cubic ellipsoid nucleus - atomic physics - part 1: the atomic radius

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Abstract

This research explains and calculates the atomic radius and combines it with the ellipsoid nuclear model [17].
According to the ellipsoid nuclear model, the nucleus consists of nuclear shells that correlate with the atomic shells (unlike the common nuclear shell model); based on this assumption we get the following results:

- The protons have no effect on the electrons beyond their correlated atomic shell.
- Moreover possibly the protons only affect the electrons that correlate with their shell.
- A physical theoretical atomic radius function was constructed to meet these requirements.
- The nuclear structure determines the atomic shape and the electronic shielding; this explains the variation of the atomic radius from the calculated value and links between the nuclear and atomic structure.

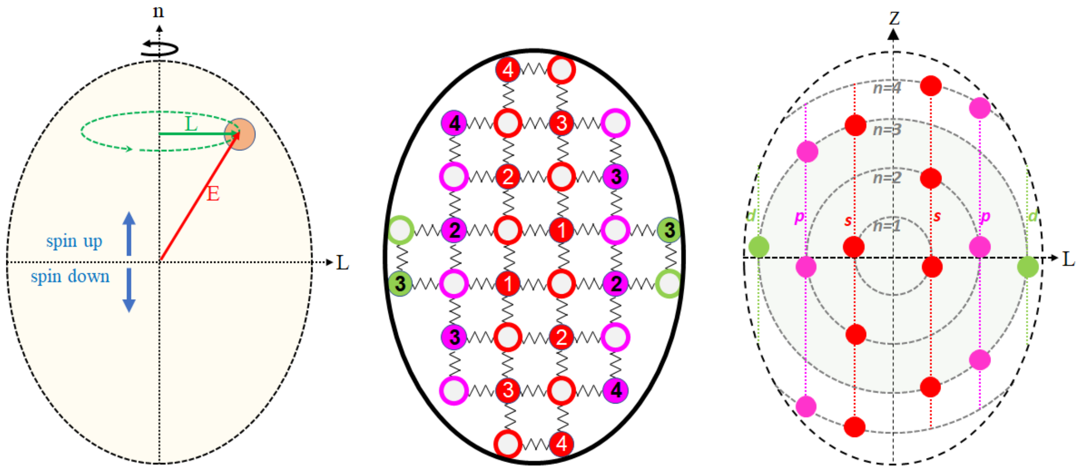
Content

The model at a glance

According to the model these are the shape and properties of the nucleus:

- the nucleus has an ellipsoid shape.
- the nucleon bonds build a cubic system.
- protons are connected to neutrons (**p-n**).
- neutrons are connected mainly to protons.
- the protons are populated and organized in shells in the nucleus in analogy to those of the electrons in the atom.
- the energy layers (principal quantum number **n**) grow with the distance from the origin.
- the perpendicular distance from the **z**-axis in the **x-y**-plane reflects the angular momentum (**L**, sub-orbitals).
- the upper half of the ellipsoid is referred to as spin-up and the lower part as spin-down.
- the nucleus possibly rotates around its **z**-axis.

The following drawings describe the idea via cross sections in the **x-z**-plane of the nucleus.

