## THE PERIODIC SYSTEM CONTINUED TO Z=172

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Sotchi, Russia, September 7, 2011 (15')

## THE PERIODIC SYSTEM 2010




| 1 | 1 | 2 |  |  |  |  |  |  |  |  |  |  | 13 | 14 | 15 | 16 | 17 | 2 He | 1s |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2 | 3 $\mathbf{L}$ | $\begin{gathered} 4 \\ \mathrm{Be} \end{gathered}$ |  |  |  |  |  |  |  |  |  |  | B | $\begin{aligned} & 6 \\ & C \end{aligned}$ | $\begin{gathered} 7 \\ \mathbf{N} \end{gathered}$ | $\begin{aligned} & 8 \\ & 0 \end{aligned}$ | $\begin{aligned} & 9 \\ & \mathrm{~F} \end{aligned}$ | 10 Ne | 2s2p |
| 3 | $\begin{array}{\|c\|} \hline 11 \\ \mathrm{Na} \\ \hline \end{array}$ | $\begin{gathered} 12 \\ \mathrm{Mg} \end{gathered}$ | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | $\begin{aligned} & 13 \\ & \text { Al } \\ & \hline \end{aligned}$ | $\begin{aligned} & 14 \\ & \mathrm{Si} \end{aligned}$ | $\begin{gathered} 15 \\ \mathbf{P} \end{gathered}$ | $\begin{gathered} 16 \\ S \\ \hline \end{gathered}$ | $\begin{aligned} & 17 \\ & \mathrm{Cl} \end{aligned}$ | $\begin{gathered} \mathbf{1 8} \\ \mathbf{A r} \\ \hline \end{gathered}$ | 3s3p |
| 4 | $\begin{gathered} 19 \\ \text { K } \end{gathered}$ | $\begin{aligned} & 20 \\ & \mathrm{Ca} \end{aligned}$ | $\begin{aligned} & 21 \\ & \mathrm{Sc} \end{aligned}$ | $\begin{aligned} & 22 \\ & \mathrm{Ti} \end{aligned}$ | $\begin{gathered} 23 \\ V \end{gathered}$ | $\begin{aligned} & 24 \\ & \mathrm{Cr} \end{aligned}$ | $\begin{gathered} 25 \\ \mathrm{Mn} \end{gathered}$ | $\begin{aligned} & 26 \\ & \mathrm{Fe} \end{aligned}$ | $\begin{aligned} & 27 \\ & \mathrm{Co} \end{aligned}$ | $\begin{aligned} & \mathbf{2 8} \\ & \mathbf{N i} \end{aligned}$ | $\begin{array}{\|l\|} \hline 29 \\ \mathrm{Cu} \\ \hline \end{array}$ | $\begin{aligned} & \mathbf{3 0} \\ & \mathbf{Z n} \end{aligned}$ | $\begin{aligned} & 31 \\ & \text { Ga } \end{aligned}$ | $\begin{aligned} & 32 \\ & \text { Ge } \end{aligned}$ | $\begin{aligned} & 33 \\ & \text { As } \end{aligned}$ | $\begin{aligned} & 34 \\ & \mathrm{Se} \end{aligned}$ | $\begin{array}{\|l\|} \hline 35 \\ \mathrm{Br} \end{array}$ | $\begin{aligned} & 36 \\ & \mathrm{Kr} \end{aligned}$ | 4s3d4p |
| 5 | $\begin{array}{\|l\|} \hline \mathbf{3 7} \\ \mathbf{R b} \\ \hline \end{array}$ | $\begin{aligned} & 38 \\ & \mathrm{Sr} \end{aligned}$ | $\begin{aligned} & 39 \\ & \mathbf{Y} \\ & \hline \end{aligned}$ | $\begin{array}{\|l\|} \hline \mathbf{4 0} \\ \mathbf{Z r} \\ \hline \end{array}$ | $\begin{aligned} & 41 \\ & \mathrm{Nb} \end{aligned}$ | $\begin{gathered} \hline 42 \\ \mathrm{Mo} \\ \hline \end{gathered}$ | $\begin{aligned} & 43 \\ & \mathrm{Tc} \end{aligned}$ | $\begin{aligned} & \mathbf{4 4} \\ & \mathrm{Ru} \end{aligned}$ | $\begin{aligned} & 45 \\ & \mathrm{Rh} \\ & \hline \end{aligned}$ | $\begin{array}{\|l\|} \hline 46 \\ \text { Pd } \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline 47 \\ \mathrm{Ag} \\ \hline \end{array}$ | $\begin{array}{\|l\|} \hline 48 \\ \mathrm{Cd} \\ \hline \end{array}$ | $\begin{aligned} & 49 \\ & \text { In } \end{aligned}$ | $\begin{aligned} & 50 \\ & \text { Sn } \end{aligned}$ | $\begin{array}{\|l\|} \hline 51 \\ \text { Sb } \end{array}$ | $\begin{array}{\|l\|} \hline 52 \\ \mathrm{Te} \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline 53 \\ \text { I } \end{array}$ | $\begin{aligned} & 54 \\ & \mathrm{Xe} \\ & \hline \end{aligned}$ | 5s4d5p |
| 6 | $\begin{array}{\|l\|} \hline 55 \\ \mathrm{Cs} \\ \hline \end{array}$ | $\begin{aligned} & 56 \\ & \mathrm{Ba} \end{aligned}$ | 57- | $\begin{aligned} & 72 \\ & \mathbf{H f} \end{aligned}$ | $\begin{gathered} 73 \\ \mathrm{Ta} \\ \hline \end{gathered}$ | $\begin{aligned} & 74 \\ & \mathbf{W} \\ & \hline \end{aligned}$ | $\begin{aligned} & 75 \\ & \operatorname{Re} \\ & \hline \end{aligned}$ | $\begin{aligned} & 76 \\ & \text { Os } \\ & \hline \end{aligned}$ | $\begin{aligned} & 77 \\ & \mathbf{I r} \\ & \hline \end{aligned}$ | $\begin{aligned} & 78 \\ & \text { Pt } \\ & \hline \end{aligned}$ | $\begin{array}{\|c\|} 79 \\ \mathbf{A u} \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline 80 \\ \mathrm{Hg} \\ \hline \end{array}$ | $\begin{aligned} & 81 \\ & \text { Tl } \end{aligned}$ | $\begin{aligned} & 82 \\ & \mathrm{~Pb} \\ & \hline \end{aligned}$ | $\begin{aligned} & 83 \\ & \mathbf{B i} \\ & \hline \end{aligned}$ | $\begin{aligned} & 84 \\ & \mathrm{Po} \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathbf{8 5} \\ & \text { At } \end{aligned}$ | $\begin{aligned} & 86 \\ & \mathbf{R n} \\ & \hline \end{aligned}$ | 6s5d6p |
| 7 | $\begin{array}{\|l\|} \hline \mathbf{8 7} \\ \mathrm{Fr} \\ \hline \end{array}$ | $\begin{array}{\|l\|} \hline \mathbf{8 8} \\ \text { Ra } \\ \hline \end{array}$ | 89- | $\begin{gathered} 104 \\ \text { Rf } \\ \hline \end{gathered}$ | $\begin{aligned} & 105 \\ & \mathrm{Db} \end{aligned}$ | $\begin{gathered} 106 \\ \mathrm{Sg} \\ \hline \end{gathered}$ | $\begin{gathered} 107 \\ \text { Bh } \end{gathered}$ | $\begin{gathered} 108 \\ \mathrm{Hs} \\ \hline \end{gathered}$ | $\begin{aligned} & 109 \\ & \mathrm{Mt} \end{aligned}$ | $\begin{gathered} 110 \\ \text { Ds } \end{gathered}$ | $\begin{aligned} & 111 \\ & \mathrm{Rg} \\ & \hline \end{aligned}$ | $\begin{aligned} & 112 \\ & \mathrm{Cn} \\ & \hline \end{aligned}$ | 113 | 114 | 115 | 116 | 117 | 118 | 7s6d7p |
| 8 | 119 | 120 | 121- | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 139 | 140 | 169 | 170 | 171 | 172 | 8s7d8p |
| 9 | 165 | 166 |  |  |  |  |  |  |  |  |  |  | 167 | 168 |  |  |  |  | 9s9p |


