



Chemistry of superheavy elements

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Konferencja Przyszłość fizyki jądrowej niskich energii w Polsce
a rozwój krajowej infrastruktury badawczej

Środowiskowe Laboratorium Ciężkich Jonów UW
14-15 stycznia 2019

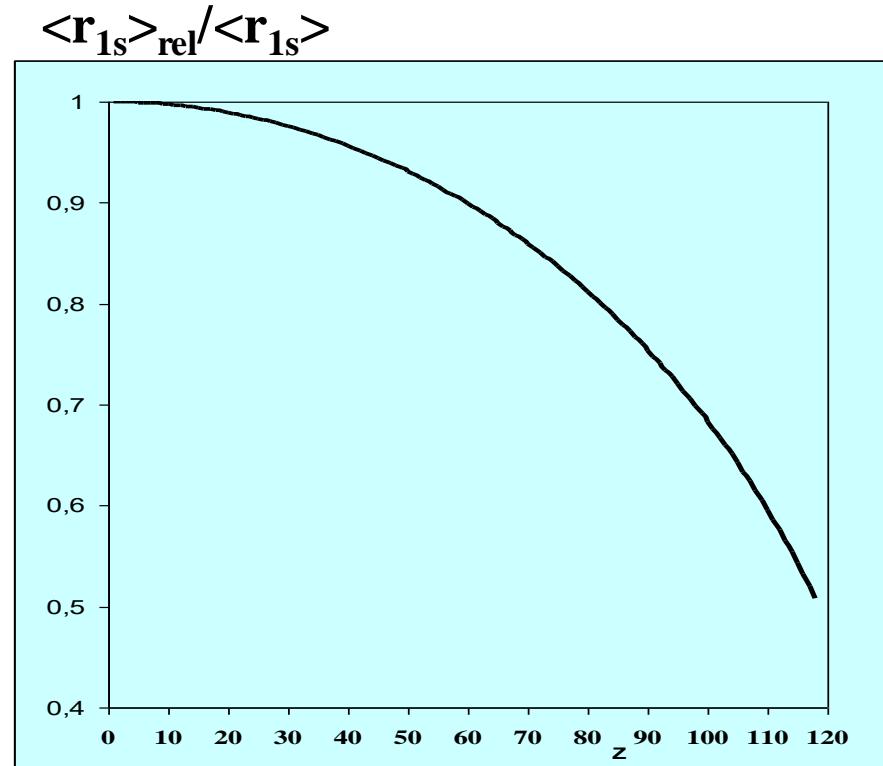
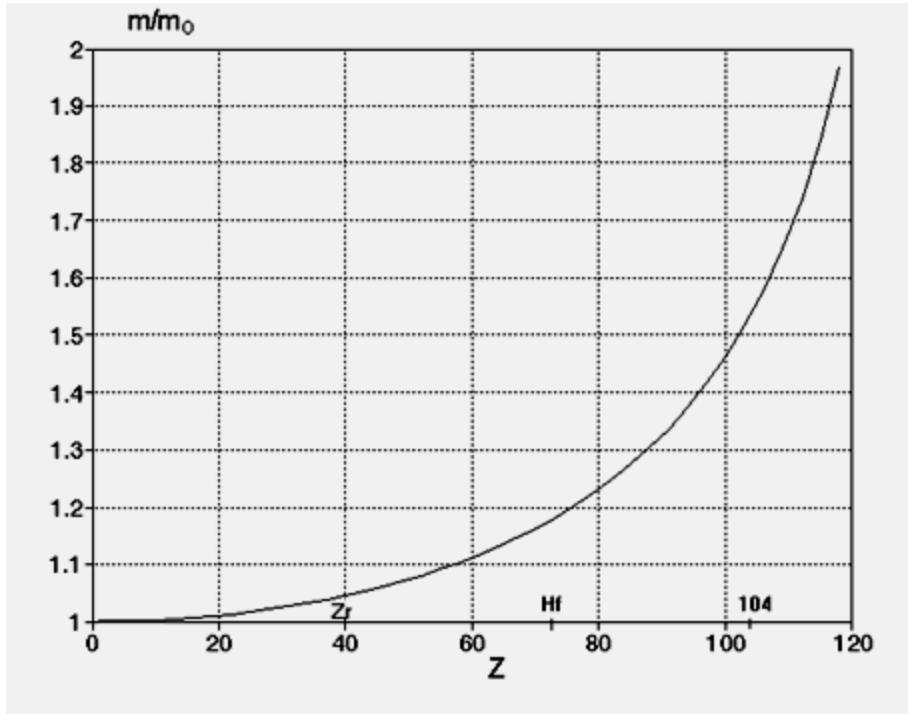
Why we study super-heavy elements?

- How many elements can exist? chemical restrictions
- How relativistic effects can affect the chemical properties of elements
- Construction of the periodic table

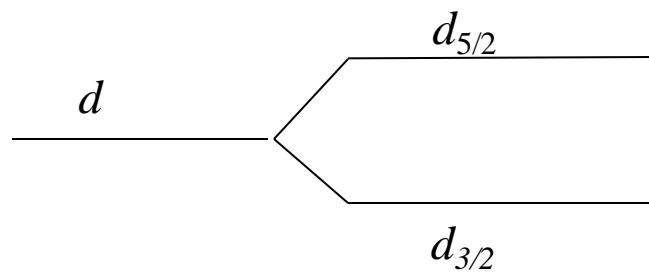
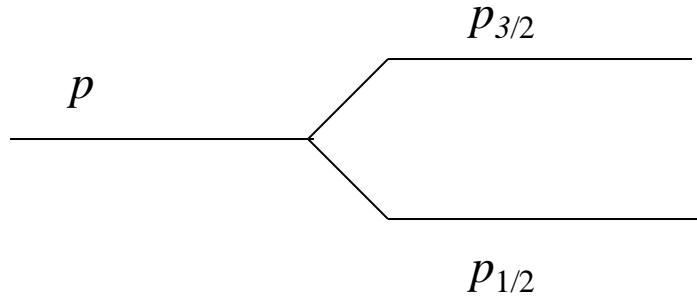
$$\langle V_r \rangle = \frac{Z}{137,035} c \quad \text{orbital 1s}$$