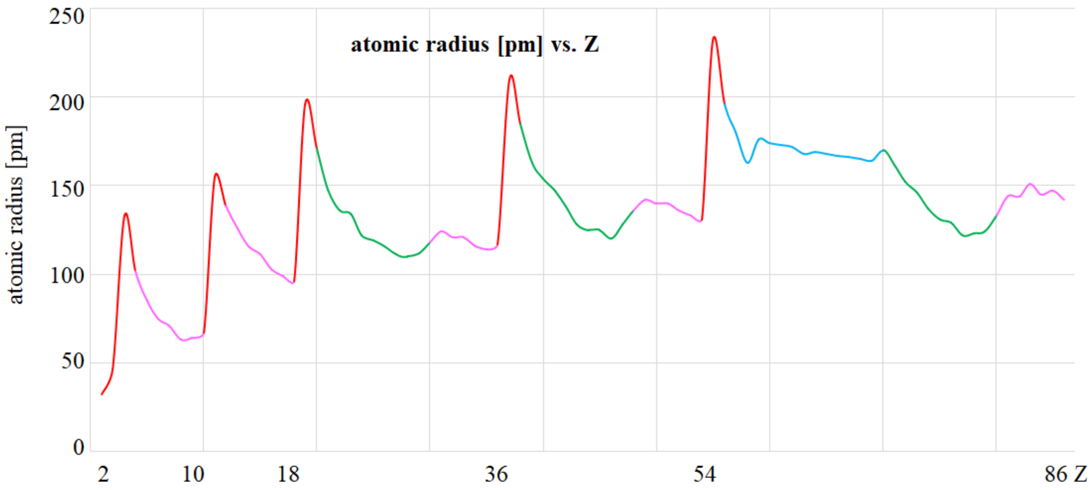


***1**: a nucleon in the nucleus* ***2**: the bonds between the nucleons* ***3**: the energy levels of the nucleus*

1. a nucleon (**circle**) is observed inside the ellipsoid (dashed line) that encloses the nucleons and schematically defines the nuclear surface:
   - the distance from the origin represents its energy **E**.
   - the distance from the **z**-axis depicts it angular momentum **L**.
   - the nucleons in the upper half have spin-up, and in the lower one spin-down.
2. the bonds between the nucleons are shown for visibility as springs.
   - **protons**: full circles of the **s**, **p** and **d** sub-orbitals. **neutrons**: hollow circles.
3. the circles of equal energy states **n** in the ellipsoid.
   - the lines mark the development of the **s**, **p** and **d** sub-orbitals along the **z**-axis.
   - the **s** line crosses all **n** circles from 1 to 4 (**s1** to **s4**).
   - the **p** line begins by **n**=2 and reaches till **n**=4 (**p2** to **p4**).
   - the **d** line begins by **n**=3 and reaches the ellipsoid border, before it reaches the **n**=4 circle, and therefore there are no **d4** states at this stage (only **d3**).

Introduction

The following graph shows the experimental data of the (covalent single bond) atomic radius as a function of the atomic number.



atomic radius vs. atomic number Z (Covalent single bond [2]); sub-orbitals: ***S***, ***P***, ***D***, ***F***

The atomic radius shows the following pattern:

- while moving from one row of the periodic table to the next one, the size of the atom grows.
- along a row of the periodic table the size of the atom shrinks.

In this research we try to explain and calculate these phenomena and connect it to the cubic ellipsoid nuclear model.

The research

Constructing the atomic radius function

We want to create a function for the atomic radius. The function should not only be adjusted mathematically, but of course also have a physical meaning.
The process we take is not precise, yet it seems to deliver results that are good enough for the assessment of the idea.
It is reminded here again that according to the model, the nuclear and atomic shells correspond to each other, and are as they appear in the periodic system.
Following definitions are used:

- Z: the atomic number of the atom observed.
- $k \in \{1, 2, 3, 4, 5, 6, 7\}$ the current nuclear (and atomic) shell.
- Z_{shell_k}: the number of protons (or electrons) currently in the shell, meaning:
- $Z_{shell_k} = Z - Z_{n.g_{k-1}}$.
- $Z_{n.g_{k-1}}$: the (noble gas) atomic number that closes the last row of the periodic table.
- r_{shell_k}: the atomic radius of the atom observed.

We estimate the force of the outermost nuclear shell on the outermost atomic shell.
Along a specific row (or shell) we suspect that the force that the nucleus acts on the electrons grows with the number of protons in the shell:
$F(Z) \sim Z_{shell_k}$
We also expect the following connection between the force and the radius:
$F \sim \frac{1}{r_{shell_k}^2}$ which leads to $r_{shell_k} \sim \frac{1}{\sqrt{F}}$ or $r_{shell_k} \sim \frac{1}{\sqrt{Z_{shell_k}}}$
and so $r_{shell_k} = \frac{a}{\sqrt{Z_{shell_k}}}$
We thus try first the following simplified atomic radius formula:

