho in parallel decay chain are known, linking them together we can obtain electron capture decay energies. These energies (experimentally unknown) were calculated by means of closed energy cycles.

It was possible to calculate proton binding energies in these nuclei. The atomic masses (in amu), electron capture decay and proton binding energies in ^{146}Gd, ^{150}Dy and ^{154}Er are given in Table III.

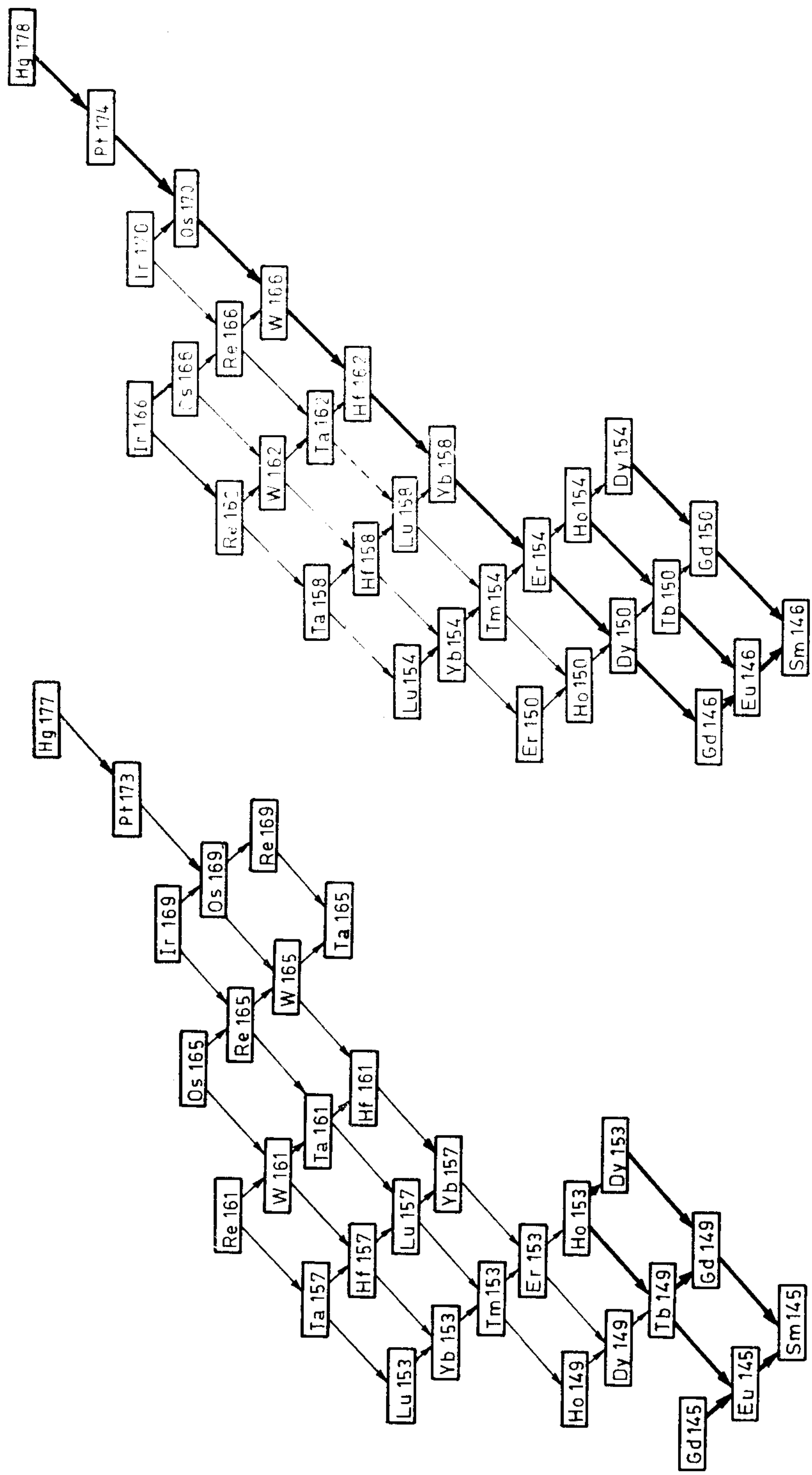
For comparison we give in this Table predictions of two droplet model mass formulae in the version of Myers [28] and Groote-Hilf-Takahashi [30]. The good agreement is found between theory and experiment.

Similar calculations were performed for alpha decay chain ^{172}Pt $\to$ ^{168}Os $\to$ ^{164}W $\to$ ^{160}Hf $\to$ ^{156}Yb $\to$ ^{152}Er $\to$ ^{148}Dy using the recently published mass excess of ^{148}Dy equal to (-67.84 ± 0.10) MeV [26]. In this work the mass excesses of ^{152}Er, ^{156}Yb, ^{160}Hf and ^{164}W were determined. In the present work alpha decay chain was extended to the two nuclei in the chain ^{168}Os and ^{172}Pt (the nucleus with 18 neutrons away from the stability). For doubly even nuclei the dominant alpha transitions connect the nuclear ground states directly. This is not true for nuclei with unpaired nucleus where strong alpha transitions are leading to excited states in the daughter nuclei.

For cases like ^{146}Gd and ^{148}Dy, the alpha chain is composed of even-even nuclei.

Alpha decay chains are also ending at ^{147}Tb. Keeping in mind all what has been said above about the correctness of mass determinations from alpha decay chains for odd-even or even-odd nuclei we calculated masses of ^{151}Ho, ^{155}Tm and ^{159}Lu taking as an experimental value $Q_{EC} = (5100\pm120)$ keV for ^{147}Tb published recently [27].

From the above examples we can conclude that measurement of alpha decay energies


Hg 178
Pt 174
Os 170
Ir 170
W 166
Re 166
Os 166
Ir 166
Hf 162
Ta 162
W 162
Re 162
Yb 158
Lu 158
Hf 158
Ta 158
Dy 154
Ho 154
Er 154
Tm 154
Yb 154
Lu 154
Gd 150
Tb 150
Dy 150
Ho 150
Er 150
Sm 146
Eu 146
Gd 146
Hg 177
Pt 173
Os 169
Re 169
Ir 169
Ta 165
W 165
Re 165
Os 165
Hf 161
Ta 161
W 161
Re 161
Yb 157
Lu 157
Hf 157
Ta 157
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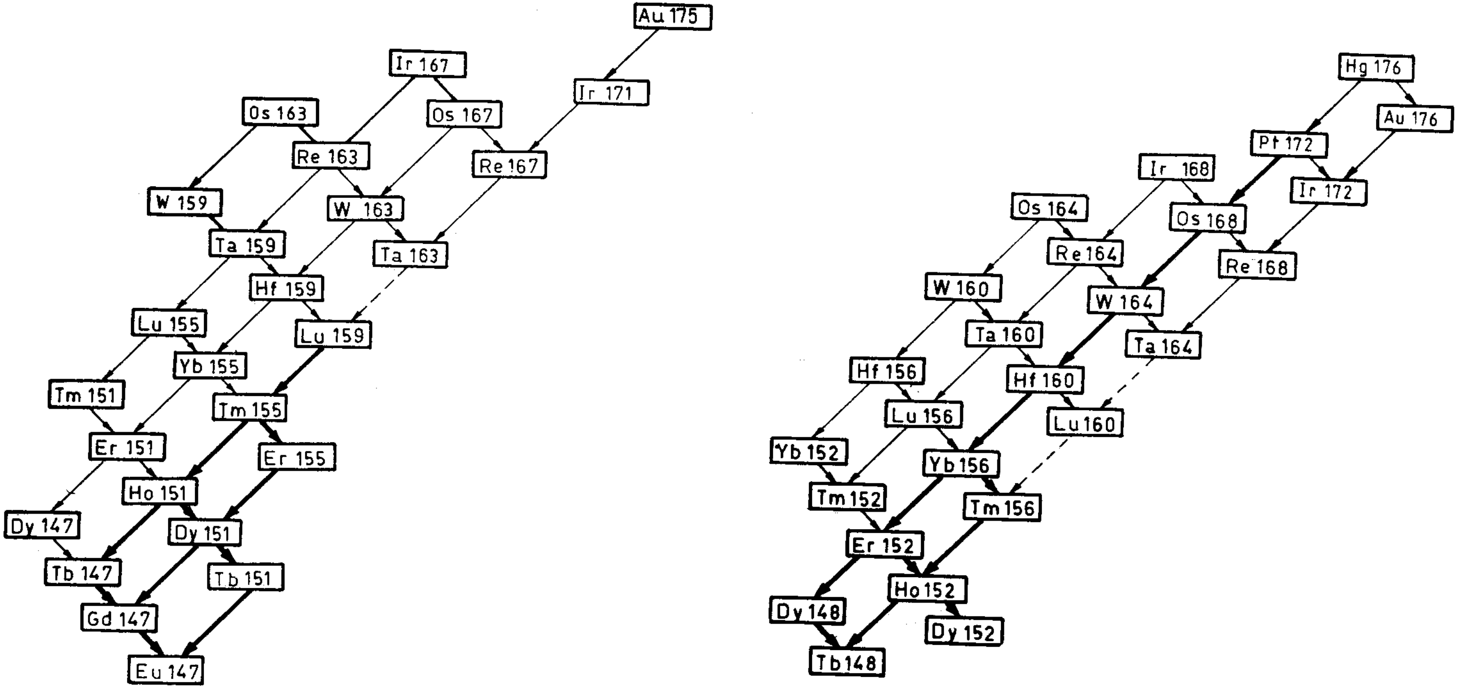
Dy 149
Ho 149
Sm 145
Eu 145
Gd 145



c   d

Fig. 2a–d. Closed decay energy cycles based on the 145, 146, 147 and 148 isobars. The known masses are linked with thick line

TABLE III

Experimental atomic masses (in amu), electron capture and proton binding energies compared to predictions from calculations of Myers and Hilf, Groote and Takahashi