| 6 | $\begin{array}{\|l\|} \hline 57 \\ \mathrm{La} \end{array}$ | $\begin{aligned} & 58 \\ & \text { Ce } \end{aligned}$ | $\begin{aligned} & \mathbf{5 9} \\ & \mathrm{Pr} \end{aligned}$ | $\begin{array}{\|c\|} \hline 60 \\ \mathrm{Nd} \end{array}$ | $\begin{array}{\|c\|} \hline 61 \\ \mathrm{Pm} \end{array}$ | $\begin{array}{\|c\|} \hline 62 \\ \mathrm{Sm} \end{array}$ | $\begin{array}{\|c\|} \hline 63 \\ \mathrm{Eu} \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline 64 \\ \text { Gd } \end{array}$ | $\begin{gathered} 65 \\ \mathrm{~Tb} \end{gathered}$ | $\begin{aligned} & 66 \\ & \text { Dy } \end{aligned}$ | $\begin{gathered} 67 \\ \text { Ho } \end{gathered}$ | $\begin{aligned} & 68 \\ & \mathrm{Er} \end{aligned}$ | $\begin{gathered} 69 \\ \mathrm{Tm} \end{gathered}$ | $\begin{array}{\|c\|} \hline 70 \\ \mathbf{Y b} \\ \hline \end{array}$ | 71 <br> $\mathbf{L u}$ |  | 4f |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 7 | $\begin{array}{\|l\|} \hline 89 \\ \text { Ac } \\ \hline \end{array}$ | $\begin{array}{\|c\|} \hline 90 \\ \text { Th } \\ \hline \end{array}$ | $\begin{aligned} & \mathbf{9 1} \\ & \mathbf{P a} \end{aligned}$ | $\begin{gathered} \hline 92 \\ \mathrm{U} \end{gathered}$ | 93 Np | 94 Pu | 95 Am | $\begin{array}{c\|} \hline 96 \\ \mathrm{Cm} \\ \hline \end{array}$ | 97 Bk | $\begin{aligned} & 98 \\ & \mathrm{Cf} \end{aligned}$ | $\begin{aligned} & 99 \\ & \text { Es } \end{aligned}$ | $\begin{aligned} & 100 \\ & \mathrm{Fm} \end{aligned}$ | $\begin{aligned} & 101 \\ & \mathrm{Md} \end{aligned}$ | $\begin{aligned} & 102 \\ & \text { No } \end{aligned}$ | $\begin{array}{\|c\|} \hline 103 \\ \mathrm{Lr} \\ \hline \end{array}$ |  | 5 f |  |
| 8 | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 |  | $6 f$ |  |
| 8 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 | 138 |

## FRICKE, GREINER, WABER, TCA 21 (1971) 235.



## FROM 6d TO 5f: DARMSTADT GSI PT




## WHAT WAS ACTUALLY DONE?

- P. Pyykkö: "A suggested Periodic Table up to $Z \leq 172$, based on Dirac-Fock calculations on atoms and ions",
Phys. Chem. Chem. Phys. 13 (2011) 161-168.
- Average-of-configuration Dirac-Fock calculations on atoms and ions. [No Breit, no QED. The new Desclaux-Indelicato code.] The last valence electron determines the character of an element.
Example: In Group 7, (E125) ${ }^{6+}$ is $5 \mathrm{~g}^{1}$. (E124) ${ }^{5+}$ still $6 f^{1}$. $(\mathrm{E} 136)^{6+}$ is $5 \mathrm{~g}^{12}$. Then $8 \mathrm{~s}, 8 \mathrm{p}_{1 / 2}$ compete.
- Indeed, (E125) $\mathrm{F}_{6}$ is calculated to be $5 \mathrm{~g}^{1}$.
M. A. Makhyoun, J. Chim. Phys. 85 (1988) 917. (QR MS Xa)
- Compare with $\mathrm{NpF}_{6}$ which is $5 \mathrm{f}^{1}$.
- Note that the earlier members of the nominal 5 g series can have other occupations, especially as more neutral atoms.
- Essential conclusion for $Z=119-172$ (overlaps may occur):

$$
8 \mathrm{~s}<5 \mathrm{~g} \leq 8 \mathrm{p}_{1 / 2}<6 \mathrm{f}<7 \mathrm{~d}<9 \mathrm{~s}<9 \mathrm{p}_{3 / 2}<8 \mathrm{p}_{3 / 2} .
$$