$$m = \frac{m_0}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

$$r_0 = \frac{4\pi\epsilon_0\hbar^2}{me^2}$$



spin-orbital coupling



Relativistic effects in chemistry

- Noble gold [Xe]5d¹⁰6s¹
- Liquid mercury [Xe]5d¹⁰6s²
- Yellow color of gold and cesium
- Anion Au⁻
- Low oxidation states
- Tl⁺, [Xe]5d¹⁰6s²6p_{1/2}
- Pb²⁺, [Xe]5d¹⁰6s²6p₂_{1/2}
- Bi⁺, [Xe]5d¹⁰6s²6p₂_{1/2}6p_{3/2}
- Po²⁺ [Xe]5d¹⁰6s²6p₂_{1/2}6p₂_{3/2}

2018

Periodic Table of the Elements

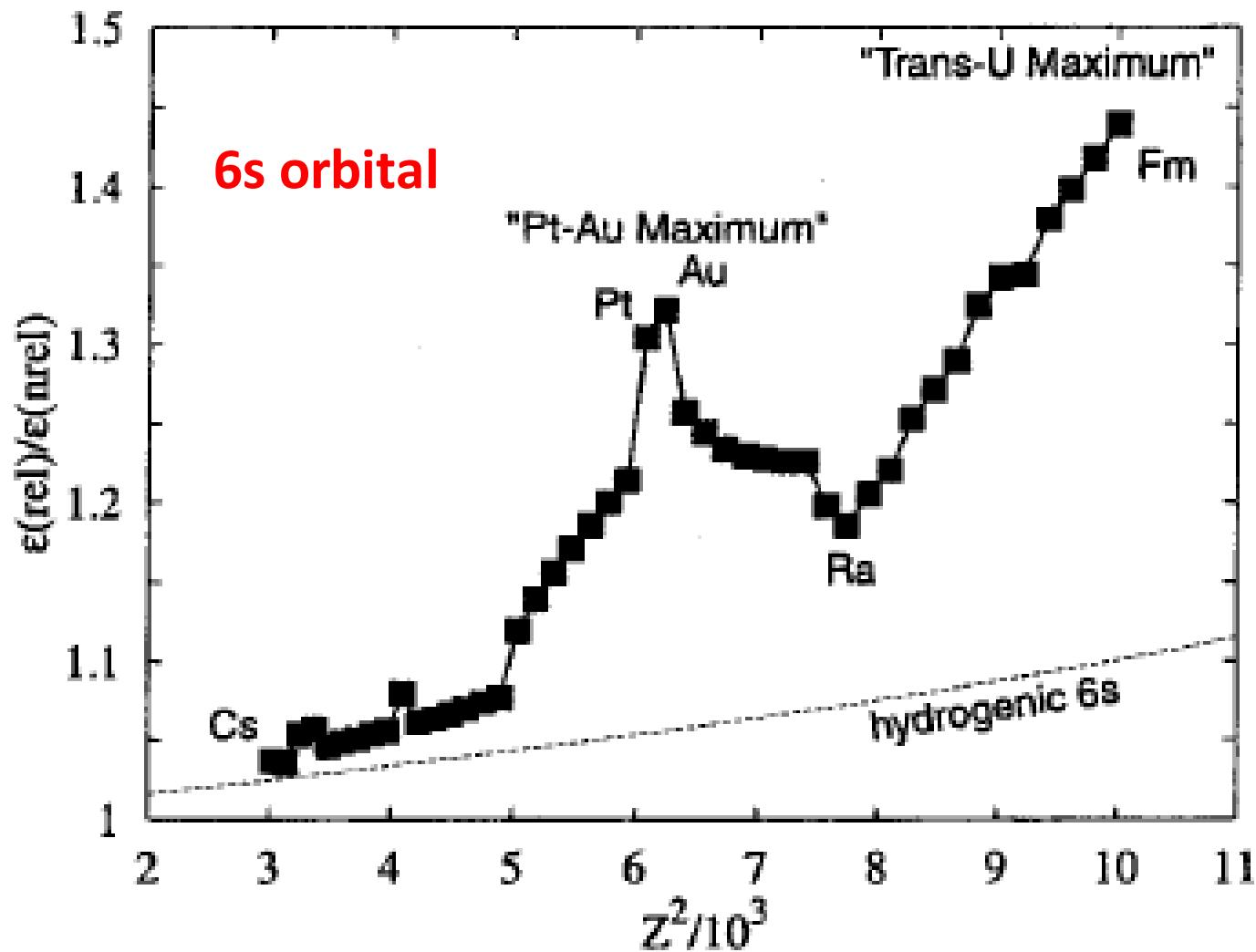
1 H Hydrogen 1.008	2 He Helium 4.003																
3 Li Lithium 6.941	4 Be Beryllium 9.012	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180										
11 Na Sodium 22.990	12 Mg Magnesium 24.305	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948										
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.972	35 Br Bromine 79.904	36 Kr Krypton 84.798
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 133.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Hf Hafnium 178.49	72 Ta Tantalum 180.948	73 W Tungsten 183.84	74 Re Rhenium 186.207	75 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.990	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018	
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Rf Rutherfordium [261]	104 Db Dubnium [262]	105 Sg Seaborgium [266]	106 Bh Bohrium [264]	107 Hs Hassium [269]	108 Mt Meitnerium [268]	109 Ds Darmstadtium [269]	110 Rg Roentgenium [272]	111 Cn Copernicium [277]	112 Nh Nihonium unknown	113 Fl Flerovium [289]	114 Mc Moscovium unknown	115 Lv Livermorium [298]	116 Ts Tennessine unknown	117 Og Oganesson unknown	
57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967			
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 <bmd< b=""> Mendelevium 258.1</bmd<>	102 No Nobelium 259.101	103 Lr Lawrencium [262]			