Isotope	Atomic masses (amu)			B_p (MeV)			Q_{EC} (MeV)		
	Exp.	Theory		calculated using closed αβ energy-cycle	Theory		calculated using closed αβ energy-cycle	Theory	
		Myers [28]	Takahashi, Groote, Hilf [30]		Myers [28]	T.G.H. [30]		Myers [28]	T.G.H. [30]
^{146}Gd	145.918308(27)	145.917918	145.918712	5.449(32)	5.18	4.98	1.015(28)	0.86	1.36
^{150}Dy	149.925604(28)	149.925207	149.925830	5.155(33)	4.84	4.60	1.776(32)	1.49	2.03
^{154}Er	153.932831(30)	153.932604	153.933162	4.903(47)	4.50	4.22	2.014(35)	2.12	2.74
^{158}Yb	157.939942(31)	157.940086	157.940548	—	4.04	3.76	—	3.36	3.81
^{162}Hf	161.947314(33)	161.947354	161.947880	—	3.53	3.30	—	4.15	4.52
^{166}W	165.955159(33)	165.955040	165.955663	—	3.08	2.86	—	4.76	5.13
^{170}Os	169.963729(34)	169.963307	169.964026	—	2.67	2.44	—	5.29	5.67
^{174}Pt	173.972994(35)	173.972034	173.972968	—	2.40	2.05	—	5.65	6.18
^{178}Hg	177.982690(36)	177.980623	177.982373	—	2.54	1.74	—	5.52	6.60
^{148}Dy	147.927171(107)	147.926033	147.927332	4.750(170)	4.27	4.03	2.800(128)	2.34	2.90
^{152}Er	151.935090(107)	151.933988	151.935223	4.461(170)	3.95	3.66	3.223(128)	2.93	3.54
^{156}Yb	155.942885(107)	155.942072	155.943296	4.228(170)	3.63	3.30	3.689(128)	3.52	4.17
^{160}Hf	159.950775(107)	159.950274	159.951594	3.862(170)	3.32	2.89	—	4.36	5.14
^{164}W	163.959070(107)	163.958637	163.959914	—	2.83	2.41	—	5.24	5.90
^{168}Os	167.967927(108)	167.967171	167.968588	—	2.45	1.99	—	5.79	6.48
^{172}Pt	171.977500(108)	171.975910	171.977756	—	2.22	1.61	—	7.57	6.98
^{147}Tb	146.924445(132)	146.922802	146.923833	1.572(126)	2.74	2.52	5.100(120)	3.45	3.98
^{151}Ho	150.932054(132)	150.930413	150.931326	1.281(126)	2.44	2.17	5.563(120)	4.04	4.61
^{155}Tm	154.939599(132)	154.938143	154.939023	0.984(126)	2.14	1.83	6.022(121)	4.61	5.26
^{159}Lu	158.947096(132)	158.946012	158.946871	—	1.77	1.40	—	5.68	6.28

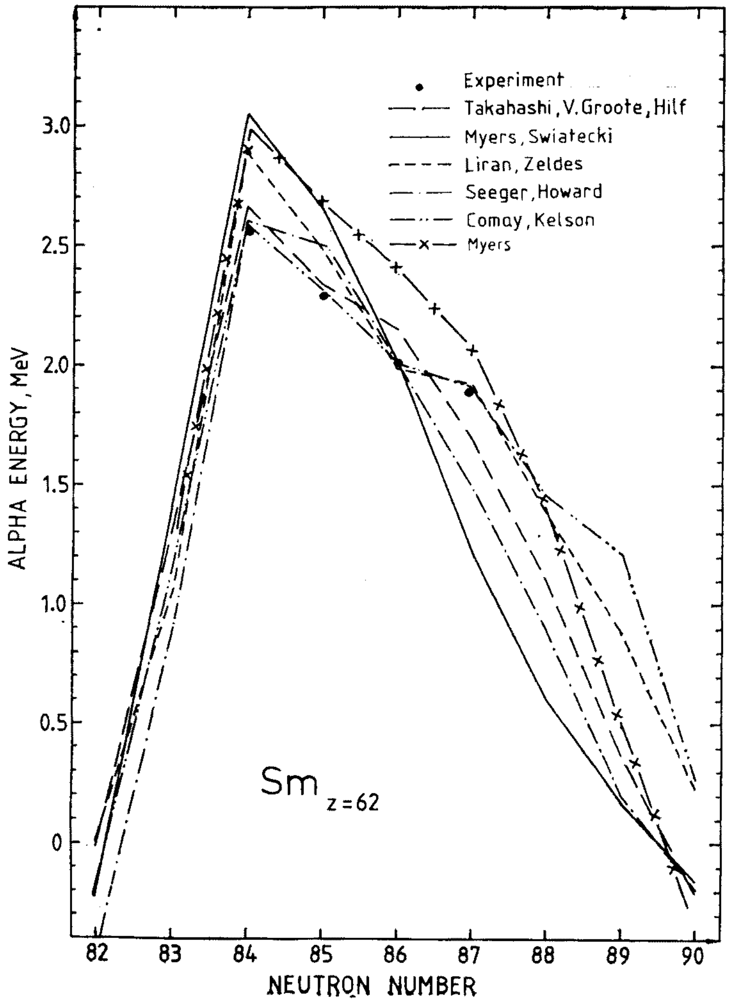

Experiment
Takahashi, V.Groote, Hilf
Myers, Swiatecki
Liran, Zeldes
Seeger, Howard
Comay, Kelson
Myers
ALPHA ENERGY, MeV
NEUTRON NUMBER
Sm z=62
0
0.5
1.0
1.5
2.0
2.5
3.0
82
83
84
85
86
87
88
89
90

Fig. 3a

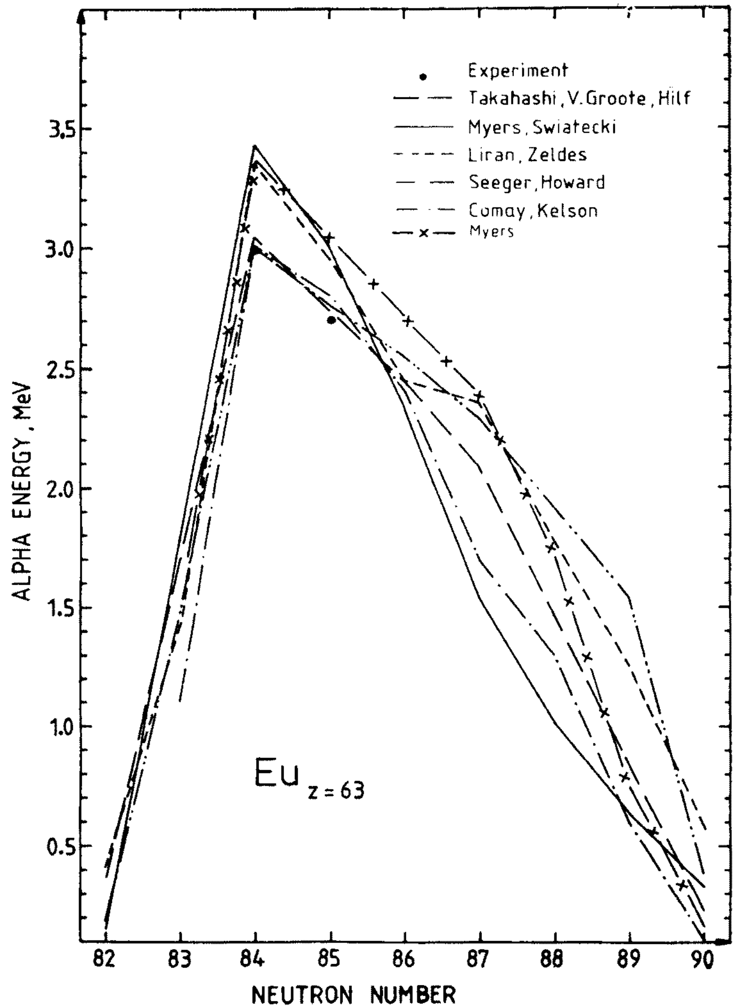
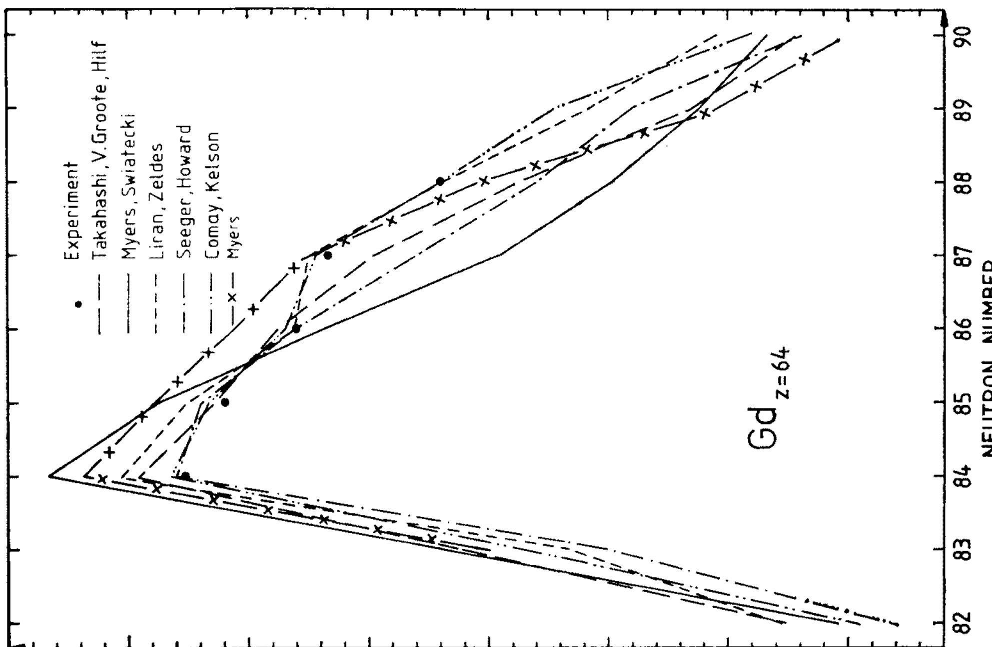
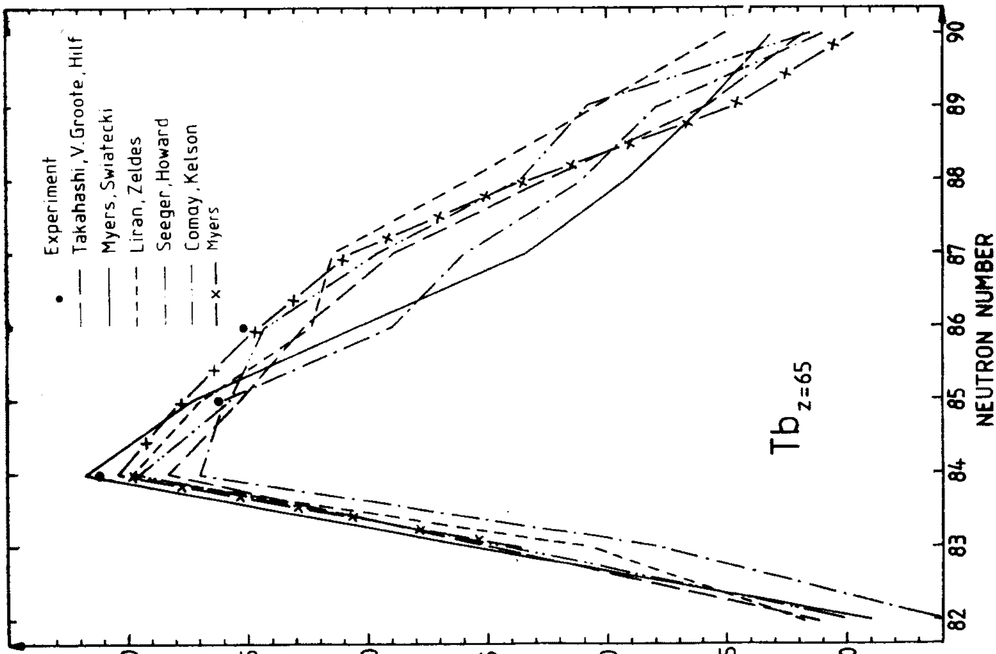