## LATER MCDF COMPARISON

- P. Indelicato, J. Bieroń, P. Jönsson, "Are MCDF calculations 101\% correct in the super-heavy elements range?
Theor. Chem. Acc. 129 (2011) 495-505.
- Yes, QED effects on the IP are of the order of $1 \%$ of the Dirac-level relativistic effects, up to $Z=173$.
- MCDF on E140: At 'Average Level (AL)', confirm the $8 s^{2} 8 p^{2} 7 d 6 f^{3} 5 g^{14}$ configuration of V.I. Nefedov, M.B. Trzhaskovskaya and V. G.
Yarzhemskiii, Doklady Phys. Chem. 408 (2006) 149.
- At 'Optimal Level (OL)': The lowest practical level $8 s^{2} 8 p^{4} 6 f 5 g^{15}, \mathrm{~J}=8$.
- The filled-shell $J=0, \quad 8 s^{2} 8 p^{2} 5 g^{18}$ is reached at (E143) ${ }^{3+}$.
- For E140-E142 ${ }^{2+}$, mix 8p-6f-5g .
- Essential conclusion for $Z=119-172$ (overlaps may occur):

$$
8 \mathrm{~s}<5 \mathrm{~g} \leq 8 \mathrm{p}_{1 / 2}<6 \mathrm{f}<7 \mathrm{~d}<9 \mathrm{~s}<9 \mathrm{p}_{3 / 2}<8 \mathrm{p}_{3 / 2}
$$

## THE SEVEN PREVIOUS PERIODS

## Aufbau Principle, $Z=1-118$



## The Dirac-Coulomb-Breit Hamiltonian: A 'Theory of everything'

$$
\begin{equation*}
H=\sum_{i} h_{i}+\sum_{i<j} h_{i j} \tag{1}
\end{equation*}
$$

The one-particle Hamiltonian

$$
\begin{equation*}
h_{\mathrm{D}}=c \alpha \cdot \mathbf{p}+\beta c^{2}+V_{n}, \quad \mathbf{p}=-i \nabla, \tag{2}
\end{equation*}
$$

The two-particle Hamiltonian

$$
\begin{gather*}
h_{i j}=1 / r_{i j}+h_{\mathrm{B}},  \tag{3}\\
h_{\mathrm{B}}=-\frac{1}{2 r_{i j}}\left[\alpha_{i} \cdot \alpha_{j}+\left(\alpha_{i} \cdot \mathbf{r}_{i j}\right)\left(\alpha_{j} \cdot \mathbf{r}_{i j}\right) / r_{i j}^{2}\right] . \tag{4}
\end{gather*}
$$

In correlated calculations, add electron-like projection operators, $P$ :

$$
\begin{equation*}
h_{i j}^{e f f}=P h_{i j} P . \tag{5}
\end{equation*}
$$

In Coulomb gauge the next term is the Araki-Sucher one, H. Araki, Progr. Theor. Phys. 17 (1957) 619. See I. lindgren, IJQC 106 (2006) 2833.

## The spectrum of the Dirac eqn.



For a point nucleus, the 1 s solution disappears at $Z=137.036$.
For a finite nucleus, that happens around $Z=172$.