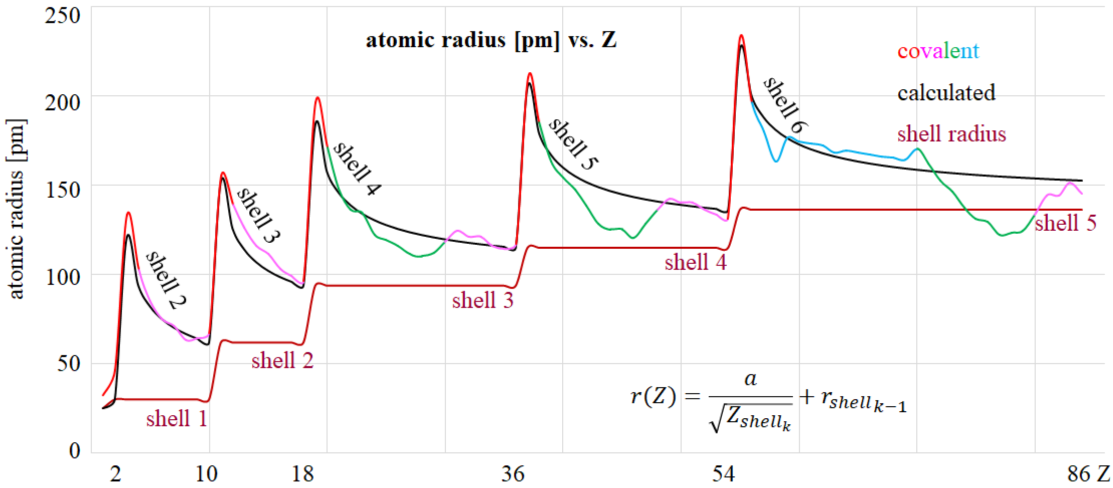
$$r(Z) = \frac{a}{\sqrt{Z_{shell_k}}} + r_{shell_{k-1}}$$

Remark: the function begins from the second row. for the first row we take the experimental data.
Testing the function produced the following values:

- $r_{shell_1} \approx 30\ pm$ this is taken from the experimental data.
- $a \approx 90\ pm$ this is gained via trials.

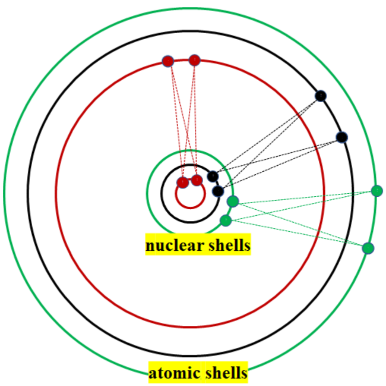
Analysis of the atomic radius function

The atomic radius function agrees well with the experiment. The variation seems to be mainly due to shielding effects, that are not taken directly into account in the function.
The shielding is discussed in detail in the appendix.



***graphs**: experimental data of the covalent radius (**S**, **P**, **D**, **F** sub-orbitals);*
calculated atomic radius; radius of the last full shell

According to the atomic radius function, protons appear to have no effect on electrons beyond their correlated atomic shell; surprisingly it seems that also below their shells they have no influence.
We get to the conclusion, that according to this simplified model at least, each atomic shell is influenced only by its correlated nuclear shell.
The following illustration depicts this idea.



each nuclear shell affects only its corresponding atomic shell

Discussion of the results and conclusions

The focus of this study is neither to define the precise atomic radius function, nor to find its exact parameters, but analyzing the mechanism that governs this process in the light of the cubic ellipsoid nuclear model.
Main statements of this research are:

- The atomic radius has the form $r \sim \frac{1}{\sqrt{Z_{shell}}}$ with:
  Z_{shell} the current number of protons (electrons) in the shell.
- The protons have no effect on the electrons beyond their correlated atomic shell.
- More precisely the protons possibly only affect the electrons that correlate with their shell.
- The nuclear structure determines the atomic shape and the amount of shielding that the field of the protons experiences; this explains the variation of the atomic radius from the calculated values and links between the nuclear and atomic structure.

These results seem to strengthen the ellipsoid nuclear model assumption that the shells of the nucleus and the atom correlate and that the structure of the nucleus determines the shape of the atom.
The model explains the growth of the atom while moving from one row of the periodic table to the next and the decreasing of the atomic radius along the shell itself.
In the appendix the graph of the atomic radius is discussed according to the atomic shells and orbitals.

