Periodic Table

- Lavoisier 1789 – 33(21) elements

Traité Élémentaire de Chimie (1789) the 1st modern chemistry textbook

- Dalton 1808 - 36 elements
- Berzelius 1813-14 - 47 elements
- Mendeleev 1869 - 63 elements
- The last element discovered in Nature 1939 – ^{223}Fr
- Nuclear synthesis of new elements since 1940
- 2012 - 118 elements, named up to 112

Periodic Table

1829, Johann Wolfgang Döbereiner (1780-1849)

Triades:

Li, Na, K

Ca, Sr, Ba

S, Se, Te

Cl, Br, I

Jena, Germany

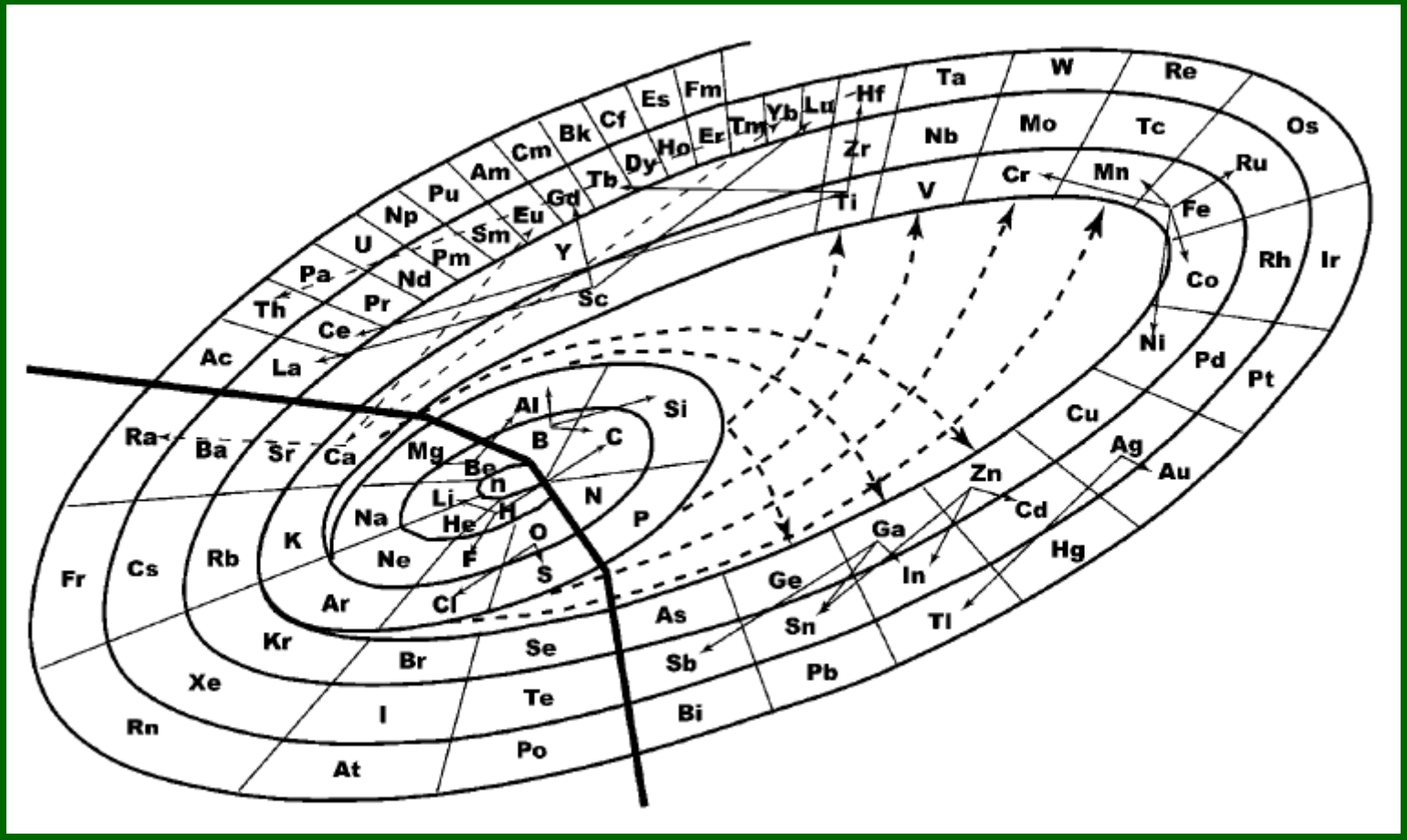
Periodic Table

1859, Jean-Baptiste Dumas (1800-1884)
Quadruplets: F, Cl, Br, I; Mg, Ca, Sr, Ba

1863, Alexandre-Émile Béguyer de Chancourtois (1820-1886)
Spiral

1864, William Odling (1829-1921)
Groups of seven elements

1864, John Alexander Reina Newlands (1837-1898)
Ordered elements according their atomic mass
Law of octaves


Fm
Es
Cf
Bk
Cm
Am
Pu
Np
U
Pa
Th
Ac
Ra
Fr
Cs
Rb
K
Ba
Sr
Ca
La
Ce
Pr
Nd
Pm
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Y
Sc
Mg
Na
Ne
Ar
Kr
Xe
Rn
Al
Si
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C
Be
n
Li
H
He
N
O
F
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Cl
Br
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At
Se
Te
Po
As
Sb
Bi
Ge
Sn
Pb
Ga
In
Tl
Zn
Cd
Hg
Cu
Ag
Au
Ni
Pd
Pt
Co
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Ir
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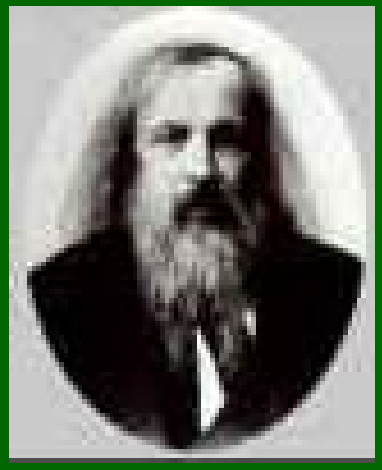
Nb
Ti
V