1) THE NODELESS 5 g SHELL IS VERY COMPACT . 2) THE 7p SHELL IS A PERSISTENT OUTER-CORE ORBITAL

P. Pyykkö, PCCP 13 (2011) 161-168.

## HOW ABOUT OXIDATION STATES? USE THE 5d AND 5f ELEMENTS FOR COMPARISON


P. Pyykkö, PCCP 13 (2011) 161-168.

## HOW ABOUT OXIDATION STATES/2 ?

USE THE 5d AND 5f ELEMENTS FOR COMPARISON

P. Pyykkö, PCCP 13 (2011) 161-168.

## POSSIBLE NEW MOLECULES

| Class | Molecule | Analogs |
| :--- | :--- | :--- |
| $8 s^{0} 5 g^{1}$ | $(E 125) \mathrm{X}_{6}$ |  |
| $8 s^{2} 5 g^{18}$ | $(\mathrm{E} 142) \mathrm{X}_{4}$ | $\mathrm{ThF}_{4}$ |
|  | $(\mathrm{E} 146) \mathrm{X}_{6}$ | $\mathrm{UF}_{6}$ |
| $8 s^{0} 5 g^{18}$ | $(\mathrm{E} 144) \mathrm{X}_{8}$ | $\mathrm{PuF}_{8}$ |
|  | $(\mathrm{E} 144) \mathrm{O}_{4}$ | $\mathrm{PuO}_{4}$ |
|  | $(\mathrm{E} 148) \mathrm{O}_{6}$ | $\mathrm{UO}_{6}$ |
| $8 s^{2} 7 d^{0} 6 f^{14} 5 g^{18}$ | $(\mathrm{E} 158) \mathrm{X}_{6}$ | $\mathrm{WF}_{6}$ |
| $7 \mathrm{~d}^{8}$ | $(\mathrm{E} 164) \mathrm{X}_{4}$ | $\mathrm{HgF}_{4}$ |

# SIMPLEST PREDICTIONS FOR CHEMICAL BONDING: Molecular, self-consistent covalent radii 

$$
\mathrm{R}(\mathrm{AB})=\mathrm{r}_{\mathrm{A}}+\mathrm{r}_{\mathrm{B}} .
$$

# SINGLE-, DOUBLE- AND TRIPLE-BOND COVALENT RADII UP TO Z = 118. Mean deviation 3 pm. P. Pyykkö, M. Atsumi, CEJ 15 (2009) 12770. 

Self-Consistent, Year-2009 Covalent Radii
$r / \mathrm{pm}\left(=10^{-12} \mathrm{~m}\right)$