Sources and references

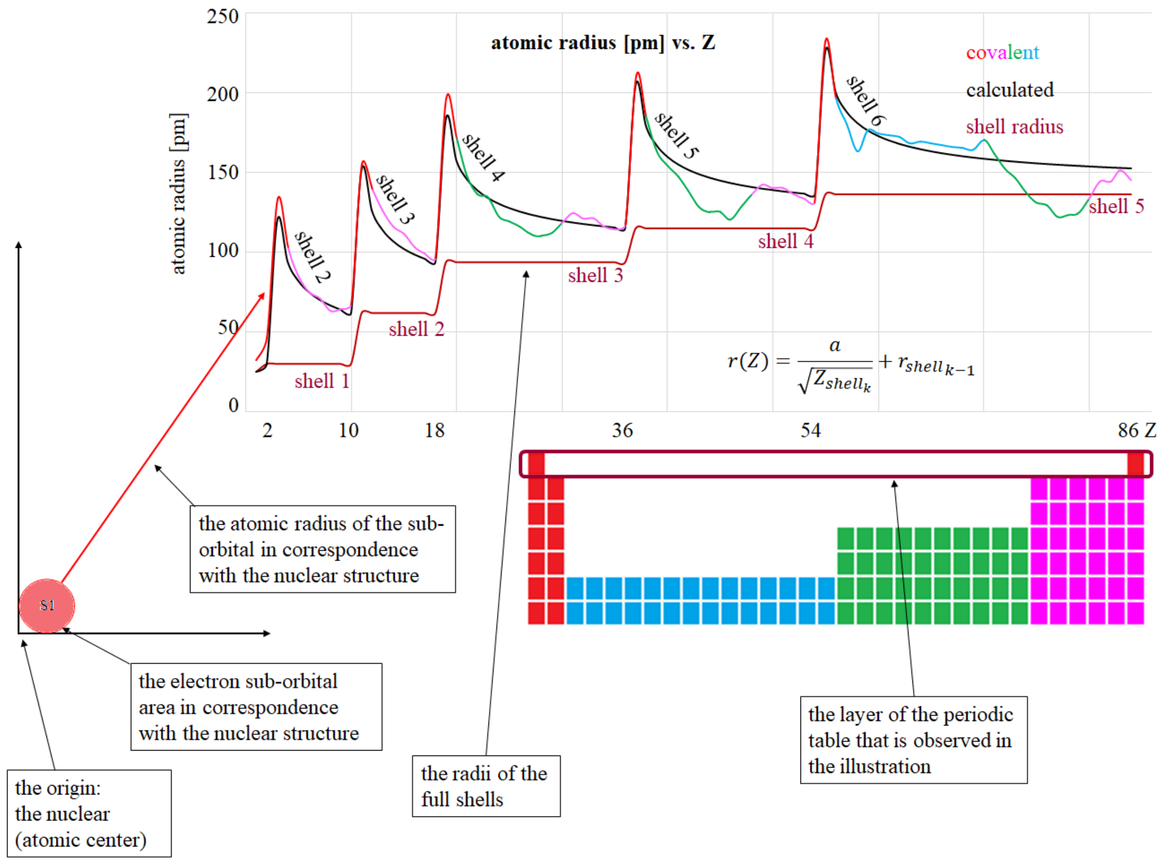
1. *Atomic radius* - Wikipedia
2. *Atomic radii of the elements (data page)* - Wikipedia
3. *Rydberg atom* - Wikipedia
4. *Hydrogen atom* - Wikipedia
5. *Ionization energy* - Wikipedia
6. *Ionization Energy in the Periodic Table of Elements* - PubChem
7. *Binding energy* - Wikipedia
8. *van der Waals radius* - Wikipedia
9. *Ionic radius* - Wikipedia
10. *Covalent radius* - Wikipedia
11. *Electron configuration* - Wikipedia
12. *d-block contraction* - Wikipedia
13. *Electronegativity* - Wikipedia
14. *Electron shell* - Wikipedia
15. *Schalenmodell (Atomphysik - German)* - Wikipedia
16. *Core electron* - Wikipedia
17. *cubic ellipsoid nucleus - part 1 - the model and its mass formula - Ronen Yavor*