Periodic Table

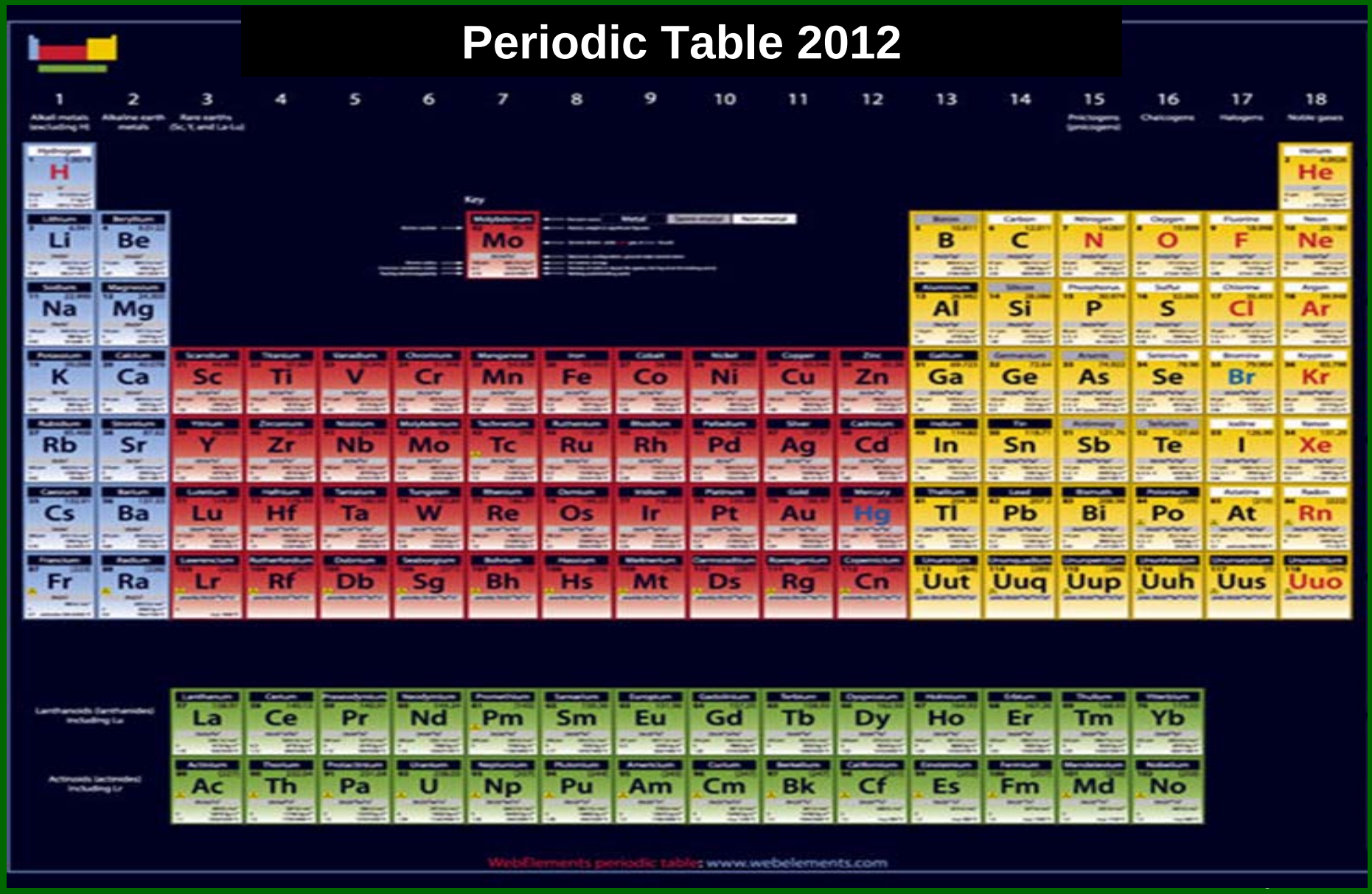


1870, Lothar Meyer (1830-1895)
Periodicity of atomic volumes

1869, 1871 Mendeleev – predicted properties of missing elements (Sc, Ga, Ge, Tc, Rh, Po, Hf), Rare gasses He, Ar
Properties of elements are a periodic function of atomic mass
(exceptions: Ar/K; Co/Ni; Te/I; Pa/Th)