Alkali Metal Alkaline Earth Transition Metal Basic Metal Semimetal Nonmetal Halogen Noble Gas Lanthanide Actinide

Transaktynowce >103

Transfermowce > 100

Superciężkie > 103



Cn - [Rn] $5f^{14}6d^{10}7s^2$

Fl - [Rn] $5f^{14}6d^{10}7s^27p_{1/2}^2$

1 IA 11A	H Hydrogen 1.008	2 IIA 2A	He Helium 4.003	18 VIIIA 8A												
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Lanthanide Series		57 La Lanthanum 138.906	58 Ce Cerium 140.115	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.966	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.26	69 Tm Thulium 169.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.957
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PERIODIC TABLE OF THE ELEMENTS

H																He	
1																18	
Li	Be																
3	4																
Na	Mg	3	4	5	6	7	8	9	10	11	12						
11	12																
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Cs	Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Fr	Ra	Ac ⁺	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	112	113	114	115	116	114	114
87	88	89	104	105	106	107	108	109	110	111	112	113	114	115	116	114	114

+Actinides



Transactinides = Superheavy Elements



* Lanthanides



<u>Rutherfordium</u>	^{267}Rf	2.5 hours
<u>Dubnium</u>	^{268}Db	29 hours
<u>Seaborgium</u>	^{269}Sg	14 minutes
<u>Bohrium</u>	^{270}Bh	1 minute
<u>Hassium</u>	^{270}Hs	10 seconds
<u>Meitnerium</u>	^{278}Mt	7.6 seconds
<u>Darmstadtium</u>	^{281}Ds	9.6 seconds
<u>Roentgenium</u>	^{282}Rg	1.6 minutes
<u>Copernicium</u>	^{285}Cn	29 seconds
<u>Nihonium</u>	^{286}Nh	9.5 seconds
<u>Flerovium</u>	^{289}Fl	1.9 seconds
<u>Moscovium</u>	^{290}Mc	650 milliseconds
<u>Livermorium</u>	^{293}Lv	57 milliseconds
<u>Tennessine</u>	^{294}Ts	51 milliseconds
<u>Oganesson</u>	^{294}Og	0.69 milliseconds ¹

Criteria for chemical studies to be carried out on a transactinide,

- at least four atoms must be produced,
- the half-life of the isotope must be at least 1 second,
- rate of production must be at least one atom per week.