Appendix

graphs

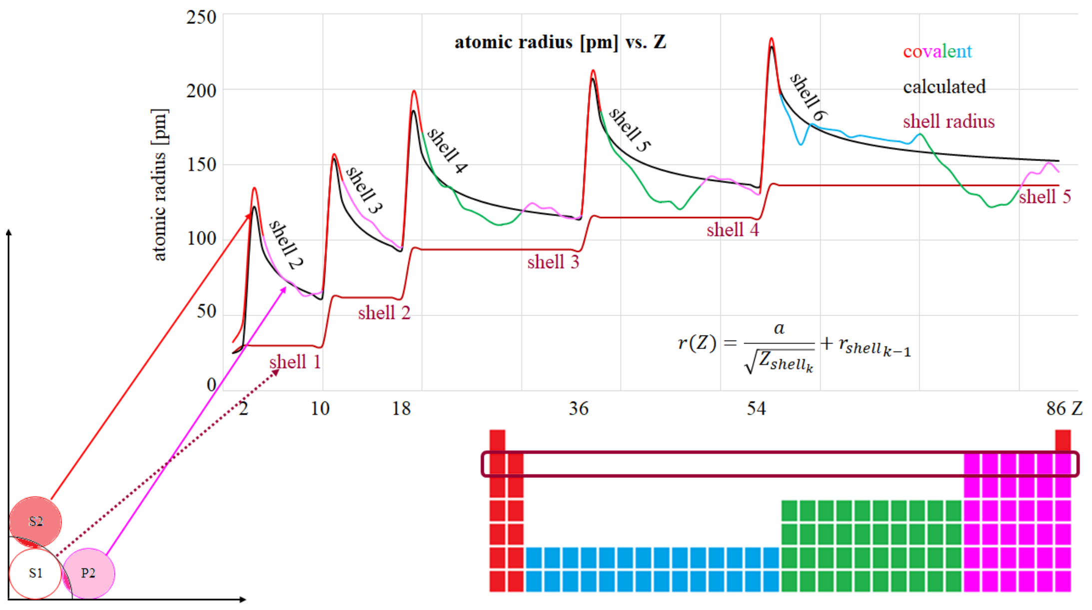
Atomic radius - row 1

Only the **S**-1 orbital is present and there is no shielding.
The radius values are taken from the experimental data.



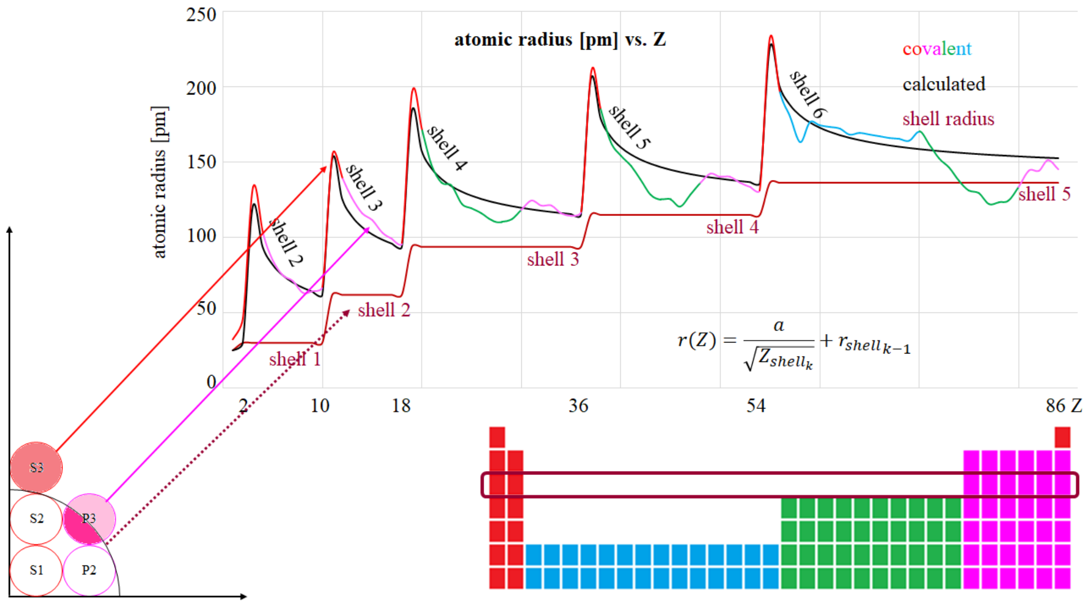
Atomic radius - row 2

The **S**-2 and P-2 orbitals are shielded almost equally by the **S**-1.
The radius values fit the experimental data.