1913 Moseley
Corrected the periodic law :
Properties of elements are a periodic function of atomic number

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18



Periodic Properties of Atoms

Atomic numbers - effective nuclear charges

Oxidation numbers

Atomic radii

Ionistaion energies

Electron affinity

Electronegativity

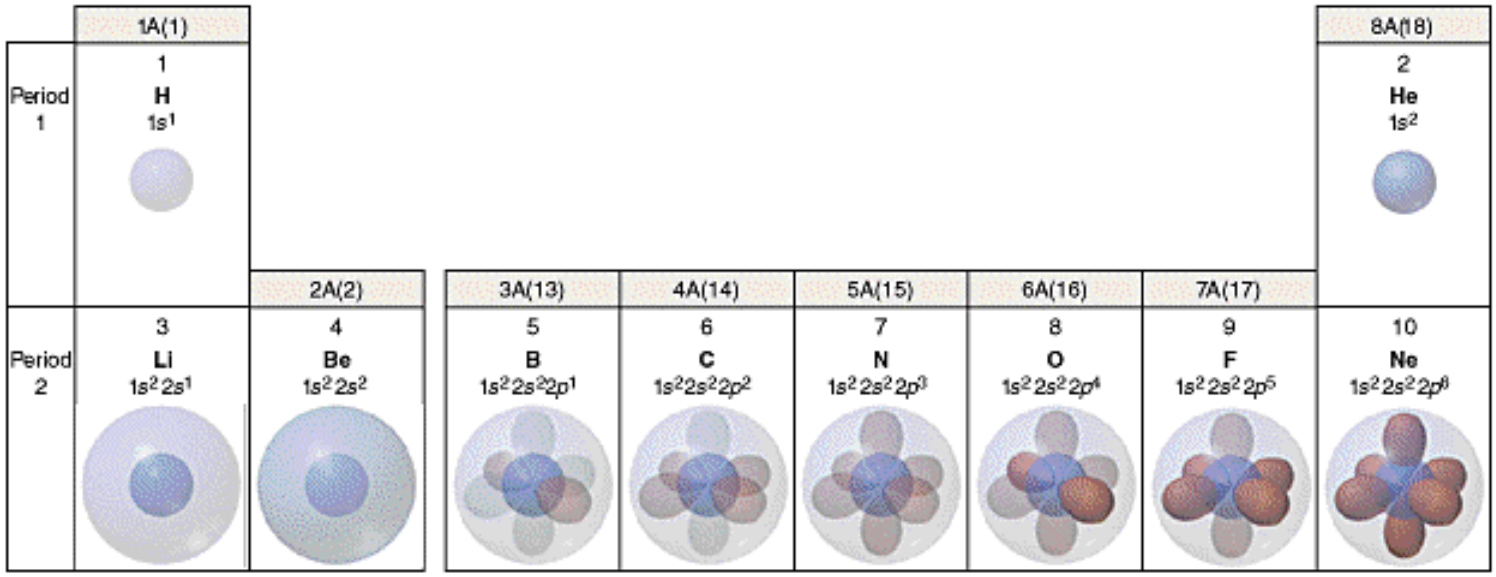
Polarizibility, polarization power

Metallic – Semimetallic – Nonmetallic Properties

Groups and Periods

Groups: repeating electron configuration governs similarity of chemical properties

Periods: stepwise filling of electron shells and nuclear charge increase govern changes in properties



Rules for Filling Orbitals with Electrons

The orbitals with lowest energy are filled first – Aufbau principle

Only two electrons fit into one orbital with opposite spin – Pauli's principle

Maximum number of unpaired electrons in energetically degenerate atomic orbitals – Hund's rule

Occupation of orbitals by electrons can change order of their energies

1																	18
1 **H** 1.0079	2											13	14	15	16	17	2 **He** 4.0026
3 **Li** 6.941	4 **Be** 9.0122											5 **B** 10.811	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.180
11 **Na** 22.990	12 **Mg** 24.305	3	4	5	6	7	8	9	10	11	12	13 **Al** 26.982	14 **Si** 28.086	15 **P** 30.974	16 **S** 32.065	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.098	20 **Ca** 40.078	21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.845	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.723	32 **Ge** 72.64	33 **As** 74.922	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.798
37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.96	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57-71 *	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89-103 #	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (270)	109 **Mt** (268)	110 **Ds** (281)	111 **Rg** (272)	112 **Uub** (285)	113 **Uut** (284)	114 **Uuq** (289)	115 **Uup** (288)	116 **Uuh** (291)		118 **Uuo** (294)

* Lanthanide series	57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
# Actinide series	89 **Ac** (227)	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Electronic Configurations of Main Group Elements

Main Group Elements = s- and p-elements

Fill s and p orbitals

$ns^2\ np^x$

Oxidation number changes by 2

CO CO_2

SO_2 SO_3 PCl_3 PCl_5

Alkali metals : ns^1
Alkaline earths : ns^2
Triels : $ns^2\ np^1$
Tetrels : $ns^2\ np^2$
Pniktogens : $ns^2\ np^3$
Chalkogens : $ns^2\ np^4$
Halogens : $ns^2\ np^5$
Rare gasses : $ns^2\ np^6$ very stable configuration

Main Group Compounds

Oxidation number changes by 2 result of $ns^2\ np^x$

Diamagnetic = no unpaired electrons
(except O_2)

Colorless

Electronic Configurations of Transition Elements

Transition elements = d-Elements

Fill (n–1)d and ns orbitals Oxidation number changes by 1

3d, 4d, 5d, 6d elements – 4^{th} to 7^{th} period $(n–1)d^x$

At least in one compound have incompletely filled d orbitals

Zn ($M^{2+} = d^{10}$) , Sc ($M^{3+} = d^{10}$), recently Sc^{1+}

Early transition elements – oxophilic, 3^{rd} – 7^{th} group, lack of d-electrons

Late transition elements – chalkophilic, 8^{th} – 12^{th} group, excess of d-electrons

Transition Element Compounds

Oxidation number changes by 1 result of $(n–1)d^x$

More oxidation states

Paramagnetic

Colored

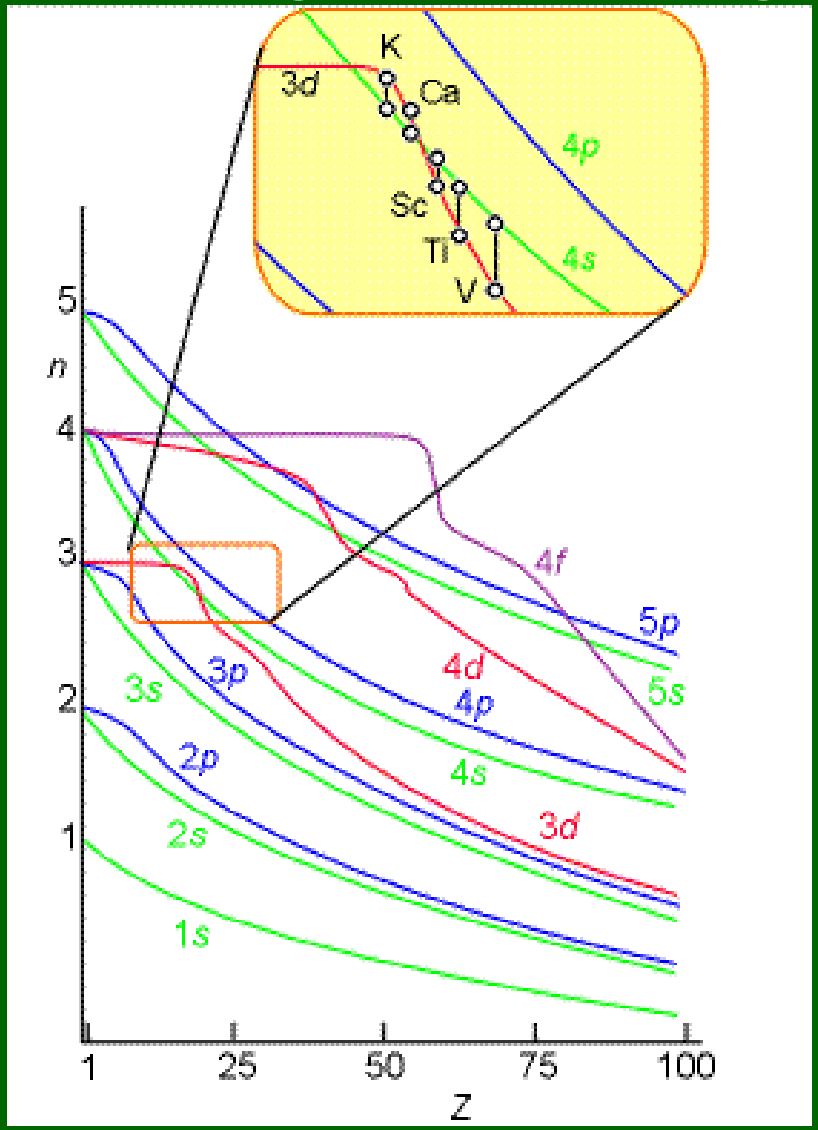
Characteristic Oxidation Numbers of 3d-Elements