Experiment
Takahashi, V.Groote, Hilf
Myers, Swiatecki
Liran, Zeldes
Seeger, Howard
Comay, Kelson
Myers
ALPHA ENERGY, MeV
NEUTRON NUMBER
Eu z=63
0.5
1.0
1.5
2.0
2.5
3.0
3.5
82
83
84
85
86
87
88
89
90

Fig. 3b



Experiment
Takahashi, V.Groote, Hilf
Myers, Swiatecki
Liran, Zeldes
Seeger, Howard
Comay, Kelson
Myers
$Gd_{z=64}$
ALPHA ENERGY, MeV
NEUTRON NUMBER

Fig. 3c



Experiment
Takahashi, V.Groote, Hilf
Myers, Swiatecki
Liran, Zeldes
Seeger, Howard
Comay, Kelson
Myers
$Tb_{z=65}$
ALPHA ENERGY, MeV
NEUTRON NUMBER

Fig. 3d

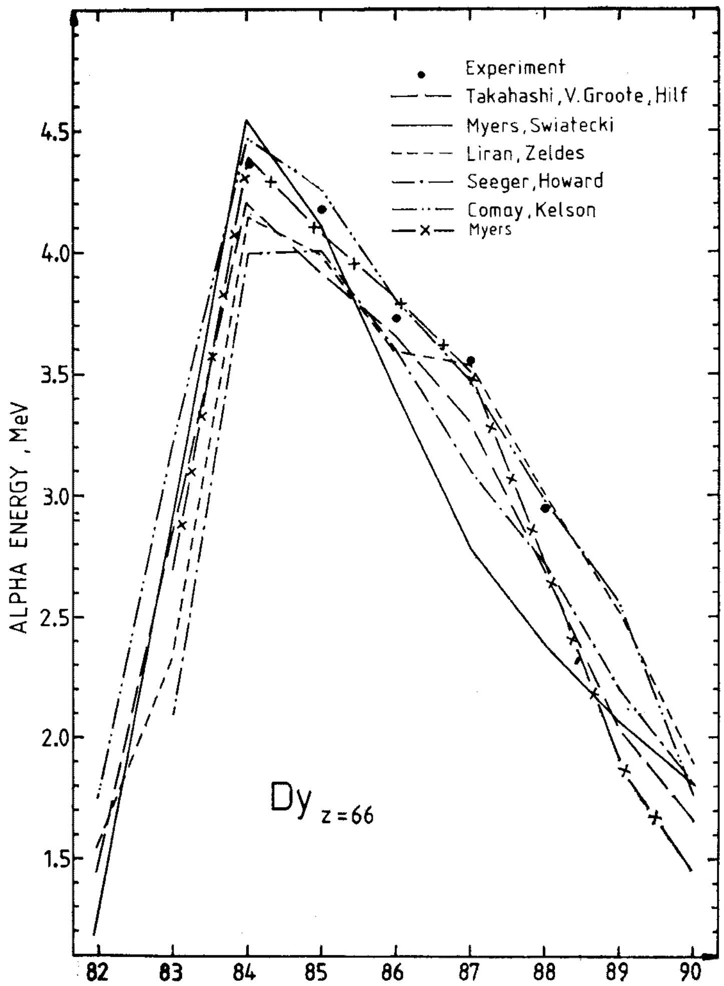

Experiment
Takahashi, V. Groote, Hilf
Myers, Swiatecki
Liran, Zeldes
Seeger, Howard
Comay, Kelson
Myers
Dy z=66
ALPHA ENERGY, MeV
NEUTRON NUMBER
4.5
4.0
3.5
3.0
2.5
2.0
1.5
82
83
84
85
86
87
88
89
90

Fig. 3e

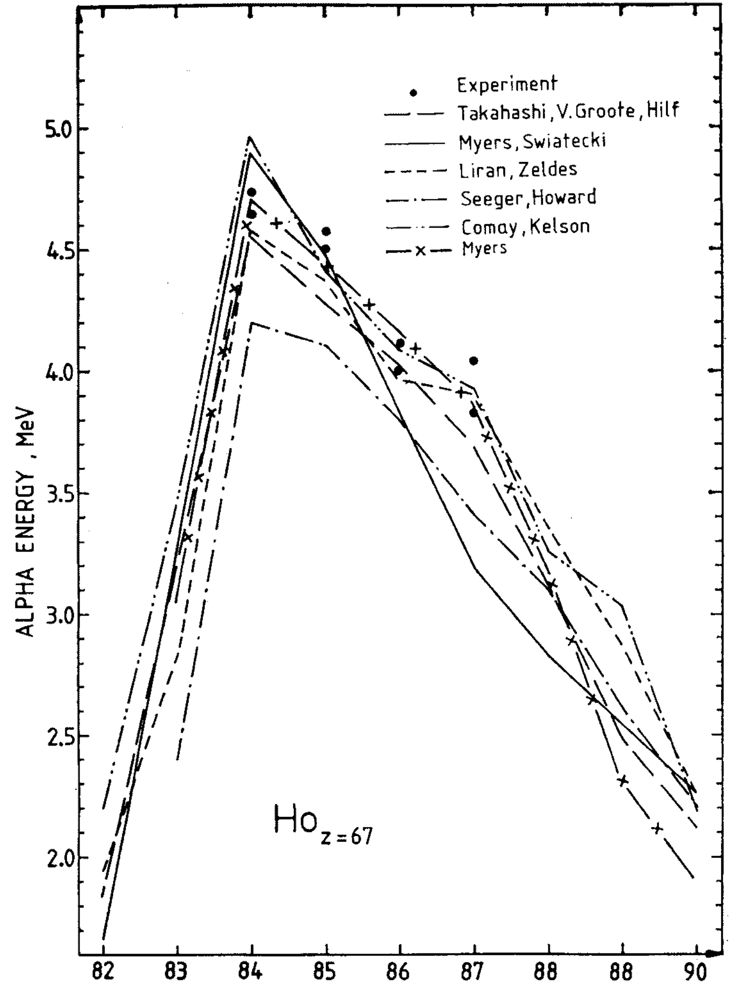

Experiment
Takahashi, V. Groote, Hilf
Myers, Swiatecki
Liran, Zeldes
Seeger, Howard
Comay, Kelson
Myers
Ho z=67
ALPHA ENERGY, MeV
NEUTRON NUMBER
5.0
4.5
4.0
3.5
3.0
2.5
2.0
82
83
84
85
86
87
88
88
90

Fig. 3f

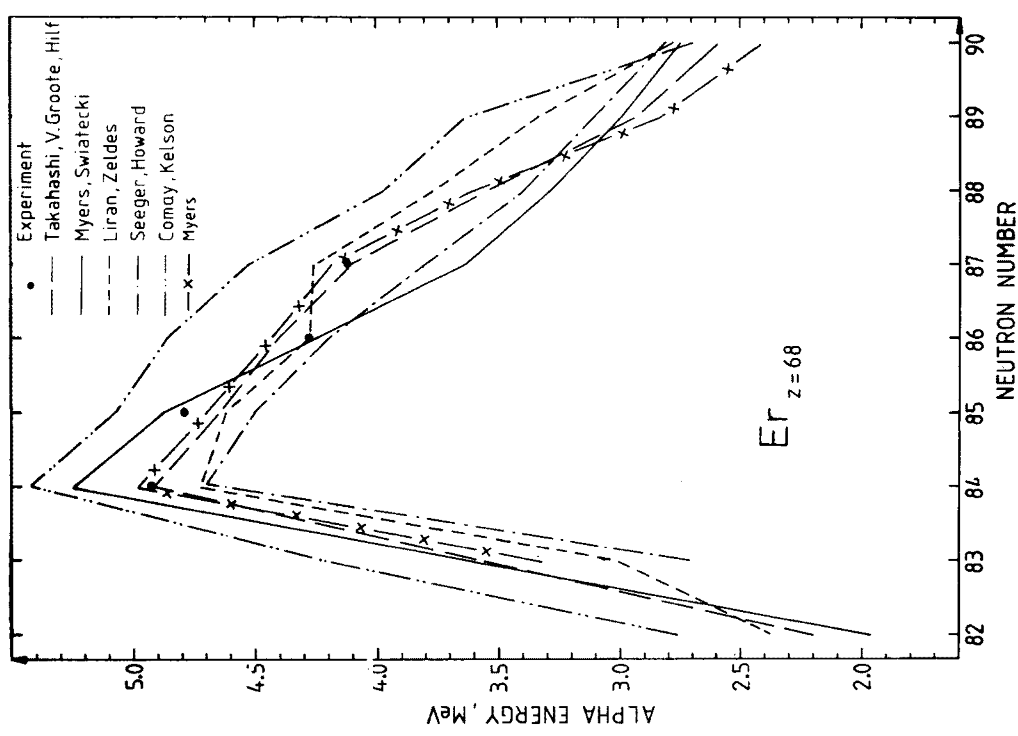

Experiment
Takahashi, V.Groote, Hilf
Myers, Swiatecki
Liran, Zeldes
Seeger, Howard
Comay, Kelson
Myers
Er z=68
ALPHA ENERGY, MeV
NEUTRON NUMBER
2.0
2.5
3.0
3.5
4.0
4.5
5.0
82
83
84
85
86
87
88
89
90