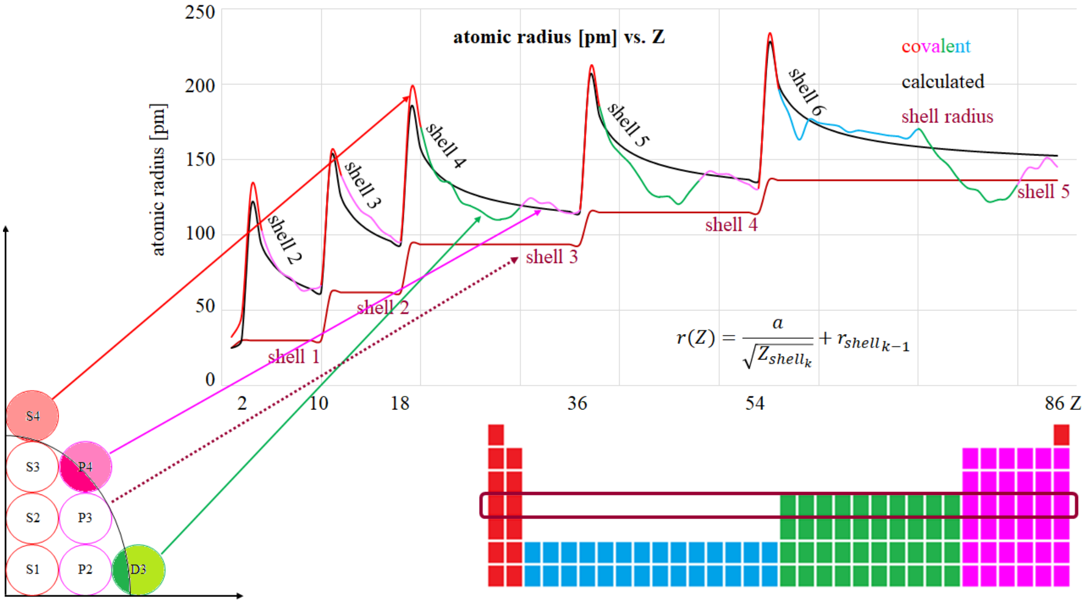
Atomic radius - row 3

The P-3 orbital is less shielded than the **S**-3 one so we might expect it to be deeper than it really is.
The explanation might be that the total shielding is quite low and that the difference between the two orbitals is low too.