1	2	3	4	5	6	7
Sc^{+}		Sc^{3+}				
		Ti^{3+}	Ti^{4+}			
	V^{2+}	V^{3+}	VO^{2+}	VO_2^{+}		
	Cr^{2+}	Cr^{3+}			CrO_4^{2-}	
	Mn^{2+}	Mn^{3+}	Mn^{4+}	MnO_4^{3-}	MnO_4^{2-}	MnO_4^{-}
	Fe^{2+}	Fe^{3+}			FeO_4^{2-}	
	Co^{2+}	Co^{3+}				
	Ni^{2+}					
Cu^{+}	Cu^{2+}					
	Zn^{2+}					

Change in Ordering of Energy Levels 4s/3d

Ar	[Ne] $3s^2$ $3p^6$ ($4s^0$)
K	[Ar] $4s^1$ ($3d^0$ $4p^0$)
Ca	[Ar] $4s^2$ ($3d^0$ $4p^0$)
Sc	[Ar] $3d^1$ $4s^2$ ($4p^0$)
Ti	[Ar] $3d^2$ $4s^2$ ($4p^0$)

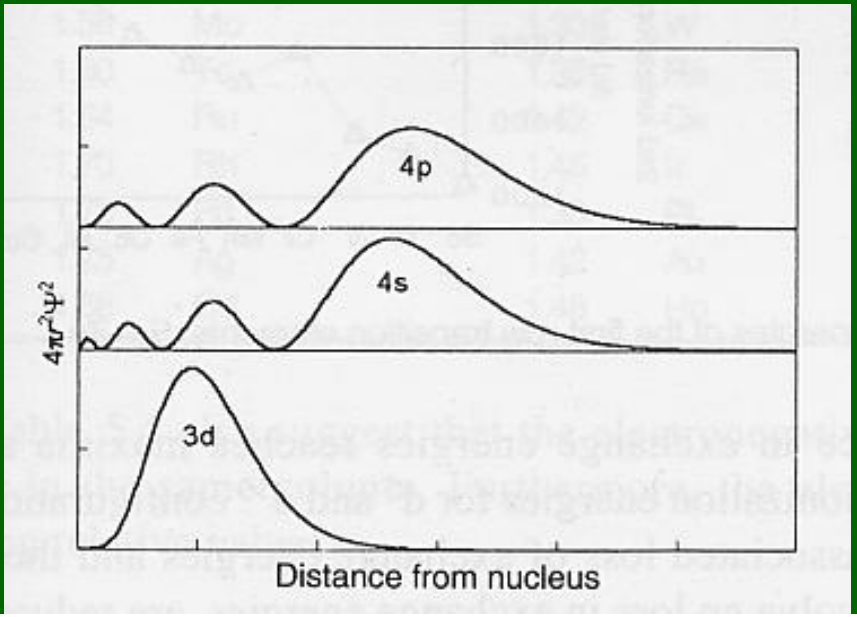
Change in Ordering of Energy Levels 4s/3d