Fig. 3g

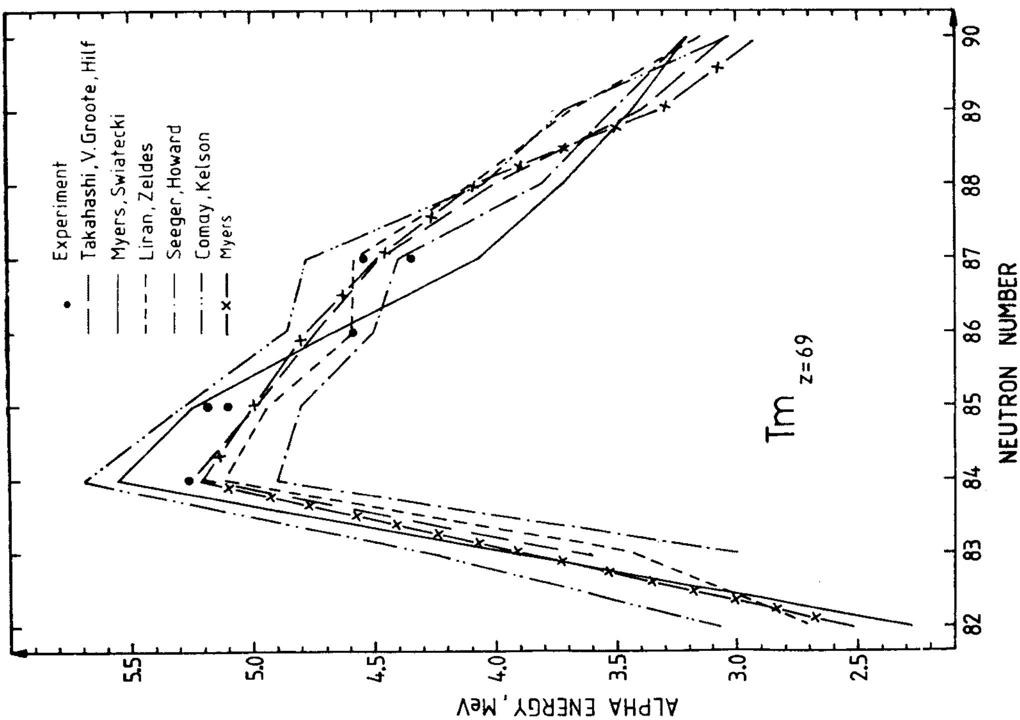

Experiment
Takahashi, V.Groote, Hilf
Myers, Swiatecki
Liran, Zeldes
Seeger, Howard
Comay, Kelson
Myers
Tm z=69
ALPHA ENERGY, MeV
NEUTRON NUMBER
2.5
3.0
3.5
4.0
4.5
5.0
5.5
82
83
84
85
86
87
88
89
90

Fig. 3h

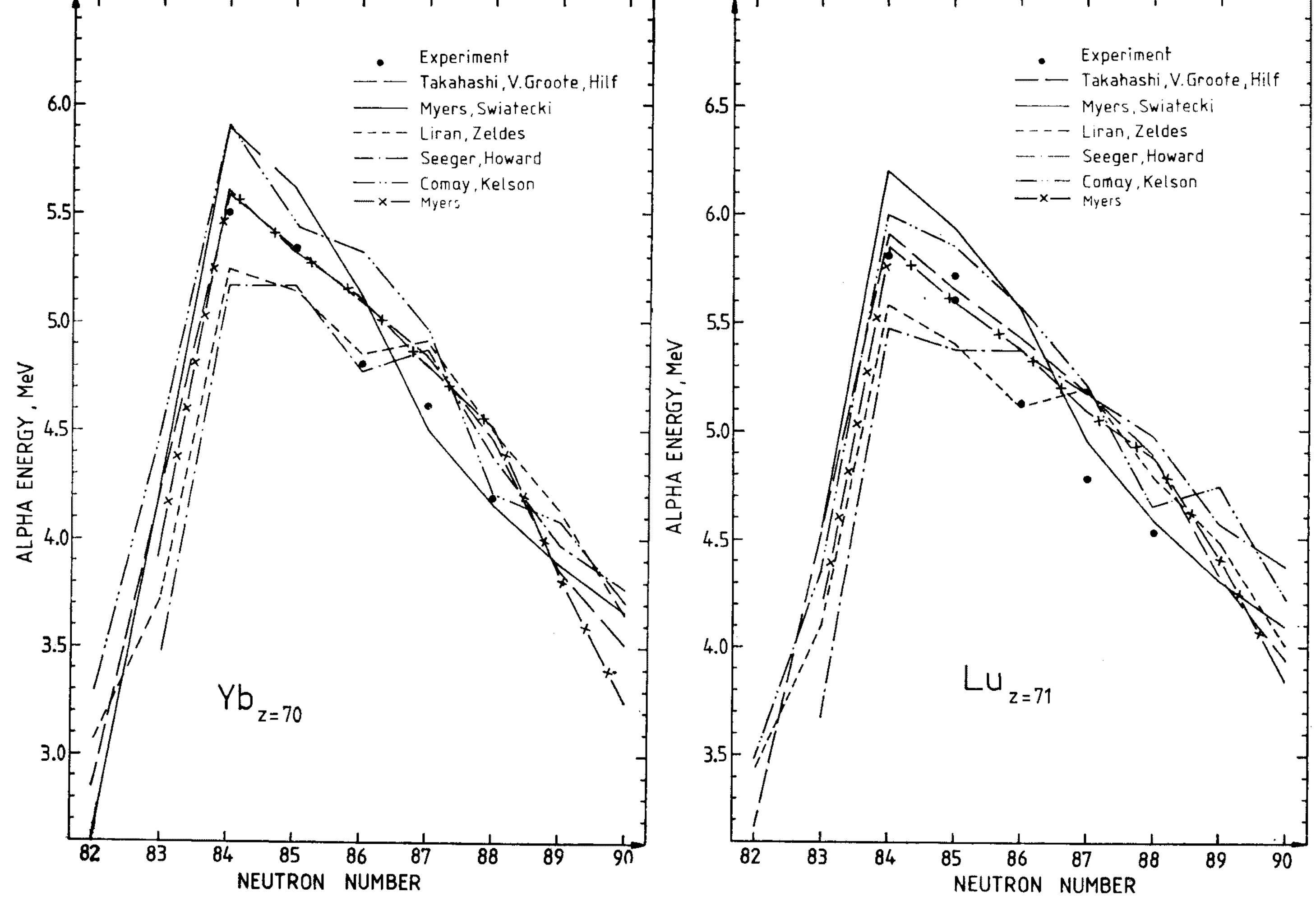


Fig. 3i

Fig. 3j

Fig. 3a–j. Comparison of alpha decay energies of Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu isotopes near the closed neutron shell $N = 82$ with predictions of six different mass tables is a good method for obtaining precise experimental atomic masses of short-lived nuclides if there exist a corresponding heavy ion transfer reaction and beta decay energy measurements. It would be useful to devote some effort in this direction and measure the mass excesses for nuclei ending the alpha decay chains and search for unknown alpha emitters in these chains.

The values of masses from Table III were used for calculations of alpha reduced widths.

For nuclei very far from the stability line their masses (in our case for ^{152}Yb, ^{153,154}Lu, ^{154,155,156}Hf, ^{157,158,159}Ta, ^{159,160,161}W) were not given by Wapstra and Bos. There are several mass formulae used for nuclei far from the stability line. Six of them were considered: Myers [28], Myers-Swiatecki [29], Groote-Hilf-Takahashi [30], Seeger-Howard [31], Liran-Zeldes [32] and Comay-Kelson [31]. To choose between them the value of χ^2 function was calculated for elements with $62 \leqslant Z \leqslant 76$, taking as the input data the experimental and predicted (by mentioned formulae) energies of the alpha decay. In the case of Myers [28] and Groote-Hilf-Takahashi [30] version of mass formula the χ^2 vaue was clearly the smallest one. A comparison (we suppose that the alpha transitions are going from the ground to the ground state) of experimental and theoretical alpha energies is shown in Fig. 3a-j for the isotopes of Sm ÷ Lu.

As can be seen from Figs. 3a-j all predictions based on the droplet model [28 ÷ 30] are very similar and reproduce the experimental data quite well. The variation of the Q_α with A is rather smooth and regular. In particular the values given by Myers agree generally within 200 keV with the data. A general trend seems to be that for elements Er ÷ Lu Q_α values are slightly overestimated by theory. For Sm ÷ Ho we observe the opposite effect.

The predictions of Liran and Zeldes [32] represent a shell approach to nuclear masses. They are generally of similar or even somewhat lower quality than those of the droplet model approaches and show fluctuations which are not present in the experimental data.

The third approach for mass predictions is inspired by the Garvey-Kelson mass relations and is represented by the table of Comay-Kelson. This method is analytic and uses known masses as input parameters. It gives extremely nice agreement for nuclei Sm ÷ Dy (close to the known ones), but the discrepancies increase as one goes far off the beta valley. The predictions for Q_α values in the range Ho ÷ Os are poor since the differences between the theory and experiment exceed 0.5 ÷ 1 MeV.