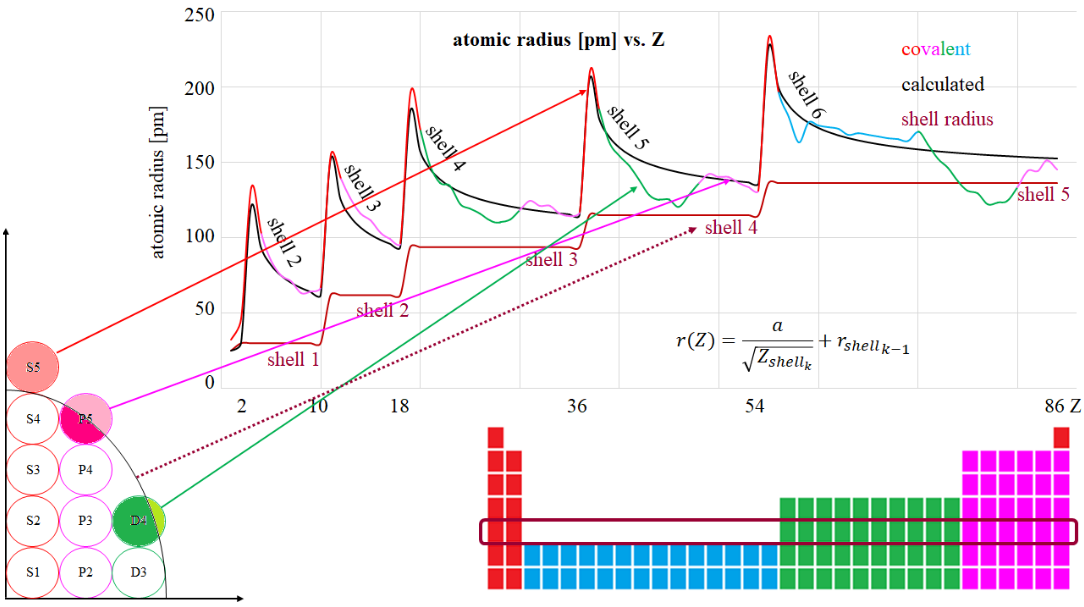
Atomic radius - row 4

The **D**-3 lies deeper, because it is less shielded than the **S**-4 and the P-4 orbitals.
The P-4 is less shielded than the **S**-4.



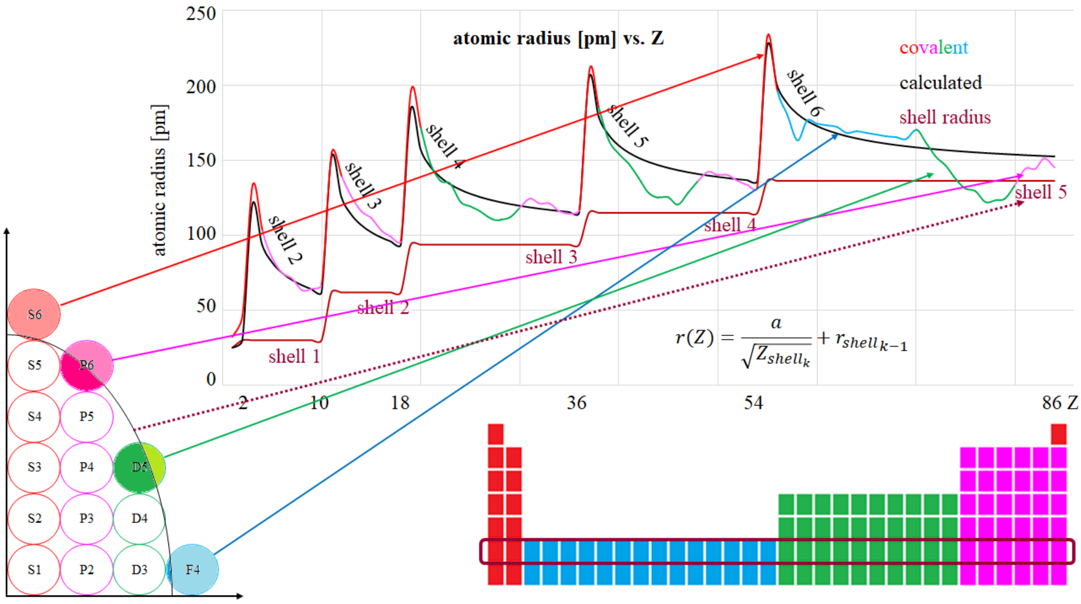
Atomic radius - row 5

The **D**-4 is deeper, as it is less shielded than the **S**-5 and the P-5 orbitals.
The P-5 is less shielded than the **S**-5.



Atomic radius - row 6

The **F**-4 orbital is shielded and so lies somewhat around the curve.
The **D**-5 lies deeper, because it is less shielded than the others.
This possibly explains the lanthanide contraction**.**
The P-6 is less shielded than the **S**-6.



data

the atomic radius function was defined as: $r(Z) = \frac{a}{\sqrt{Z_{shell_k}}} + r_{shell_{k-1}}$

with:

- Z: the atomic number of the atom observed.
- $k \in \{1, 2, 3, 4, 5, 6, 7\}$ the current nuclear (and atomic) shell.
- Z_{shell_k}: the number of protons (or electrons) currently in the shell, meaning:
- $Z_{shell_k} = Z - Z_{n.g_{k-1}}$.
- $Z_{n.g_{k-1}}$: the (noble gas) atomic number that closes the last row of the periodic table.
- r_{shell_k}: the atomic radius of the atom observed.