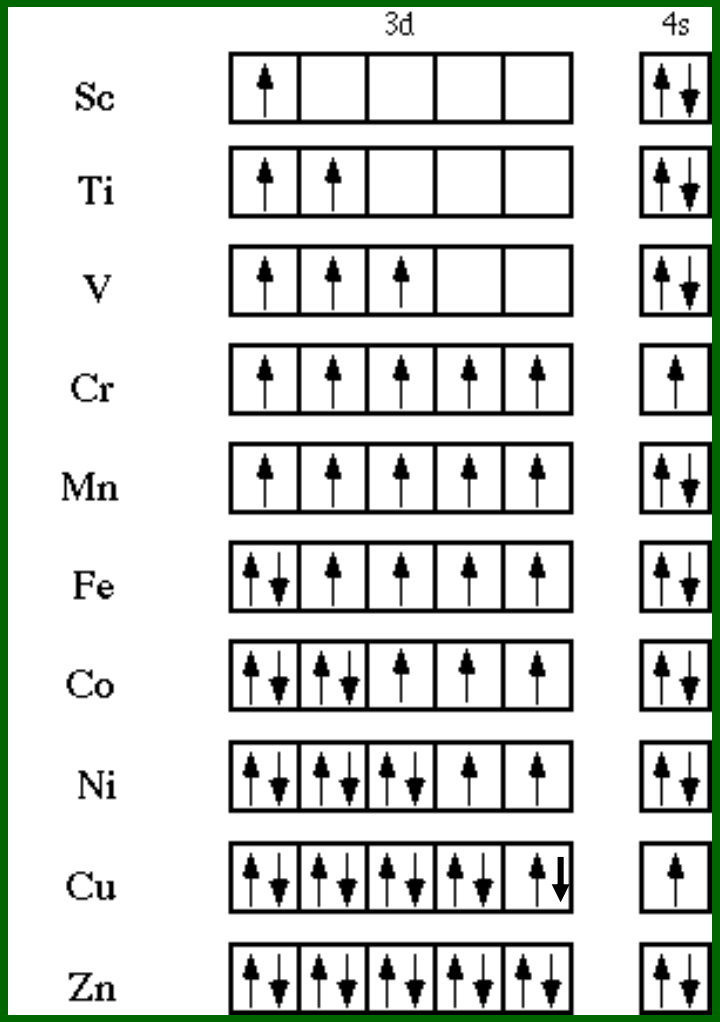
Experimental results

Increasing effective nuclear charge

Screenig of electrons



High Stability of Half-Filled Orbitals



Cr [Ar] $3d^5\ 4s^1\ (4p^0)$

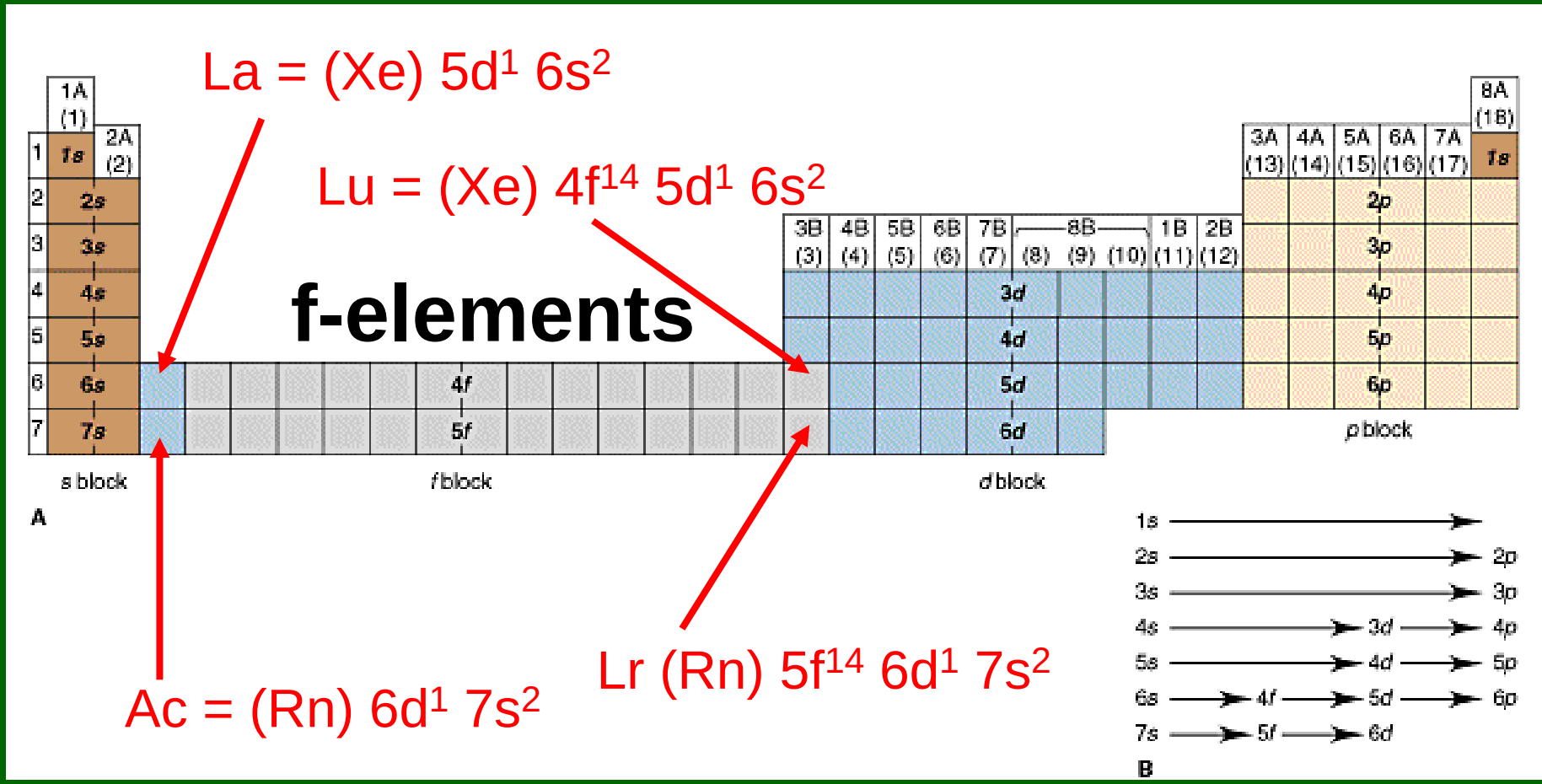
Cu [Ar] $3d^{10}\ 4s^1\ (4p^0)$

Electronic Configurations of Free and Bound Atoms

Ni [Ar] $3d^9\ 4s^1\ (4p^0)$ free atom in vacuum

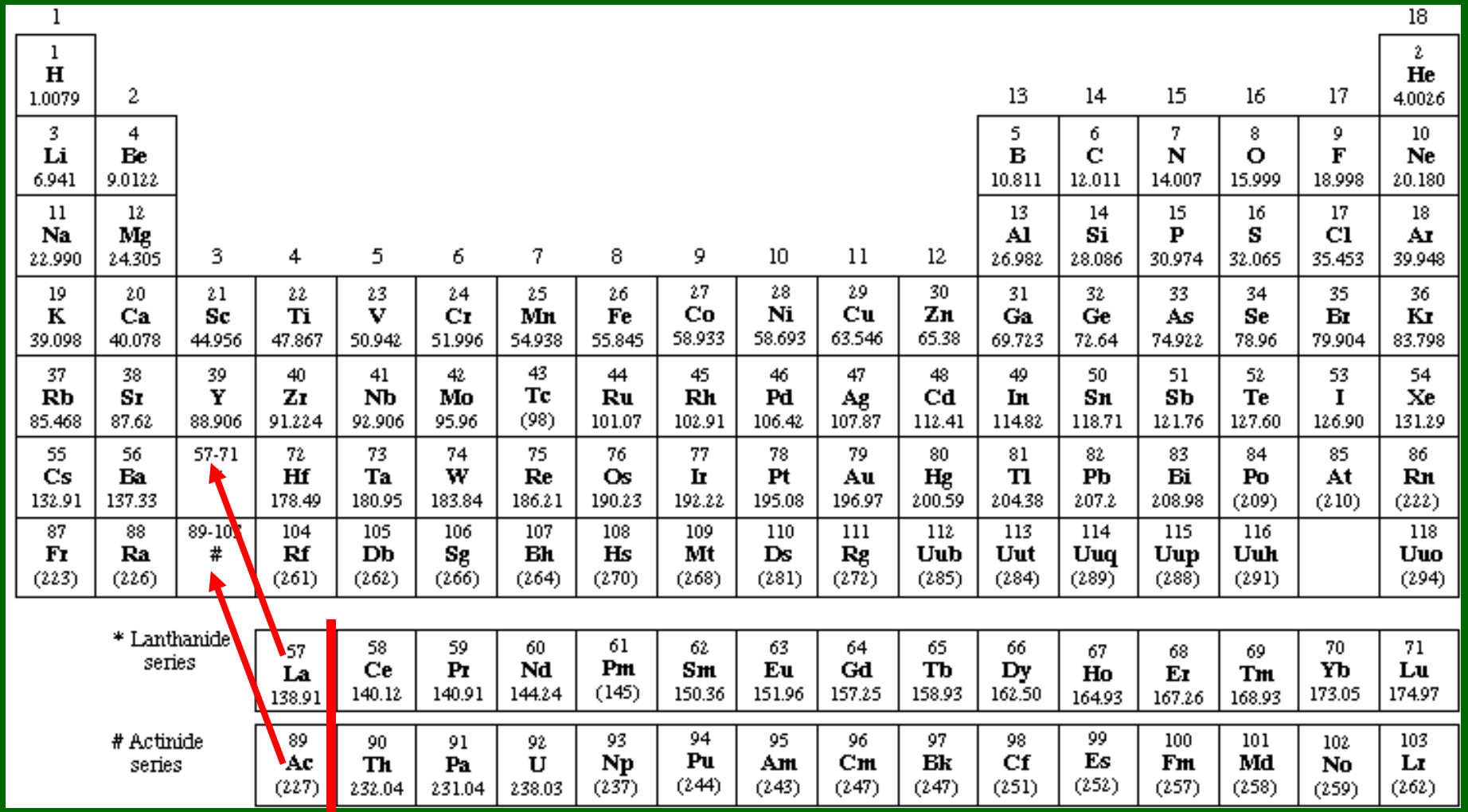
Ni [Ar] $3d^{10}\ (4s^0\ 4p^0)$ in compounds, $Ni(CO)_4$