Partition

technique

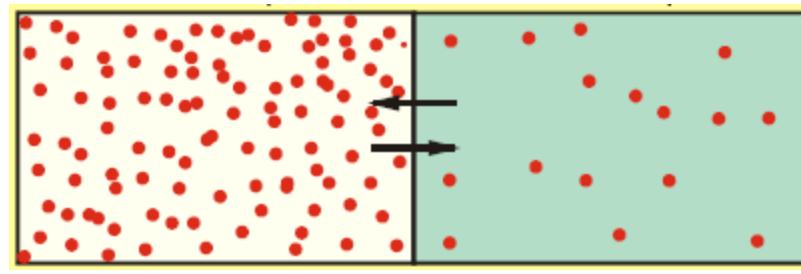
Solid state – gas

liquid – liquid

liquid – solid state

Faza 1

Faza 2



Classical system

$$K_d = \frac{C_{F1}}{C_{F2}} = 5$$

Faza 1

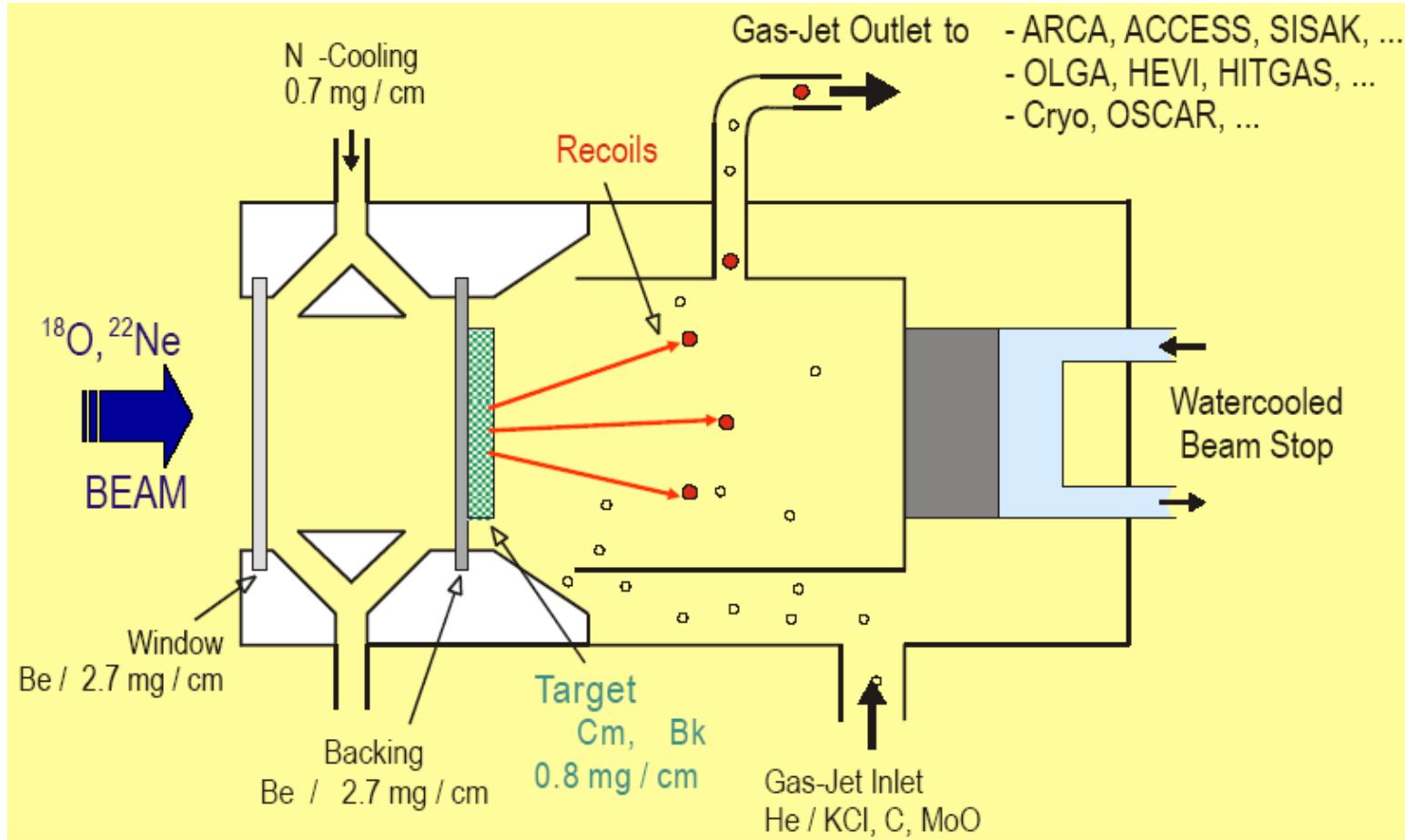
Faza 2



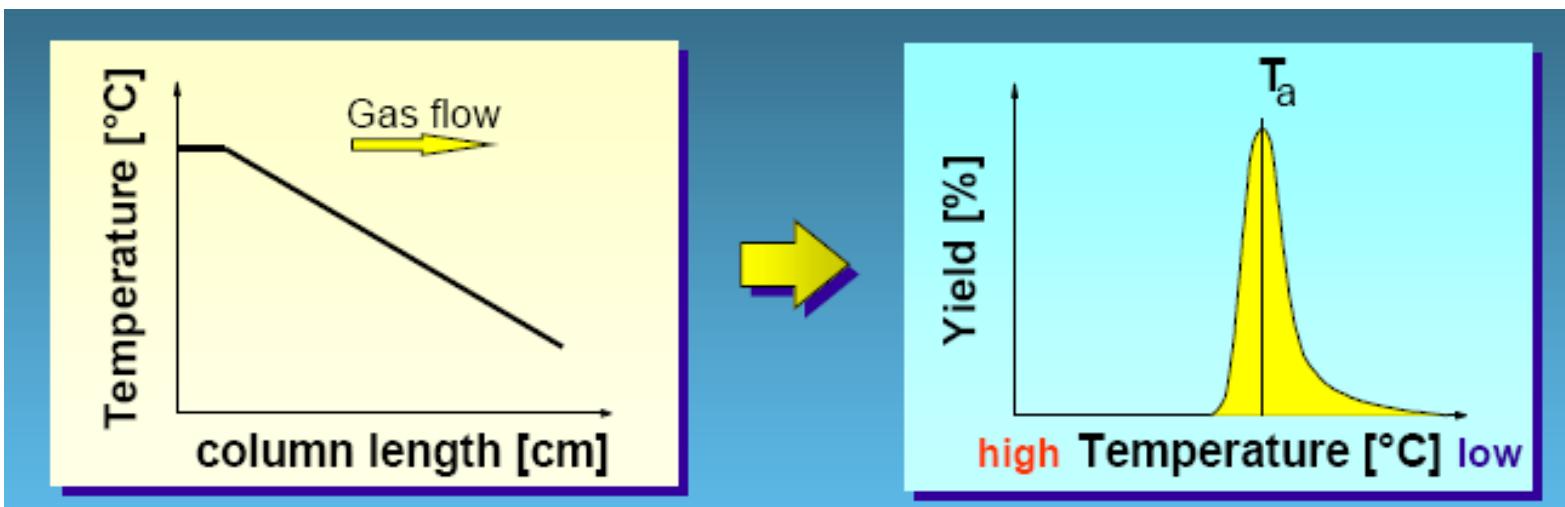
One atom chemistry

$$K_d = 5$$

Techniki badań



Termochromatography



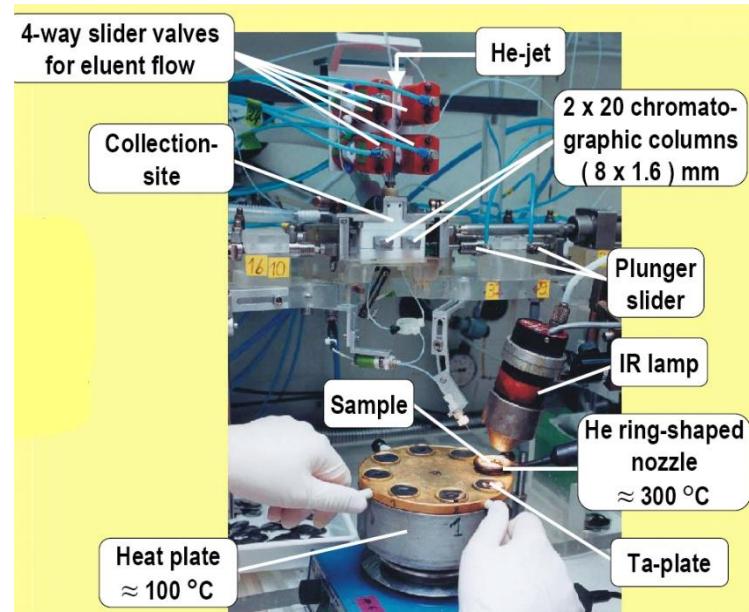
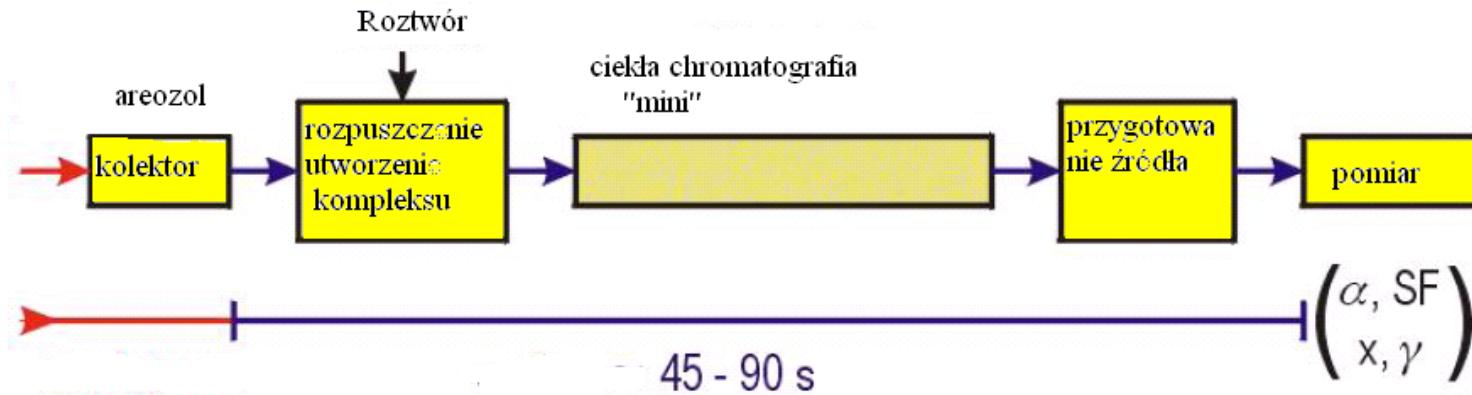
Liquid chromatography