and the values:

- $r_{shell_1} = 30\ pm$
- $a_{row} \approx 90\ pm$

The covalent radius in the table was taken from [2].

symbol	Z	$Z_{n.g}$	Z_{shell}	sub orbital	shell radius	calc radius	cov. radius
H	1	0	1	s	25	25	32
He	2	2	2	s	30	30	46
Li	3	2	1	s	30	120	133
Be	4	2	2	s	30	94	102
B	5	2	3	p	30	82	85
C	6	2	4	p	30	75	75
N	7	2	5	p	30	70	71
O	8	2	6	p	30	67	63
F	9	2	7	p	30	64	64
Ne	10	10	8	p	30	62	67
Na	11	10	1	s	62	152	155
Mg	12	10	2	s	62	125	139
Al	13	10	3	p	62	114	126
Si	14	10	4	p	62	107	116
P	15	10	5	p	62	102	111
S	16	10	6	p	62	99	103
Cl	17	10	7	p	62	96	99
Ar	18	18	8	p	62	94	96
K	19	18	1	s	94	184	196
Ca	20	18	2	s	94	157	171
Sc	21	18	3	d	94	146	148
Ti	22	18	4	d	94	139	136
V	23	18	5	d	94	134	134
Cr	24	18	6	d	94	130	122
Mn	25	18	7	d	94	128	119
Fe	26	18	8	d	94	125	116
Co	27	18	9	d	94	124	111
Ni	28	18	10	d	94	122	110
Cu	29	18	11	d	94	121	112
Zn	30	18	12	d	94	120	118
Ga	31	18	13	p	94	119	124
Ge	32	18	14	p	94	118	121
As	33	18	15	p	94	117	121
Se	34	18	16	p	94	116	116
Br	35	18	17	p	94	115	114
Kr	36	36	18	p	94	115	117
Rb	37	36	1	s	115	205	210
Sr	38	36	2	s	115	178	185
Y	39	36	3	d	115	167	163
Zr	40	36	4	d	115	160	154
Nb	41	36	5	d	115	155	147
Mo	42	36	6	d	115	152	138
Tc	43	36	7	d	115	149	128
Ru	44	36	8	d	115	147	125
Rh	45	36	9	d	115	145	125
Pd	46	36	10	d	115	143	120
Ag	47	36	11	d	115	142	128
Cd	48	36	12	d	115	141	136
In	49	36	13	p	115	140	142

symbol	Z	$Z_{n.g}$	Z_{shell}	sub orbital	shell radius	calc radius	cov. radius
Sn	50	36	14	p	115	139	140
Sb	51	36	15	p	115	138	140
Te	52	36	16	p	115	137	136
I	53	36	17	p	115	137	133
Xe	54	54	18	p	115	136	131
Cs	55	54	1	s	136	226	232
Ba	56	54	2	s	136	200	196
La	57	54	3	f	136	188	180
Ce	58	54	4	f	136	181	163
Pr	59	54	5	f	136	176	176
Nd	60	54	6	f	136	173	174
Pm	61	54	7	f	136	170	173
Sm	62	54	8	f	136	168	172
Eu	63	54	9	f	136	166	168
Gd	64	54	10	f	136	165	169
Tb	65	54	11	f	136	163	168
Dy	66	54	12	f	136	162	167
Ho	67	54	13	f	136	161	166
Er	68	54	14	f	136	160	165
Tm	69	54	15	f	136	159	164
Yb	70	54	16	f	136	159	170
Lu	71	54	17	d	136	158	162
Hf	72	54	18	d	136	157	152
Ta	73	54	19	d	136	157	146
W	74	54	20	d	136	156	137
Re	75	54	21	d	136	156	131
Os	76	54	22	d	136	155	129
Ir	77	54	23	d	136	155	122
Pt	78	54	24	d	136	154	123
Au	79	54	25	d	136	154	124
Hg	80	54	26	d	136	154	133
Tl	81	54	27	p	136	153	144
Pb	82	54	28	p	136	153	144
Bi	83	54	29	p	136	153	151
Po	84	54	30	p	136	152	145
At	85	54	31	p	136	152	147
Rn	86	86	32	p	136	152	142