Lanthanides and Actinides



Electronic Configurations of Lanthanides

Xe	[Kr] $4d^{10}\ 5s^2\ 5p^6$	E(4f) > E(6s)
Cs	[Xe] $6s^1\ \ 4f^0\ 5d^0$	
Ba	[Xe] $6s^2\ 4f^0\ 5d^0$	
La	[Xe] $4f^0\ 5d^1\ 6s^2$	transition metal
Ce	[Xe] $4f^1\ 5d^1\ 6s^2$	E(4f) < E(6s), E(5d)
Pr	[Xe] $4f^3\ 6s^2$	
Eu	[Xe] $4f^7\ 5s^2\ 5p^6\ 5d^0\ 6s^2$	
~~Gd~~	~~[Xe] $4f^8\ 5s^2\ 5p^6\ 5d^0\ 6s^2$~~	
Gd	[Xe] $4f^7\ 5s^2\ 5p^6\ 5d^1\ 6s^2$	4f half filled
Lu	[Xe] $4f^{14}\ 5d^1\ 6s^2$	4f completely filled


1
18
1 H 1.0079
2 He 4.0026
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3 Li 6.941
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9 F 18.998
10 Ne 20.180
11 Na 22.990
12 Mg 24.305
3
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9
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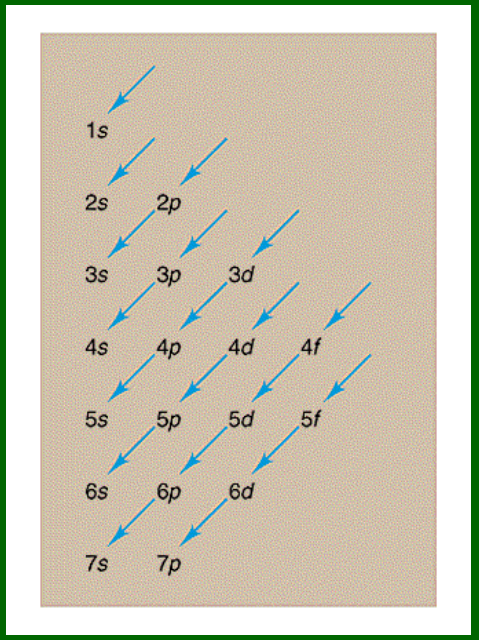
11
12
13 Al 26.982
14 Si 28.086
15 P 30.974
16 S 32.065
17 Cl 35.453
18 Ar 39.948
19 K 39.098
20 Ca 40.078
21 Sc 44.956
22 Ti 47.867
23 V 50.942
24 Cr 51.996
25 Mn 54.938
26 Fe 55.845
27 Co 58.933
28 Ni 58.693
29 Cu 63.546
30 Zn 65.38
31 Ga 69.723
32 Ge 72.64
33 As 74.922
34 Se 78.96
35 Br 79.904
36 Kr 83.798
37 Rb 85.468
38 Sr 87.62
39 Y 88.906
40 Zr 91.224
41 Nb 92.906
42 Mo 95.96
43 Tc (98)
44 Ru 101.07
45 Rh 102.91
46 Pd 106.42
47 Ag 107.87
48 Cd 112.41
49 In 114.82
50 Sn 118.71
51 Sb 121.76
52 Te 127.60
53 I 126.90
54 Xe 131.29
55 Cs 132.91
56 Ba 137.33
57-71
72 Hf 178.49
73 Ta 180.95
74 W 183.84
75 Re 186.21
76 Os 190.23
77 Ir 192.22
78 Pt 195.08
79 Au 196.97
80 Hg 200.59
81 Tl 204.38
82 Pb 207.2
83 Bi 208.98
84 Po (209)
85 At (210)
86 Rn (222)
87 Fr (223)
88 Ra (226)
89-103
#
104 Rf (261)
105 Db (262)
106 Sg (266)
107 Bh (264)
108 Hs (270)
109 Mt (268)
110 Ds (281)
111 Rg (272)
112 Uub (285)
113 Uut (284)
114 Uuq (289)
115 Uup (288)
116 Uuh (291)
118 Uuo (294)
* Lanthanide series
57 La 138.91
58 Ce 140.12
59 Pr 140.91
60 Nd 144.24
61 Pm (145)
62 Sm 150.36
63 Eu 151.96
64 Gd 157.25
65 Tb 158.93
66 Dy 162.50
67 Ho 164.93
68 Er 167.26
69 Tm 168.93
70 Yb 173.05
71 Lu 174.97
Actinide series
89 Ac (227)
90 Th 232.04
91 Pa 231.04
92 U 238.03
93 Np (237)
94 Pu (244)
95 Am (243)
96 Cm (247)
97 Bk (247)
98 Cf (251)
99 Es (252)
100 Fm (257)
101 Md (258)
102 No (259)
103 Lr (262)