5. *Alpha reduced widths*

Using published, experimentally determined branching ratios and total half-lives the resulting alpha partial half-lives were calculated. For completeness, the lacking values of partial half-lives were supplemented by estimated values (see the proceeding chapter). All these values, given in Table I were then used to calculate alpha reduced widths δ^2 in order to examine the nuclear structure aspects of alpha decay in the region of Z from 58 up to 76.

In calculating δ^2 the following definition was used [33]:

$$\delta^2 = \frac{h \ln 2}{P_\alpha T^\alpha_{1/2}} = \frac{\lambda_\alpha h}{P_\alpha}, \tag{4}$$

where h is the Planck constant, λ_α is the partial alpha decay constants, P_α — the alpha particle penetration factor through the Coulomb barrier (calculated from the nuclear surface to infinity). Barrier penetrability factors were calculated for a barrier that includes an optical model potential derived by Igo [33] from the analysis of alpha particle scattering data. A centrifugal barrier is also included so that an l dependence can be taken into account.

Owing to the fact that majority of nuclides in Table I have no definite spin assignments so far, all δ^2 were calculated for $l = 0$ case. The alpha particle energies were corrected for nuclear recoil and electron screening.

The resulting δ^2 values are given in Table IV. They are, in general consistent with the fragmentary results given in published papers. In addition in the sixth column of Table IV the relative values W_α of alpha reduced widths are given $\left(\text{normalized to the reduced width of } Po^{212} \text{ for ground state transition, } W_\alpha = \frac{\delta^2}{\delta^2_{Po^{212}}}\right)$.

The maximum allowable reduced width is given by the Wigner limit [34]. According to Arima et al. [34] this limit δ^2_W is given by

$$\delta^2_W = \frac{3\hbar^2}{2\mu R^2} = \frac{62.70}{\mu R^2}\,(\text{MeV}) = \frac{6.52\, A_{\text{mother}}}{A^{5/3}_{\text{daughter}}}\,(\text{MeV}) \tag{5}$$

where μ is the reduced mass of the alpha particle and R is the channel radius taken to be $1.55\, A^{1/3}$ fm.

It is convenient to define a dimensionless reduced alpha width

$$\theta^2 = \frac{\delta^2}{\delta^2_W} \supset \delta^2 = \theta^2 \delta^2_W$$

which is the ratio between the experimental reduced alpha width and the Wigner limit and gives the probability of finding a particle in the desired nuclear shell at the nuclear surface. According to Wigner, the limiting value of θ^2 is $\theta^2 = 1$; value equal 1 corresponds to the case when the wave function of the nucleus at the surface $r = R$ completely consists of clusters: s-wave alpha particle plus ground state daughter nucleus. Hence, the θ^2 values are direct measure of the degree of alpha clusterization. The values of θ^2 for considered nuclei are given in the last column of Table IV. These values in all cases confirm very well the Wigner predictions that $\theta^2 \leqslant 1$. The surprisingly high θ^2 values ($\theta^2 > 1$) can be seen for ${}^{156}_{70}Yb_{86}$, ${}^{165,166}_{74}W_{91,92}$ and ${}^{172}_{26}Os_{96}$.

The variation of δ^2 with atomic number is presented for $N = 84$–88 in Figs. 4a–e. Fig. 4a is a plot of δ^2 vs atomic number for $N = 84$ (where the alpha energy has its maximum

TABLE IV

Barrier penetrabilities and reduced widths for alpha decay in the Ce÷Os region

	Isotope	Q_α [a] (KeV)	λ_α (sec^{-1})	P [b]	δ^2 (KeV) Present work	δ^2 (KeV) Other works	W_α [c]	θ^2 [d]
1	${}^{142}_{58}Ce_{84}$	1332 ± 100	4.39×10^{-25}	4.038×10^{-54}	4×10^{12}	2.4×10^{7} [36]	$6.31^{+239}_{-0.2}\ 10^{10}$	
2	${}^{144}_{60}Nd_{84}$	1922 ± 3	9.58×10^{-24}	2.118×10^{-43}	187^{+25}_{-22}	$\left(149^{+38}_{-30}\right)$ [35]; (219 ± 150) [37]; (188 ± 16) [42]; 457 [36]	$2.63^{+0.35}_{-0.31}$	0.75
3	${}^{145}_{61}Pm_{84}$	2324 ± 40	3.48×10^{-18}	6.532×10^{-38}	220^{+587}_{-158}	214 [36]	$3.10^{+8.26}_{-2.23}$	0.88
4	${}^{146}_{62}Sm_{84}$	2642 ± 30	2.14×10^{-16}	1.890×10^{-35}	47^{+53}_{-25}	$\left(98^{+86}_{-45}\right)$ [37]; (82 ± 18) [35]; (105 ± 24) [42]; 139 [36]	$0.66^{+0.74}_{-0.35}$	0.19
5	${}^{147}_{62}Sm_{85}$	2316 ± 5	2.07×10^{-19}	7.366×10^{-39}	116^{+21}_{-18}	(125 ± 52) [42]; 120 [36]	$1.64^{+0.29}_{-0.25}$	0.47
6	${}^{148}_{62}Sm_{86}$	2035 ± 20	2.75×10^{-24}	3.004×10^{-43}	38^{+47}_{-21}	43 [42]; 25 [36]	$0.53^{+0.66}_{-0.29}$	0.15
7	${}^{149}_{62}Sm_{87}$	1911 ± 50	2.59×10^{-25}	1.782×10^{-44}	602^{+5045}_{-532}	1.26×10^{5} [36]	$8.47^{+70.96}_{-7.48}$	0.14
8	${}^{147}_{63}Eu_{84}$	3011 ± 5	8.21×10^{-12}	1.562×10^{-31}	217^{+26}_{-23}	(177 ± 26) [42]; 181 [36]	$3.06^{+0.36}_{-0.33}$	0.88
9	${}^{148}_{63}Eu_{85}$	2724 ± 30	1.40×10^{-15}	1.653×10^{-34}	35^{+42}_{-19}	(35 ± 72) [42]; 34 [36]	$0.49^{+0.59}_{-0.26}$	0.14
10	${}^{148}_{64}Gd_{84}$	3293 ± 1	2.25×10^{-10}	1.169×10^{-29}	80 ± 2	(97 ± 10) [35]; (87 ± 5) [36]; (86 ± 6) [42]	1.12 ± 0.02	0.32
11	${}^{149}_{64}Gd_{85}$	3123 ± 5	3.98×10^{-12}	3.677×10^{-31}	45^{+5}_{-2}	(49 ± 22) [42]; 46 [36]	0.63 ± 0.07	0.18
12	${}^{150}_{64}Gd_{86}$	2826 ± 10	1.23×10^{-14}	4.012×10^{-34}	127^{+36}_{-28}	(163 ± 23) [42]; 107 [36]	$1.79^{+0.51}_{-0.39}$	0.52

13	$^{151}_{64}Gd_{87}$	2693 ± 30	5.33×10^{-16}	1.297×10^{-35}	170^{+215}_{-94}	(170 ± 50) [42]; 165 [36]	$2.39^{+3.01}_{-1.32}$	0.70
14	$^{152}_{64}Gd_{88}$	2219 ± 30	2.03×10^{-22}	5.360×10^{-42}	157^{+312}_{-103}	(154 ± 80) [42]; 150 [36]	$2.20^{+4.40}_{-1.45}$	0.71
15	$^{149}_{65}Tb^{g}_{84}$	4098 ± 10	7.74×10^{-6}	2.061×10^{-24}	15 ± 2	(20 ± 4) [38]; (17 ± 5) [9]; (31 ± 26) [42]; 9 [36]	0.22 ± 0.03	0.06
16	$^{149}_{65}Tb^{m}_{84}$	–	–	–	–	(2.8 ± 0.6) [38]; (3.3 ± 15) [42]; 0.9 [36]; 3.6 [39]	–	0.01
17	$^{150}_{65}Tb_{85}$	3610 ± 5	3.96×10^{-9}	9.589×10^{-28}	17 ^{e}	$\left(0.48^{+1.12}_{-0.36}\right)$ [38]; $\left(5^{+200}_{-60}\right)$ [42]; 0.5 [36]	0.24 ± 0.02	0.07
18	$^{151}_{65}Tb_{86}$	3524 ± 5	1.04 ± 10^{-9}	2.181×10^{-28}	20 ± 2	(18 ± 6) [38]; (38 ± 17) [42]; 1.2 [39]; 1 [36]	0.28 ± 0.02	0.08
19	$^{150}_{66}Dy_{84}$	4371 ± 5	4.99×10^{-4}	2.355×10^{-23}	88 ± 6	(91 ± 12) [38]; (105 ± 12) [37]; (116 ± 17) [9]; (114 ± 11) [42]; 95 [40]; 51 [36]; 51.7 [39]	1.23 ± 0.09	0.36
20	$^{151}_{66}Dy_{85}$	4200 ± 3	3.77×10^{-5}	2.431×10^{-24}	64 ± 3	(62 ± 10) [38]; (68 ± 13) [9]; (65 ± 12) [42]; 71 [39]; 54 [36]	0.90 ± 0.04	0.26
21	$^{152}_{66}Dy_{86}$	3751 ± 5	7.63×10^{-8}	2.592×10^{-27}	122 ± 10	(123 ± 21) [38]; (137 ± 13) [42]; 72 [36]; 39 [39]	1.71 ± 0.15	0.51
22	$^{153}_{66}Dy_{87}$	3580 ± 5	3.07×10^{-9}	1.396×10^{-28}	91 ± 8	(77 ± 15) [38]; (89 ± 17) [42]; 25 [36]; 20 [39]	1.28 ± 0.12	0.38
23	$^{154}_{66}Dy_{88}$	2971 ± 5	2.19×10^{-15}	4.855×10^{-33}	19 ^{e}	(16 ± 6) [38]; 67 [36]	0.26 ± 0.03	0.08
24	$^{151}_{67}Ho^{ls}_{84}$	4755 ± 3	1.44×10^{-3}	8.124×10^{-22}	7.6 ± 0.4	(6.6 ± 3.9) [41]; (9.6 ± 5.3) [41]; (11 ± 4) [9]; (9.8 ± 3) [42]; 25 [36]	0.10 ± 0.01	0.03
25	$^{151}_{67}Ho^{hs}_{84}$	4663 ± 3	3.55×10^{-3}	2.691×10^{-22}	55 ± 2	(52 ± 19) [41]; (38 ± 16) [41]; (57 ± 16) [9]; (54 ± 28) [42]; 64 [36]	0.77 ± 0.03	0.22
26	$^{152}_{67}Ho^{ls}_{85}$	4529 ± 3	7.65×10^{-5}	5.330×10^{-23}	5.9 ± 0.3	(6.2 ± 1.5) [41]; (11 ± 4) [41]; (28 ± 23) [42]; 42 [40]	$(8.3 \pm 0.3)10^{-2}$	0.02
27	$^{152}_{67}Ho^{hs}_{85}$	4596 ± 10	8.96×10^{-4}	1.248×10^{-22}	30 ± 4	(30 ± 8) [41]; (17 ± 5) [41]; (36 ± 23) [42]; 122 [36]	0.42 ± 0.05	0.12
28	$^{153}_{67}Ho^{ls}_{86}$	4139 ± 10	1.49×10^{-6}	2.760×10^{-25}	22 ± 3	(21 ± 10) [41]; (31 ± 17) [41]; (62 ± 47) [42]	0.31 ± 0.05	0.09
29	$^{153}_{67}Ho^{hs}_{86}$	4033 ± 10	2.31×10^{-6}	5.705×10^{-26}	167^{+27}_{-23}	(125 ± 65) [41]; (180 ± 90) [41]; (132 ± 44) [42]; 219 [36]	2.35 ± 0.35	0.70
30	$^{154}_{67}Ho^{ls}_{87}$	4069 ± 10	1.67×10^{-7}	1.035×10^{-25}	7 ± 1	(6.7 ± 2) [41]; (11 ± 4) [41]; (7 ± 34) [42]	0.09 ± 0.01	0.03
31	$^{154}_{67}Ho^{hs}_{87}$	3846 ± 5	1.75×10^{-7}	3.157×10^{-27}	230 ^{e}	96 [36]; 124 [42]	3.23 ± 0.26	0.96