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | $\begin{gathered} 2 \mathrm{He} \\ \mathbf{4 6} \\ - \end{gathered}$ |
| $3 \quad \mathrm{Li}$ <br> 133 <br> 124 <br> - | $\begin{array}{cc} 4 \quad \mathrm{Be} \\ 102 \\ 90 \\ 85 \end{array}$ |  |  |  |  | Rad | $\text { us, } \mathrm{r}_{n} \text { : }$ | Symbol |  |  |  | 5 B <br> 85 <br> 78 <br> 73 |  | $7 \quad \mathrm{~N}$ 71 60 54 | 8 O 63 57 53 | $9 \quad \mathrm{~F}$ 64 59 53 | $\begin{gathered} 10 \mathrm{Ne} \\ \mathbf{6 7} \\ \mathbf{9 6} \end{gathered}$ |
| $\begin{gathered} \hline 11 \mathrm{Na} \\ 155 \\ 160 \end{gathered}$ | $\begin{gathered} 12 \mathrm{Mg} \\ 139 \\ 132 \\ 127 \\ \hline \end{gathered}$ |  |  |  |  |  |  |  |  |  |  | 13 Al 126 113 111 | $14 \quad \mathrm{Si}$ 116 107 102 | 15 P 111 102 94 | 16 S 103 94 95 | 17 Cl 99 95 93 | $\begin{array}{\|c} \hline 18 \mathrm{Ar} \\ 96 \\ 107 \\ 96 \end{array}$ |
| $\begin{gathered} 19 \mathrm{~K} \\ 196 \\ 193 \end{gathered}$ | $\begin{gathered} 20 \mathrm{Ca} \\ 171 \\ 147 \\ 133 \end{gathered}$ | 21 Sc 148 116 114 | 22 Ti 136 117 108 | 23 V <br> 134 <br> 112 <br> 106 | 24 Cr <br> 122 <br> 111 <br> 103 | 25 Mn <br> 119 <br> 105 <br> 103 | 26 Fe <br> 116 <br> 109 <br> 102 | 27 Co <br> 111 <br> 103 <br> 96 | 28 Ni 110 101 101 | 29 Cu 112 115 120 | $\begin{array}{\|c} 30 \mathrm{Zn} \\ 118 \\ 120 \end{array}$ | $\begin{gathered} 31 \mathrm{Ga} \\ 124 \\ 117 \\ 121 \\ \hline \end{gathered}$ | 32 Ge <br> 121 <br> 111 <br> 114 | 33 As 121 114 106 | 34 Se 116 107 107 | 35 Br 114 109 110 | $\begin{array}{\|c\|} \hline 36 \mathrm{Kr} \\ \mathbf{1 1 7} \\ \mathbf{1 2 1} \\ \mathbf{1 0 8} \\ \hline \end{array}$ |
| $\begin{gathered} \hline 37 \mathrm{Rb} \\ 210 \\ 202 \end{gathered}$ | $\begin{gathered} 38 \mathrm{Sr} \\ 185 \\ 157 \\ 139 \end{gathered}$ | 39 Y 163 130 124 | $40 \quad \mathrm{Zr}$ 154 127 121 | 41 Nb <br> 147 <br> 125 <br> 116 | 42 Mo 138 121 113 | 43 Tc <br> 128 <br> 120 <br> 110 | 44 Ru <br> 125 <br> 114 <br> 103 | 45 Rh 125 110 106 | 46 Pd 120 117 112 | 47 Ag 128 139 137 | $\begin{gathered} 48 \mathrm{Cd} \\ \mathbf{1 3 6} \\ \mathbf{1 4 4} \end{gathered}$ | 49 In <br> 142 <br> 136 <br> 146 | $50 \quad \mathrm{Sn}$ 140 130 132 | $51 \quad$ Sb 140 133 127 | 52 Te 136 128 121 | $\begin{gathered} 53 \quad \text { I } \\ 133 \\ 129 \\ 125 \end{gathered}$ | $\begin{gathered} 54 \mathrm{Xe} \\ 131 \\ 135 \\ 122 \end{gathered}$ |
| $\begin{gathered} \hline 55 \mathrm{Cs} \\ 232 \\ 209 \end{gathered}$ | $\begin{array}{\|c\|} \hline 56 \mathrm{Ba} \\ 196 \\ 161 \\ 149 \\ \hline \end{array}$ | $\mathrm{La}-\mathrm{Lu}$ | $\begin{gathered} 72 \mathrm{Hf} \\ 152 \\ 128 \\ 122 \\ \hline \end{gathered}$ | 73 Ta <br> 146 <br> 126 <br> 119 | 74 W <br> 137 <br> 120 <br> 115 | 75 Re <br> $\mathbf{1 3 1}$ <br> $\mathbf{1 1 9}$ <br> $\mathbf{1 1 0}$ | 76 Os 129 116 109 | $77 \quad$ Ir <br> 122 <br> 115 <br> 107 | $\begin{array}{\|c\|} \hline 78 \mathrm{Pt} \\ 123 \\ 112 \\ 110 \\ \hline \end{array}$ | $\begin{gathered} 79 \quad \mathrm{Au} \\ \mathbf{1 2 4} \\ 121 \\ 123 \\ \hline \end{gathered}$ | $\begin{gathered} 80 \mathrm{Hg} \\ \mathbf{1 3 3} \\ \mathbf{1 4 2} \end{gathered}$ | $\begin{gathered} 81 \mathrm{Tl} \\ \mathbf{1 4 4} \\ \mathbf{1 4 2} \\ \mathbf{1 5 0} \\ \hline \end{gathered}$ | 82 Pb <br> 144 <br> 135 <br> 137 <br> 1 | $83 \quad \mathrm{Bi}$ 151 141 135 | 84 Po 145 135 129 | $\begin{array}{\|c\|} \hline 85 \mathrm{At} \\ 147 \\ 138 \\ 138 \\ \hline \end{array}$ | $\begin{array}{\|c} \hline 86 \mathrm{Rn} \\ \mathbf{1 4 2} \\ \mathbf{1 4 5} \\ \mathbf{1 3 3} \\ \hline \end{array}$ |
| $\begin{array}{cc} \hline 87 \mathrm{Fr} \\ 223 \\ 218 \end{array}$ | $\begin{gathered} 88 \mathrm{Ra} \\ 201 \\ 173 \\ 159 \end{gathered}$ | $\mathrm{Ac}-\mathrm{Lr}$ | 104 Rf 157 140 131 | 105 Db <br> 149 <br> 136 <br> 126 | 106 Sg <br> 143 <br> 128 <br> 121 | 107 Bh 141 128 $\mathbf{1 1 9}$ | 108 Hs 134 125 118 | 109 Mt <br> 129 <br> 125 <br> 113 | $\begin{array}{\|c\|} \hline 110 \mathrm{Ds} \\ 128 \\ 116 \\ 112 \end{array}$ | $\begin{array}{\|c} \hline 111 \mathrm{Rg} \\ 121 \\ 116 \\ 118 \end{array}$ | $\begin{array}{\|l\|} \hline 112 \\ 122 \\ 137 \\ 130 \\ \hline \end{array}$ | $\begin{gathered} 113 \\ 136 \end{gathered}$ | $\begin{array}{\|c\|} \hline 114 \\ 143 \end{array}$ | $\begin{array}{\|l\|} \hline 115 \\ 162 \end{array}$ | $\begin{aligned} & 116 \\ & \mathbf{1 7 5} \end{aligned}$ | $\begin{array}{\|l\|} \hline 117 \\ 165 \end{array}$ | $\begin{array}{\|l\|} \hline 118 \\ 157 \end{array}$ |