Electronic Configurations of Actinides

Rn	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p^6$	E(5f) > E(7s)
Fr	[Rn] $7s^1$	
Ra	[Rn] $7s^2$ $5f^0$ $6d^0$	
Ac	[Rn] $5f^0$ $6d^1$ $7s^2$	transition metal
Th	[Rn] $5f^0$ $6d^2$ $7s^2$	E(5f) < E(7s), E(6d)
Pa	[Rn] $5f^2$ $6d^1$ $7s^2$	
U	[Rn] $5f^3$ $6d^1$ $7s^2$	
Np	[Rn] $5f^4$ $6d^1$ $7s^2$	
Pu	[Rn] $5f^6$ $6d^0$ $7s^2$	
Am	[Rn] $5f^7$ $6d^0$ $7s^2$	
Cm	[Rn] $5f^7$ $6d^1$ $7s^2$	
Bk	[Rn] $5f^8$ $6d^1$ $7s^2$	
Cf	[Rn] $5f^{10}$ $6d^0$ $7s^2$	
Es	[Rn] $5f^{11}$ $6d^0$ $7s^2$	
Fm	[Rn] $5f^{12}$ $6d^0$ $7s^2$	
Md	[Rn] $5f^{13}$ $6d^0$ $7s^2$	
No	[Rn] $5f^{14}$ $6d^0$ $7s^2$	
Lr	[Rn] $5f^{14}$ $6d^1$ $7s^2$	



Elektronová slupka

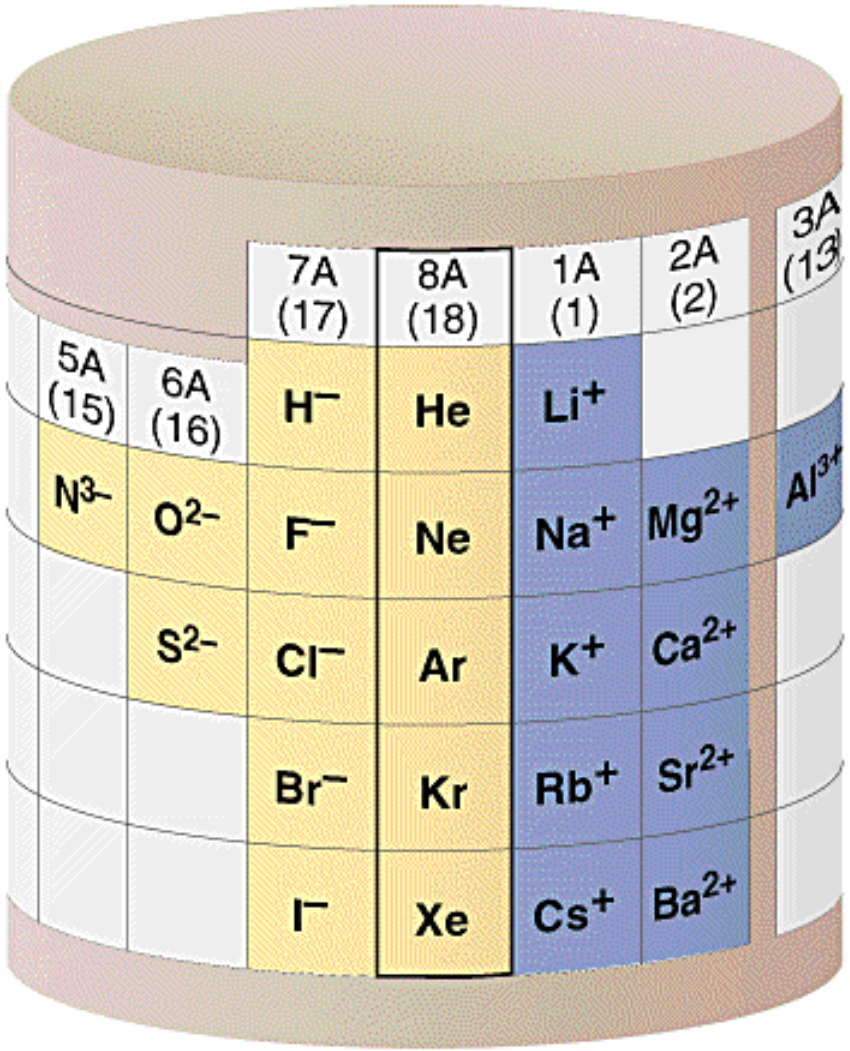
Valenční sféra – atomové orbitaly, nejvzdálenější od jádra, zcela nebo zčásti zaplněné, které leží nad elektronovou konfigurací nejbližšího nižšího vzácného plynu

Valenční sféra rozhoduje o fyzikálních a chemických vlastnostech

Vnitřní elektrony – elektronové "jádro" – všechny nižší zcela zaplněné elektronové hladiny vzácných plynů, neúčastní se chemických reakcí