TABLE IV (continued)

	Isotope	Q_α [a] (KeV)	λ_α (sec^{-1})	P [b]	δ^2 (KeV) Present work	δ^2 (KeV) Other works	W_α [c]	θ^2 [d]
32	$^{152}_{68}Er_{84}$	4952±3	5.99×10^{-2}	2.344×10^{-21}	105±4	$\left(124^{+17}_{-33}\right)$ [37]; (91±10) [35]; (122±9) [9]; (110±7) [42]; 100 [40]; 101 [36]	1.48±0.05	0.44
33	$^{153}_{68}Er_{85}$	4820±3	8.57×10^{-3}	5.397×10^{-22}	66±2	$\left(55^{+32}_{-13}\right)$ [38]; (82±11) [9]; (67±13) [42]; 68 [40]; 140 [36]	0.92±0.03	0.27
34	$^{154}_{68}Er_{86}$	4307±10	1.45×10^{-5}	8.029×10^{-25}	74±10	(77±15) [38]; (81±32) [42]	1.05±0.15	0.31
35	$^{155}_{68}Er_{87}$	4145±10	1.31×10^{-6}	8.217×10^{-26}	66 [e]	(27±9) [38]; 26 [42]	0.93±0.14	0.28
36	$^{153}_{69}Tm_{84}$	5267±10	3.30×10^{-1}	2.187×10^{-20}	62±6	(92±12) [9]; (73±12) [42]; 72 [40]; 71 [36]	0.88±0.09	0.26
37	$^{154}_{69}Tm_{85}$	5113±10	5.09×10^{-2}	4.495×10^{-21}	47±5	(60±23) [9]; (56±40) [42]	0.66±0.07	0.20
38	$^{154}_{69}Tm_{85}$	5191±10	1.27×10^{-1}	1.038×10^{-20}	51 [e]	(69±18) [42]	0.71±0.08	0.21
39	$^{155}_{69}Tm_{86}$	4604±10	1.25×10^{-4}	1.178×10^{-23}	44 [e]	<73 [42]	0.62±0.08	0.18
40	$^{156}_{69}Tm_{87}$	4370±10	5.13×10^{-6}	5.431×10^{-25}	39±6		0.55±0.08	0.16
41	$^{156}_{69}Tm_{87}$	4602±10	1.19×10^{-23}	1.193×10^{-23}	0.41 [e]		$(5.8\pm0.8)\ 10^{-3}$	$1.7\times$ $\times10^{-3}$
42	$^{154}_{70}Yb_{84}$	5501±10	1.46	7.546×10^{-20}	81±8	(91±5) [35]; $\left(129^{+22}_{-18}\right)$ [37]; (95±8) [9]; (86±9) [42]; 98 [36]	1.14±0.11	0.34
43	$^{155}_{70}Yb_{85}$	5372±10	3.24×10^{-1}	2.172×10^{-20}	62±6	(77±15) [9]; (75±19) [42]; 70 [36]	0.87±0.09	0.26
44	$^{156}_{70}Yb_{86}$	4836±10	5.46 ± 10^{-3}	6.050×10^{-23}	373^{+48}_{-42}	(462±142) [9]; (377±90) [42]	5.25±0.65	1.58
45	$^{157}_{70}Yb_{87}$	4646±10	7.57×10^{-5}	6.041×10^{-24}	52 [e]	59 [42]	0.73±0.10	0.22
46	$^{158}_{70}Yb_{88}$	4199±10	1.54×10^{-7}	1.300×10^{-26}	49 [e]	28440 [9]; 67 [42]	0.69±0.10	0.21
47	$^{155}_{71}Lu_{84}$	5831±5	7.87	5.821×10^{-19}	56±2	(60±7) [9]; (70±11) [42]; 89 [36]	0.79±0.04	0.24
48	$^{156}_{71}Lu_{85}$	5740±5	3.85	2.634×10^{-19}	60±3	(65±8) [9]; (60±28) [42]; 58 [36]	0.85±0.04	0.26
49	$^{156}_{71}Lu_{85}$	5619±10	1.05	8.342×10^{-20}	52±5	(48±18) [42]; 75 [9]	0.73±0.07	0.22
50	$^{157}_{71}Lu_{86}$	5151±10	7.56×10^{-3}	6.955×10^{-22}	45±5	(59±28) [9]; (54±47) [42]	0.63±0.07	0.19
51	$^{158}_{71}Lu_{87}$	4811±10	1.39×10^{-4}	1.389×10^{-23}	41 [e]		0.58±0.07	0.18

52	$^{159}_{71}Lu_{88}$	4559±10	5.13×10^{-6}	5.728×10^{-24}	37 e		0.52±0.07	0.16
53	$^{156}_{72}Hf_{84}$	6058±10	2.77×10^{1}	1.553×10^{-18}	74±6	(80±15) [9]; (74±26) [42]	1.04±0.09	0.31
54	$^{157}_{72}Hf_{85}$	5911±5	5.73	4.394×10^{-19}	54±3	(58±6) [9]; (54±10) [42]; 90 [36]	0.76±0.03	0.23
55	$^{158}_{72}Hf_{86}$	5430±5	9.97 ± 10^{-2}	4.432×10^{-21}	93±5	(100±21) [9]; (117±28) [42]; 165 [36]	1.31±0.07	0.40
56	$^{159}_{72}Hf_{87}$	5252±5	1.48×10^{-2}	7.002×10^{-22}	88±5	(95±13) [9]; (92±13) [42]	1.23±0.07	0.38
57	$^{160}_{72}Hf_{88}$	4925±5	5.50×10^{-4}	1.732×10^{-23}	131 e	(341±21) [9]; (346±28) [42]	1.85±0.11	0.57
58	$^{161}_{72}Hf_{89}$	4743±10	7.87×10^{-5}	1.891×10^{-24}	172 e		2.42±0.31	0.74
59	$^{162}_{72}Hf_{90}$	4441±10	1.92×10^{-6}	3.313×10^{-26}	240^{+37}_{-32}	325^{+42}_{-85} [9]	3.38±0.50	1.04
60	$^{174}_{72}Hf_{102}$	2584±30	1.10×10^{-23}	4.067×10^{-43}	112^{+187}_{-69}	110 [36]	$1.57^{+2.63}_{-0.97}$	0.51
61	$^{157}_{73}Ta_{84}$	6408±10	1.31×10^{2}	1.063×10^{-17}	51±4 e	(55±19) [9]	0.72±0.06	0.22
62	$^{158}_{73}Ta_{85}$	6234±6	1.78×10^{1}	2.663×10^{-18}	28±1	(29±3) [9]	0.39±0.02	0.12
63	$^{159}_{73}Ta_{86}$	5772±6	9.73×10^{-1}	4.394×10^{-20}	92±5	(99±33) [9]	1.29±0.08	0.39
64	$^{160}_{73}Ta_{87}$	5578±5	2.02×10^{-1}	6.905×10^{-21}	121 e		1.71±0.08	0.52
65	$^{161}_{73}Ta_{88}$	5305±5	2.40×10^{-1}	4.170×10^{-22}	199 e		2.79±0	0.86
66	$^{158}_{74}W_{84}$	6644±30	3.15×10^{2}	2.608×10^{-17}	50 e		$0.70^{+0.19}_{-0.14}$	0.21
67	$^{159}_{74}W_{85}$	6488±6	1.92×10^{2}	7.990×10^{-18}	100±5	53±26 [9]	1.40±0.07	0.43
68	$^{160}_{74}W_{86}$	6098±10	8.06	3.110×10^{-19}	107±10	(123±26) [9]	1.51±0.13	0.46
69	$^{161}_{74}W_{87}$	5951±5	1.39	8.579×10^{-20}	67±3	(72±24) [9]	0.94±0.04	0.29
70	$^{162}_{74}W_{88}$	5705±5	2.29×10^{-1}	8.611×10^{-21}	110±5	(119±13) [9]	1.55±0.08	0.48
71	$^{163}_{74}W_{89}$	5546±5	9.49×10^{-2}	1.822×10^{-21}	215±11	(232±35) [9]	3.03±0.16	0.94
72	$^{164}_{74}W_{90}$	5303±5	2.82×10^{-3}	1.431×10^{-22}	81±5	(88±59) [9]	1.14±0.06	0.36
73	$^{165}_{74}W_{91}$	5050±5	6.93 ± 10^{-4}	8.203×10^{-24}	350 e	<1564 [9]	4.91±0.30	1.54
74	$^{166}_{74}W_{92}$	4883±5	2.57×10^{-4}	1.100×10^{-24}	965^{+63}_{-59}	(1138±462) [9]	13.57±0.85	4.27
75	$^{161}_{75}Re_{86}$	6466±10	3.46×10^{1}	2.622×10^{-18}	55 e	$\left(119^{+142}_{-78}\right)$ [9]	0.77±0.06	0.24
76	$^{162}_{75}Re_{87}$	6301±6	9.90	6.897×10^{-19}	59 e	(45±14) [9]	0.83±0.04	0.26
77	$^{163}_{75}Re_{88}$	6094±6	1.69	1.174×10^{-19}	60±3	(65±21) [9]	0.84±0.05	0.26
78	$^{164}_{75}Re_{89}$	5950±10	4.75×10^{-1}	3.265×10^{-20}	60 e		0.85±0.08	0.26
79	$^{165}_{75}Re_{90}$	5670±10	3.75×10^{-2}	2.253×10^{-21}	69±7	(75±27) [9]	0.97±0.10	0.30