ARCA

Rf - Sg

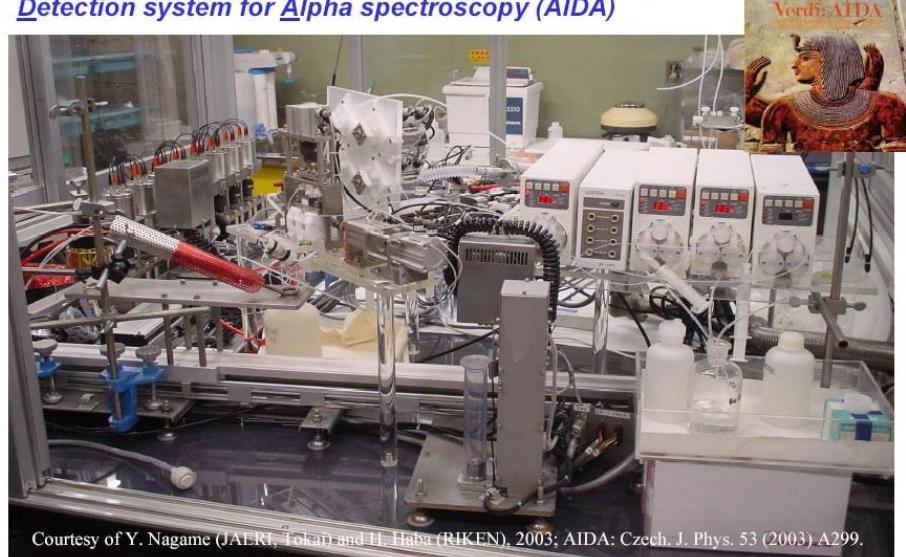
AIDA

Rf



A
I
D
A

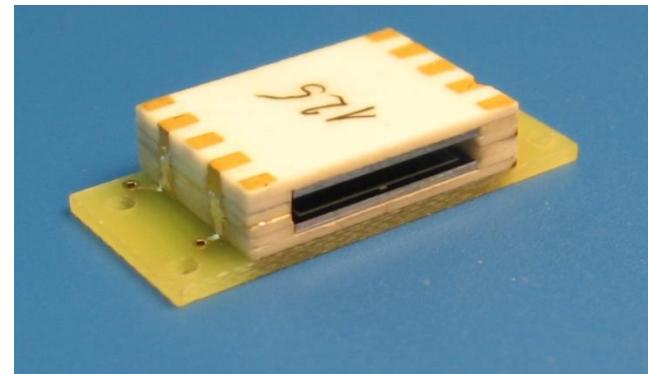
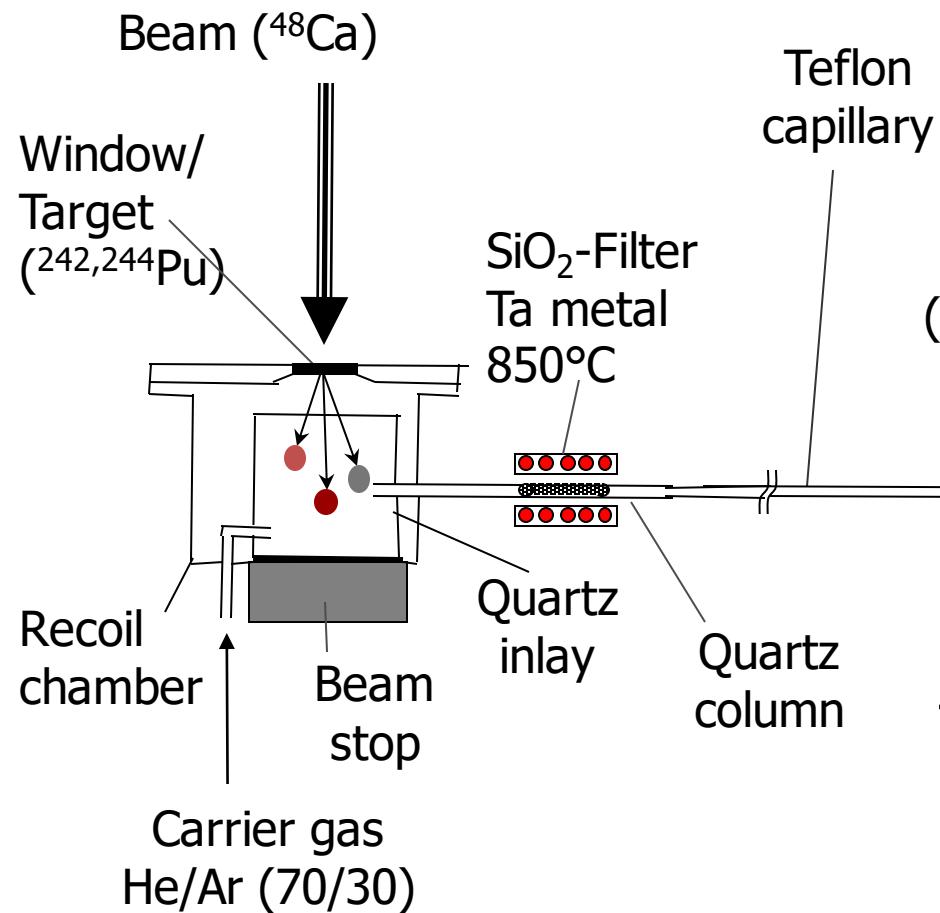
Automated ion exchange separation apparatus coupled with the Detection system for Alpha spectroscopy (AIDA)