| 57 La <br> $\mathbf{1 8 0}$ <br> $\mathbf{1 3 9}$ <br> $\mathbf{1 3 9}$ | $\begin{gathered} 58 \mathrm{Ce} \\ 163 \\ 137 \\ 131 \end{gathered}$ | $\begin{array}{\|cc} 59 \quad \mathrm{Pr} \\ 176 \\ 138 \\ 128 \end{array}$ | 60 Nd 174 137 | 61 Pm 173 135 | $\begin{array}{c\|} \hline 62 \mathrm{Sm} \\ \mathbf{1 7 2} \\ 134 \end{array}$ | $\begin{array}{\|cc} \hline 63 \mathrm{Eu} \\ \mathbf{1 6 8} \\ \mathbf{1 3 4} \end{array}$ | 64 Gd 169 135 132 | $\begin{array}{cc} 65 \mathrm{~Tb} \\ \mathbf{1 6 8} \\ 135 \end{array}$ | $\begin{array}{\|c} \hline 66 \mathrm{Dy} \\ 167 \\ 133 \end{array}$ | $\begin{gathered} \hline 67 \text { Ho } \\ 166 \\ 133 \end{gathered}$ | $\begin{array}{\|cc} \hline 68 \quad \mathrm{Er} \\ 165 \\ 133 \end{array}$ | $\begin{gathered} 69 \mathrm{Tm} \\ \mathbf{1 6 4} \\ \mathbf{1 3 1} \end{gathered}$ | $\begin{gathered} 70 \quad \mathrm{Yb} \\ \mathbf{1 7 0} \\ 129 \end{gathered}$ | 71 Lu 162 131 131 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 89 Ac | 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |
| 186 | 175 | 169 | 170 | 171 | 172 | 166 | 166 | 168 | 168 | 165 | 167 | 173 | 176 | 161 |
| 153 | 143 | 138 | 134 | 136 | 135 | 135 | 136 | 139 | 140 | 140 |  | 139 |  | 141 |
| 140 | 136 | 129 | 118 | 116 |  |  |  |  |  |  |  |  |  |  |

## MEAN-SQUARE DEVIATION ONLY 3 pm

 for both single-, double- and triple-bond radii, $r_{1}-r_{3}$

## THE COLLAPSE OF COVALENT RADII AT GROUP 10 ( $\downarrow$ SINGLE, $\square$ TRIPLE BONDS) .



## The Kumpula Campus, University of Helsinki, Finland

- Faculty of Science.
- Government labs:
- Meteorology
- Marine Research
- Including students, about 9000 people.
- Entire U of $\mathrm{H}: 38000$ students.
- 8 national CoE:s, including
'Finnish Centre of Excellence of


Computational Molecular Science'
(2006-2011). (CMS)

- CMS groups: Pyykkö-Sundholm, Halonen, Räsänen, Nordlund.

About 60 people.
Nordic 'umbrella' of CoE:s.