TABLE IV (continued)

	Isotope	Q_α [a] (KeV)	λ_α (sec^{-1})	P [b]	δ^2 (KeV) Present work	δ^2 (KeV) Other works	W_α [c]	θ^2 [d]
80	$^{166}_{75}Re_{91}$	5658±10	3.15×10^{-2}	2.091×10^{-21}	62 [e]		0.88±0.09	0.28
81	$^{167}_{75}Re_{92}$	5488±10	6.08×10^{-3}	3.757×10^{-22}	67 [e]		0.94±0.10	0.30
82	$^{168}_{75}Re_{93}$	5293±10	8.15×10^{-4}	4.640×10^{-23}	73 [e]		1.02±0.12	0.32
83	$^{169}_{75}Re_{94}$	5199±10	3.30×10^{-4}	1.684×10^{-23}	81 [e]		1.14±0.14	0.36
84	$^{163}_{76}Os_{87}$	6701±30	9.90×10^{1}	6.900×10^{-18}	59 [e]		$0.83^{+0.22}_{-0.18}$	0.26
85	$^{164}_{76}Os_{88}$	6506±20	1.69×10^{-1}	1.493×10^{-18}	47±8	$\left(50^{+67}_{-21}\right)$ [9]	0.66±0.11	0.20
86	$^{165}_{76}Os_{89}$	6345±10	1.07×10^{1}	4.044×10^{-19}	109±9	$\left(114^{+121}_{-64}\right)$ [9]	1.53±0.13	0.48
87	$^{166}_{76}Os_{90}$	6156±6	2.77	8.087×10^{-20}	142±8	(153±43) [9]	1.99±0.10	0.63
88	$^{167}_{76}Os_{91}$	6007±5	3.83×10^{-1}	2.150×10^{-20}	74±4	(78±28) [9]	1.04±0.05	0.33
89	$^{168}_{76}Os_{92}$	5826±10	1.36×10^{-1}	3.966×10^{-21}	142 [e]		1.99±0.20	0.63
90	$^{169}_{76}Os_{93}$	5722±10	5.33×10^{-2}	1.486×10^{-21}	148 [e]		2.09±0.21	0.66
91	$^{170}_{76}Os_{94}$	5558±10	1.33×10^{-2}	2.839×10^{-22}	194 [e]		2.73±0.30	0.87
92	$^{171}_{76}Os_{95}$	5393±10	2.77×10^{-3}	5.003×10^{-23}	229 [e]		3.22±0.36	1.04
93	$^{172}_{76}Os_{96}$	5254±10	8.01×10^{-4}	1.088×10^{-23}	305 [e]		4.28±0.51	1.38
94	$^{173}_{76}Os_{97}$	5084±10	0.87×10^{-5}	1.527×10^{-24}	23 [e]		0.33±0.04	0.11
95	$^{174}_{76}Os_{98}$	4900±10	3.24×10^{-5}	1.581×10^{-25}	85 [e]		1.19±0.16	0.39

[a] The total α decay energy calculated from the expression: $Q_\alpha = \left[E_\alpha + \frac{m}{M}E_\alpha + (65.3Z_p^{7/5} - 80Z_p^{2/5})10^{-6}\right]$ MeV where Q_α — total decay energy, E_α — kinetic energy of α particle, m — mass of α particle, M — mass of daughter nucleus, Z_p — atomic number of parent nucleus. The first term of the expression gives the kinetic energy of the α particle, the second the kinetic energy of the recoil daughter nucleus, the third the correction factor for electron screening; [b] barrier penetration factor; [c] calculated relative to the α width for ^{212}Po, $W_\alpha = \frac{\delta^2}{\delta^2_{Po^{212}}}$; [d] the dimensionless reduced width $\theta^2 = \frac{\delta^2_\alpha}{\delta^2_W}$ where $\delta^2_W = \frac{3\hbar^2}{2\mu R^2} = \frac{6.52A_{mother}}{A^{5/3}_{daughter}}$; [e] calculated assuming the procedure for calculation of $T^\alpha_{1/2}$ from the present work.

and reduced widths have smallest experimental errors). In the $58 \leqslant Z \leqslant 74$ region the δ values concentrate around 0.1 MeV for $N = 84$ except nuclides round $Z = 64$ where smaller reduced widths are observed. The constancy of δ^2 above $Z = 67$ is likely to be the result of filling of the $h_{11/2}$ proton shell and the effect of the residual pairing foices which tend to smooth out the vaiiations in δ^2.

The theoretical calculations of Macfarlane et al. [35] predict a nearly constant δ^2 for the $N = 84$. We note that the alpha reduced widths for $N = 84$ of odd-even nuclei are on the average about 30%–40% lower than alpha widths of the even-even nuclei.

Fig. 4b shows the δ^2 values for $N = 85$ isotones. These δ^2 values show the same dependence as function of the proton number. There is a clear minimum at terbium showing, that its decay is hindered in comparison with the other lanthanides. This is probably due to the fact that shell model $d_{5/2}$ proton subshell is filled in gadolinium and terbium nucleus can only produce an alpha particle from protons belonging to different levels. We observe similarity in absolute values of δ^2 for odd-even nuclei at $N = 84$ isotones and even-odd nuclei at $N = 85$ isotones.

We note that the alpha widths of odd-odd $N = 85$ isotones are on the average about 50% lower than the alpha widths of the odd-even $N = 85$ and even-odd $N = 84$ nuclei.

One can see that the reduced widths for $N = 86$ isotones (Fig. 4c) aie on the average about 50% larger than the widths of the even-even $N = 84$ isotones. Remarkable is the high value of δ^2 at $Z = 70$ what is probably connected with the fact that the midshell $\pi h_{11/2}$ is filled.

The reduced widths at $N = 87$ (Fig. 4d) are unexpectedly equal for even-odd and odd-odd nuclei. In addition, the widths decrease for even-odd nuclei as one goes from $Z = 62$ to $Z = 66$ and oscillate around 0.1 MeV for higher Z than 66.