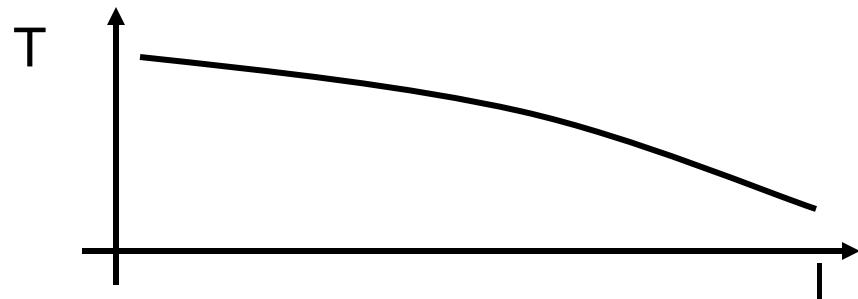
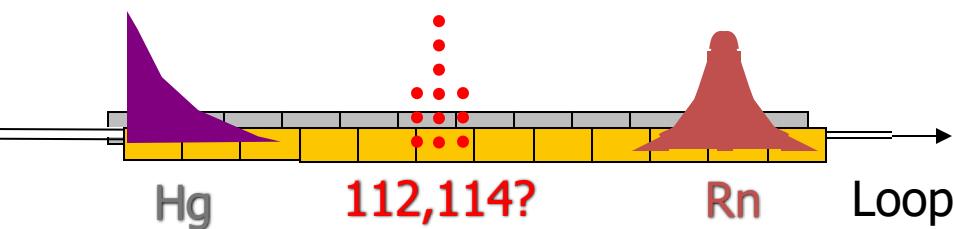
Courtesy of Y. Nagame (JAERI, Tokai) and H. Haba (RIKEN), 2003; AIDA: Czech. J. Phys. 53 (2003) A299.

The Cn and Fl experiments

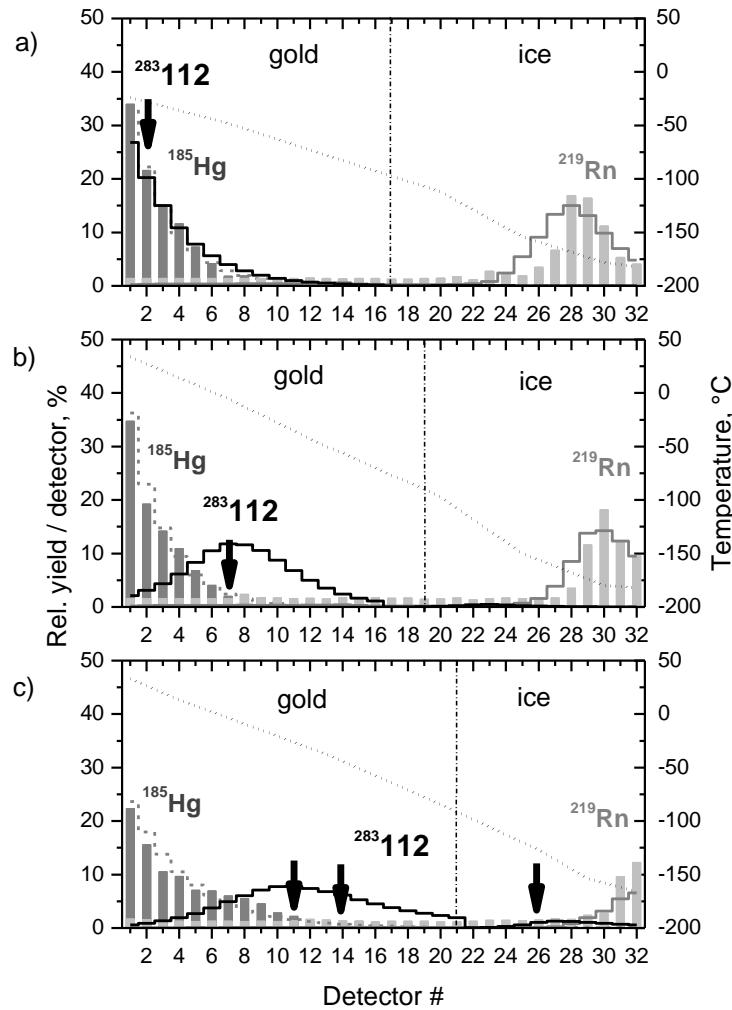
^{242}Pu ($^{48}\text{Ca}, 3\text{n}$) ^{287}Fl - 3.5 pb



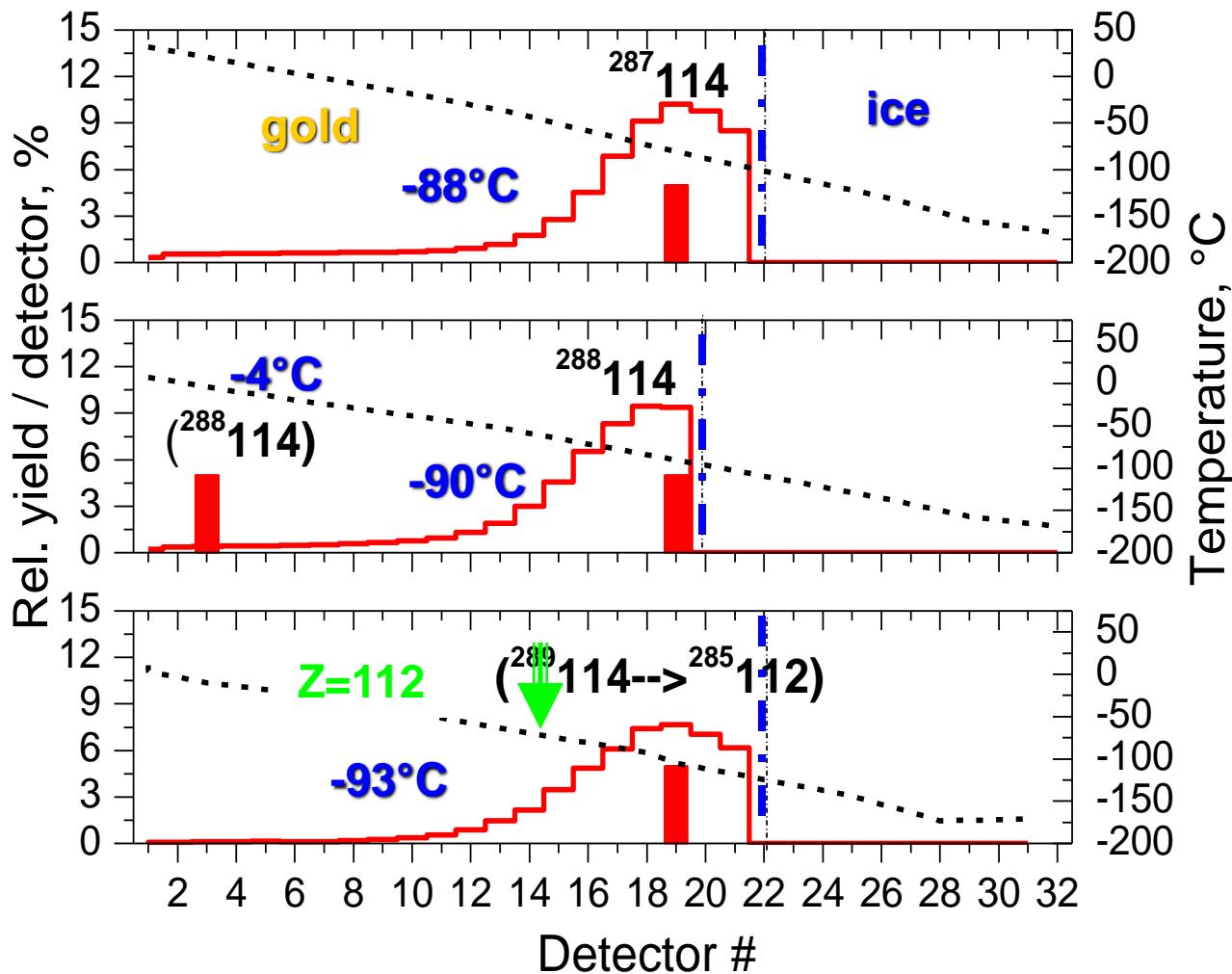
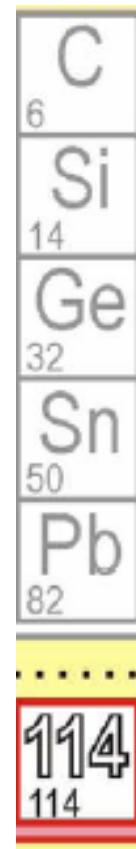
Cryo On-line Detector (4 π COLD)
(32 pairs PIN diodes, one side gold covered)