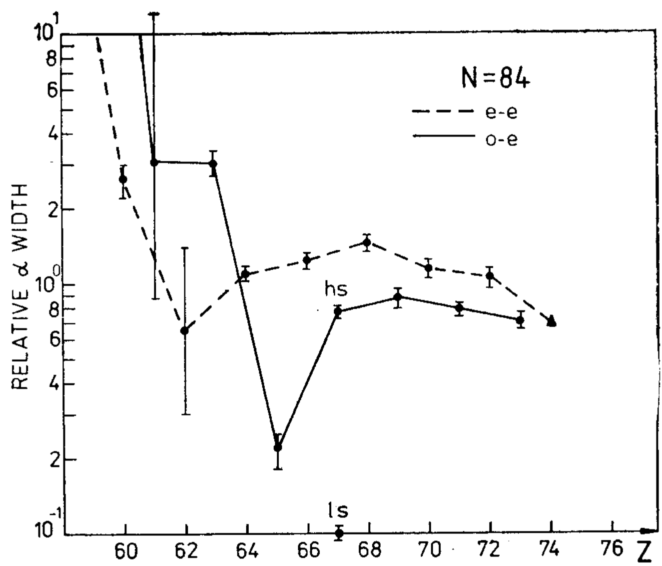


Fig. 4a

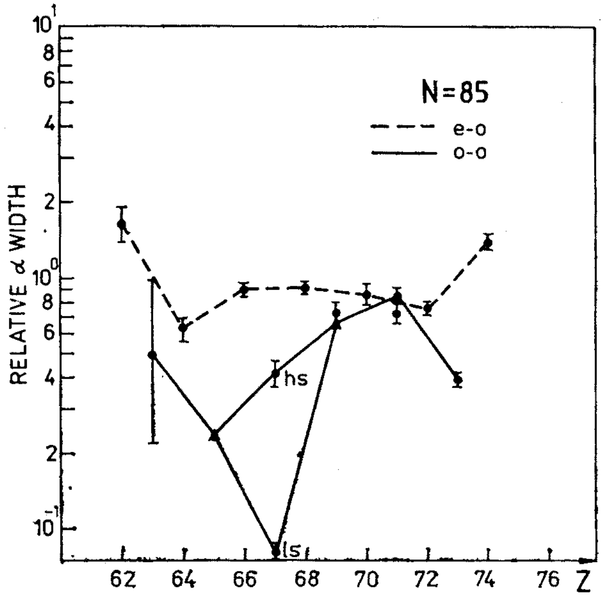

N=85
e-o
o-o
RELATIVE α WIDTH
hs
ls
Z
62
64
66
68
70
72
74
76

Fig. 4b

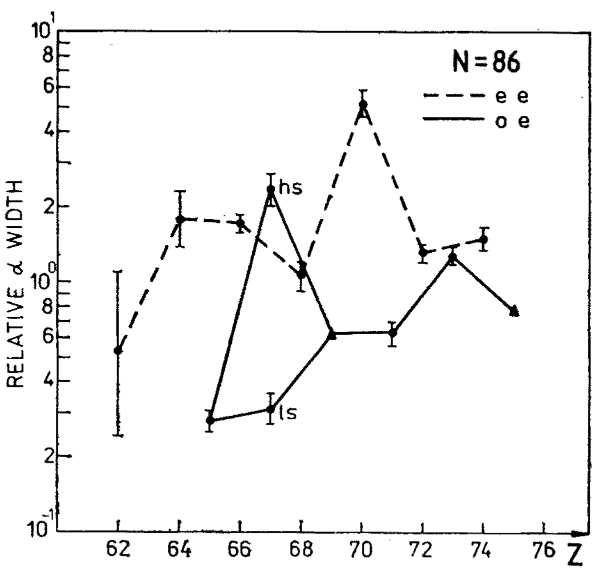

N=86
e e
o e
RELATIVE α WIDTH
hs
ls
Z
62
64
66
68
70
72
74
76

Fig. 4c

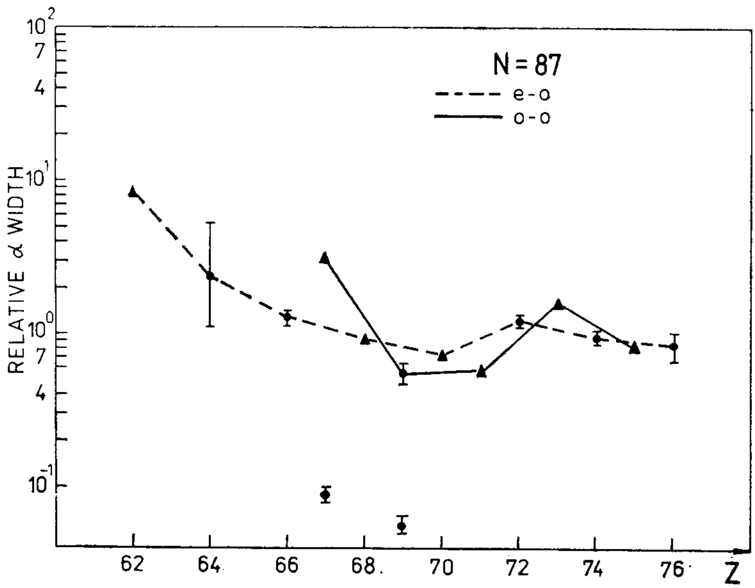


Fig. 4d

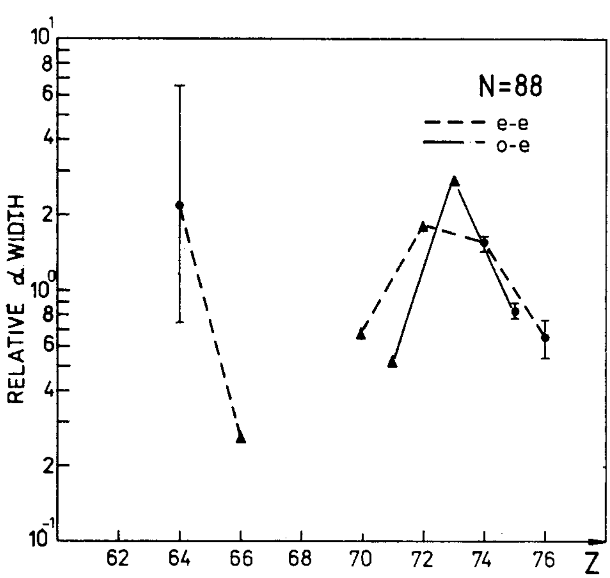


Fig. 4e

Fig. 4a–e. Reduced alpha widths of N = 84, 85, 86, 87 and 88 isotones as function of the atomic number. For isotopes marked with triangles estimated (in the present work) alpha partial half-lives were used

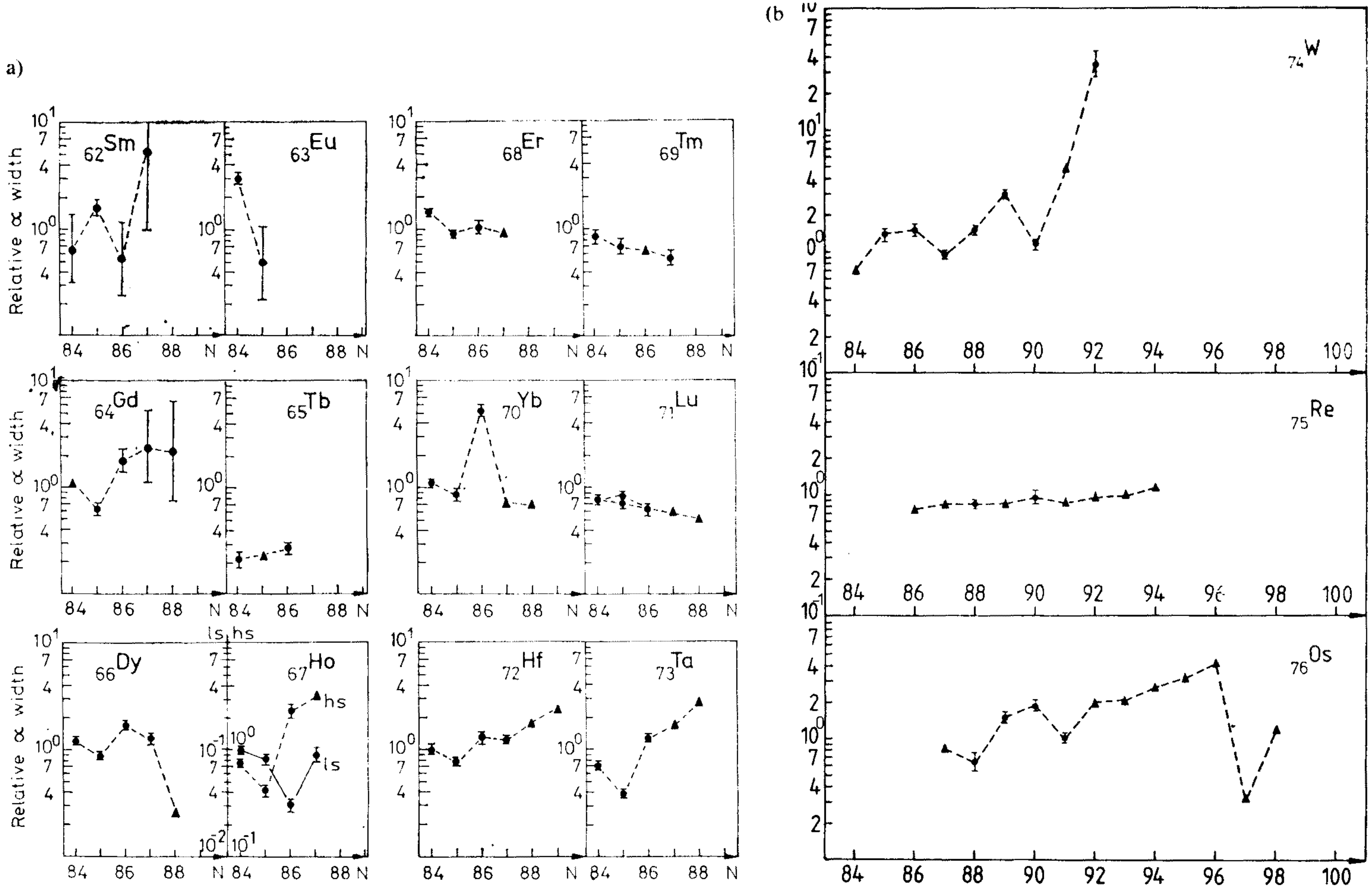


Fig. 5a–b. Reduced alpha widths versus neutron number for constant atomic number. For isotopes marked with triangles estimated (in the present work) alpha partial half-lives were used

The reduced widths for $N = 88$ (Fig. 4e) are equal for even-odd and even-even nuclei. These equalities are probably related to structural changes associated with the end of filling of the $g_{7/2}$ neutron and $h_{11/2}$ proton shells (or with the deformation).

The effects due to deformation at $N = 84$, 85 and 86 nuclei in the ground state are absent in this region of Z. Progress of deformation is very slow. A gradual increase in deformation is suggested by spectroscopic data and abrupt onset of deformation occurs between the nuclei with neutron numbers $N = 88$–90. With the spins unknown we cannot say anything quantitative about the deformation.

The dependence of δ^2 on Z shows a continuous shift of maximum of δ^2 (first at $N = 84$ and $Z = 68$, second at $N = 86$ and $Z = 70$, and third at $N = 88$ and $Z = 72$) what corresponds to 1/3, 1/2 and 2/3 of filling $h_{11/2}$ proton shell.

A regular trend with δ^2 (odd-odd) $<$ δ^2 (even-odd, odd-even) and δ^2 (even-odd, odd-even) $<$ δ^2 (even-even) for identical N resulted.

The next feature we examine is the δ^2 dependence on neutron number N for constant Z. The complete systematics of δ^2 as a function of N is shown in Fig. 5.

One notes that the large widths are found for nuclei with two or four neutrons more than magic number $N = 82$. In the classical region of lanthanides the general trend is a decrease of δ^2 towards the next closure. For Lu and Re the δ^2 exhibit a very smooth behaviour with changes of N. For transitional nuclei Ta-Os there is an interesting increase of δ^2 with increasing neutron number up to 90. It appears to be likely that the alpha widths for W-Os are closely connected with the systematic change of shape. If the nucleons which form the emitted alpha particle originate from the same subshell, the δ^2 increases with the number of available nucleons. When nucleons from other subshells are also involved, the δ^2 rapidly decreases. Thus a good measure of a significant role of cluster structure of nuclei is obtained.

6. *Summary*

A measurement of missing branching ratios would be desirable in order to confirm our expected values of alpha partial half-lives and alpha reduced widths.

By studying chains of alpha and beta decays and linking these chains to known mass values it is possible to extend the knowledge of experimental masses up to very exotic nuclei. From the extended knowledge of atomic masses certain information about proton binding energies can be extracted.

The theories are successful in describing the relative behaviour of the alpha widths as a function of Z or N. The calculations of the absolute values of alpha widths are more difficult. We expect that our "experimental" values of alpha widths may help in such calculations.

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