Adsorption of Cn on gold surface

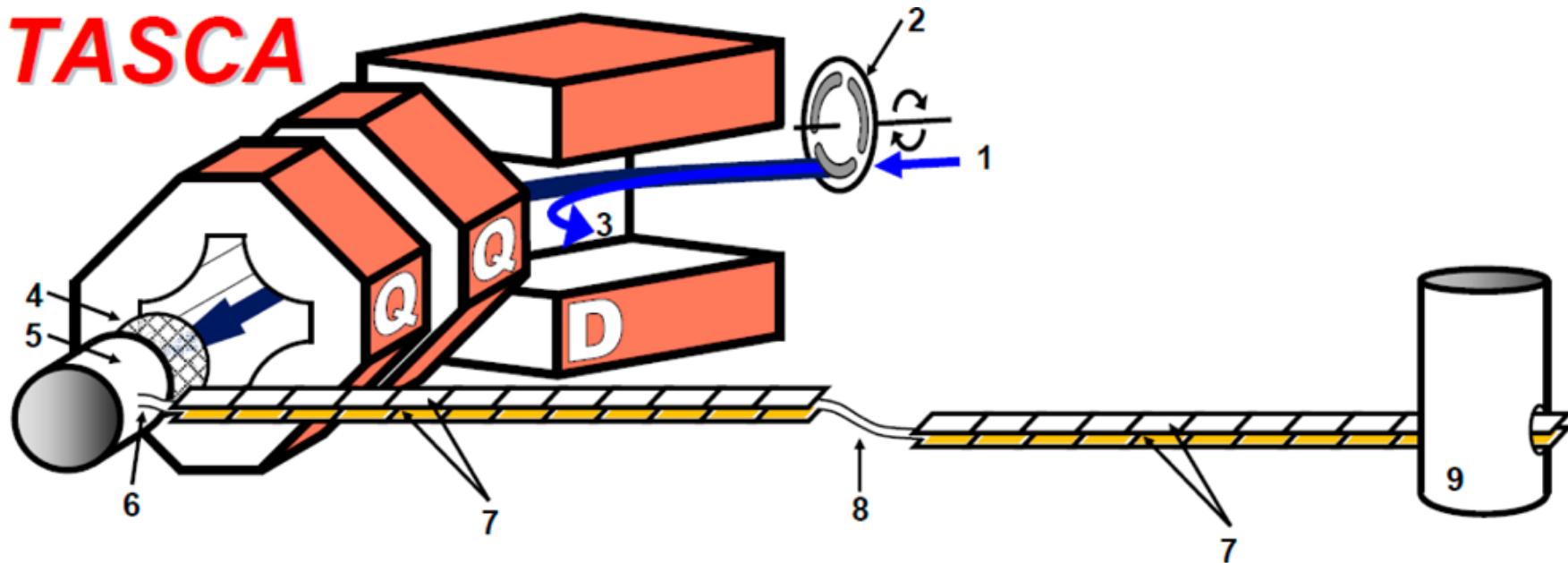


Cn is similar to Hg but more volatile



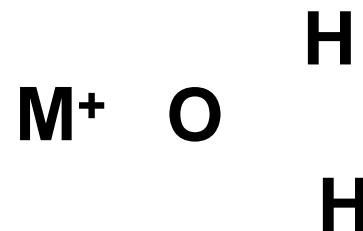
FI gas chemistry

TASCA



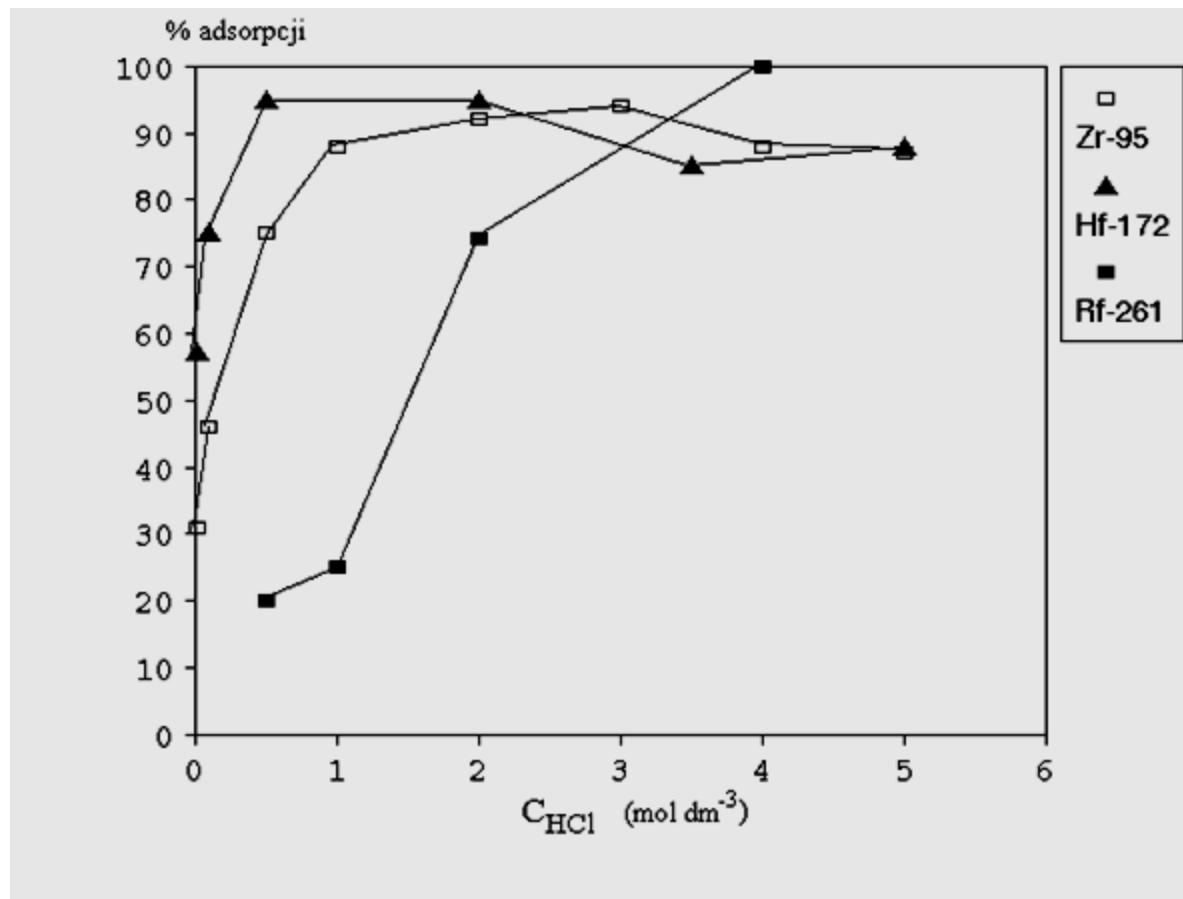
COMPACT I (IC)

COMPACT II (TC)



Ionic radius - r_i

$Rf^{4+} > Hf^{4+} > Zr^{4+} > Ti^{4+}$



Hydrolysis in Group 4

Ti>Rf>Zr>Hf

Stałe hydrolizy

Grupa 11

kation	r_i , pm	pK_{1h}
Cu^+	77	-
Ag^+	115	12
Au^{+}	137	3.8

Grupa 12

kation	r_i , pm	pK_{1h}
Zn^{2+}	74	8.96
Cd^{2+}	95	10.08
Hg^{2+}	102	3.40

Grupa 13

kation	r_i , pm	pK_{1h}
Ga^{3+}	62.0	3.6
In^{3+}	80.0	4.0
Tl^{3+}	88.5	0.6

Grupa 2

kation	r_i (pm) (CN=8)	pK_{1h}
Ca^{2+}	112	13,22
Sr^{2+}	126	13,83
Ba^{2+}	142	14,07
Ra^{2+}	148	14,07

Perspectives of SHE research in Poland

1. Studies on Cn^{2+} hydrolysis
2. Termochromatography studies of chelates Rf, Db, Fl
3. Electrochemical studies of Cn and Fl