Octet Formation

Ar [Ne] $3s^2\ 3p^6$



Isoelectronic ions

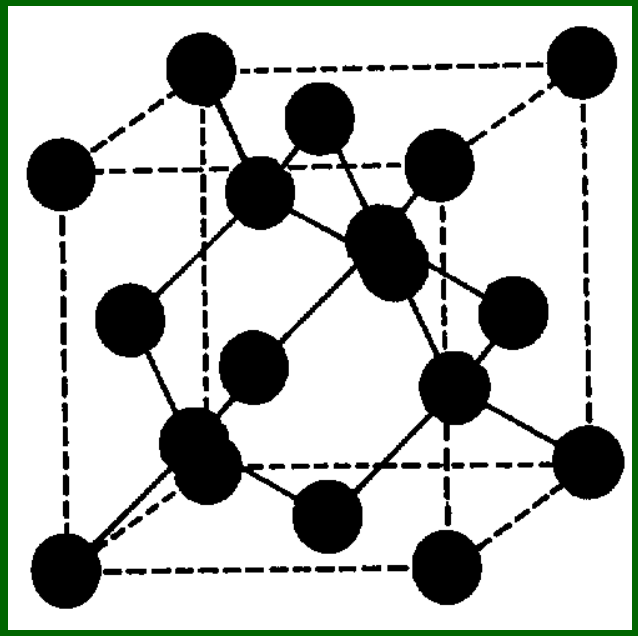
Size of Atoms

Atomic radii
Approximation of atoms as inflxible koule, r = 10^{-10} m

Covalent radius = half of interatomic distance between same atoms

Diamond
C-C distance = 1.54 Å

Covalent radius = 0.77 Å



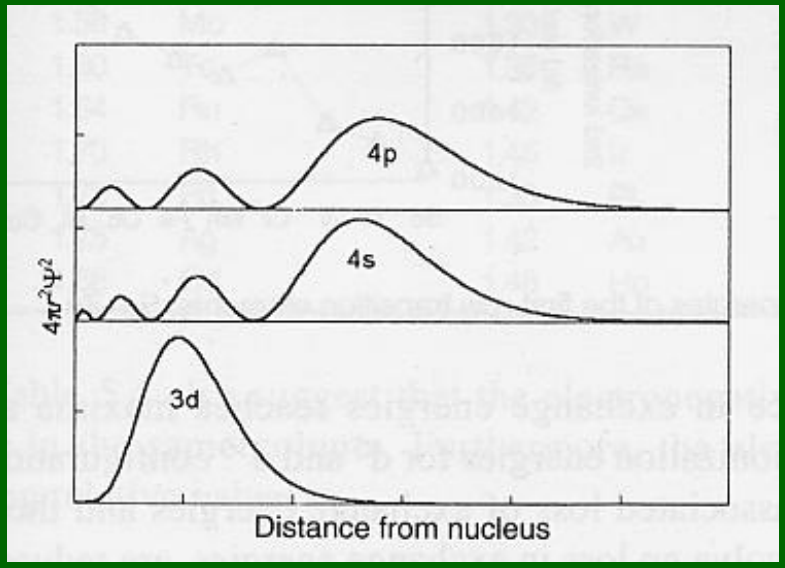
Size of Atoms

Atomic radii increase down the group – filling of higher (*n*) orbitals by electrons, electrons are further from nucleus

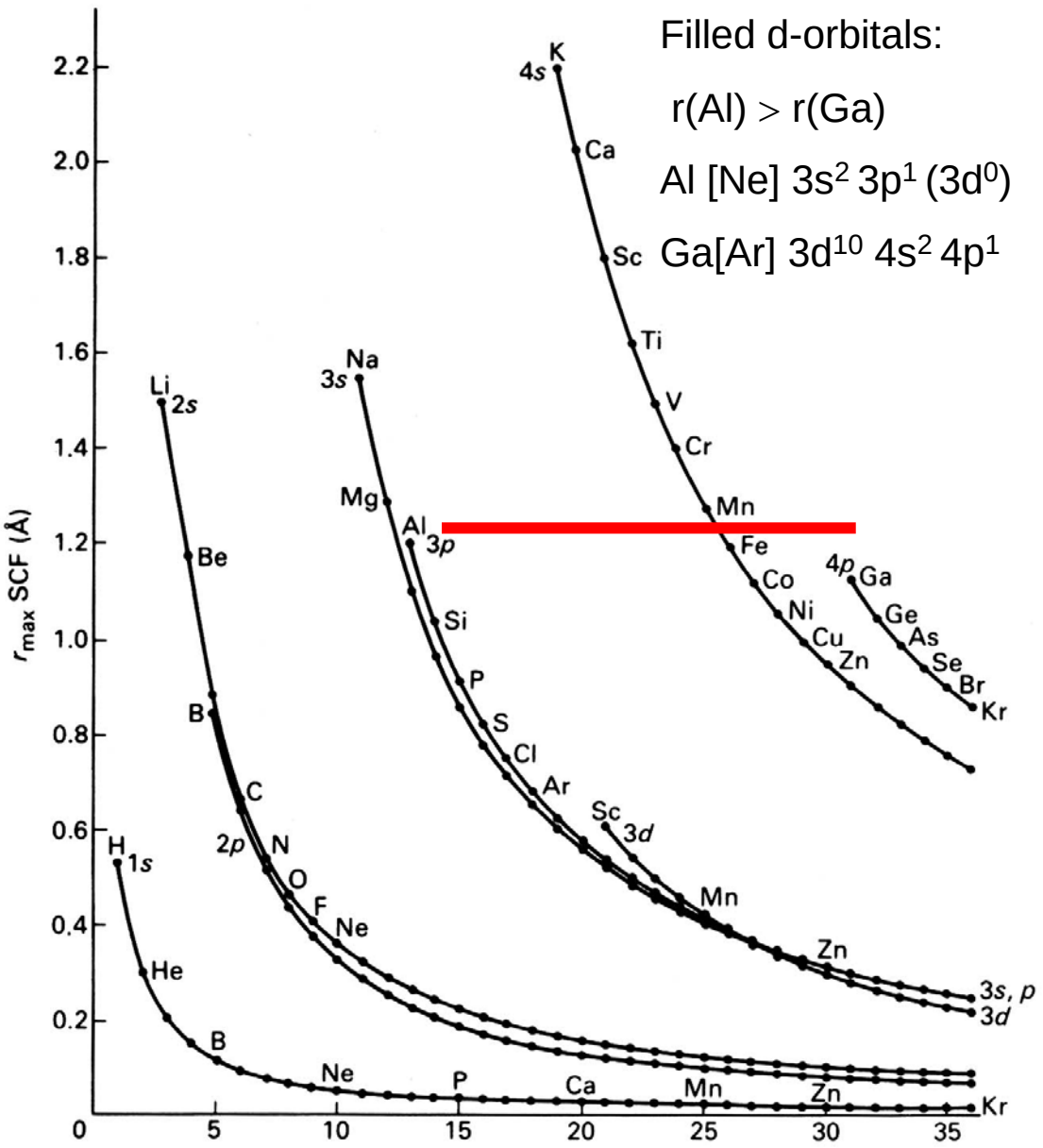
Filled d-orbitals: r(Al) > r(Ga)

Al [Ne] $3s^2\ 3p^1\ (3d^0)$

Ga [Ar] $3d^{10}\ 4s^2\ 4p^1$

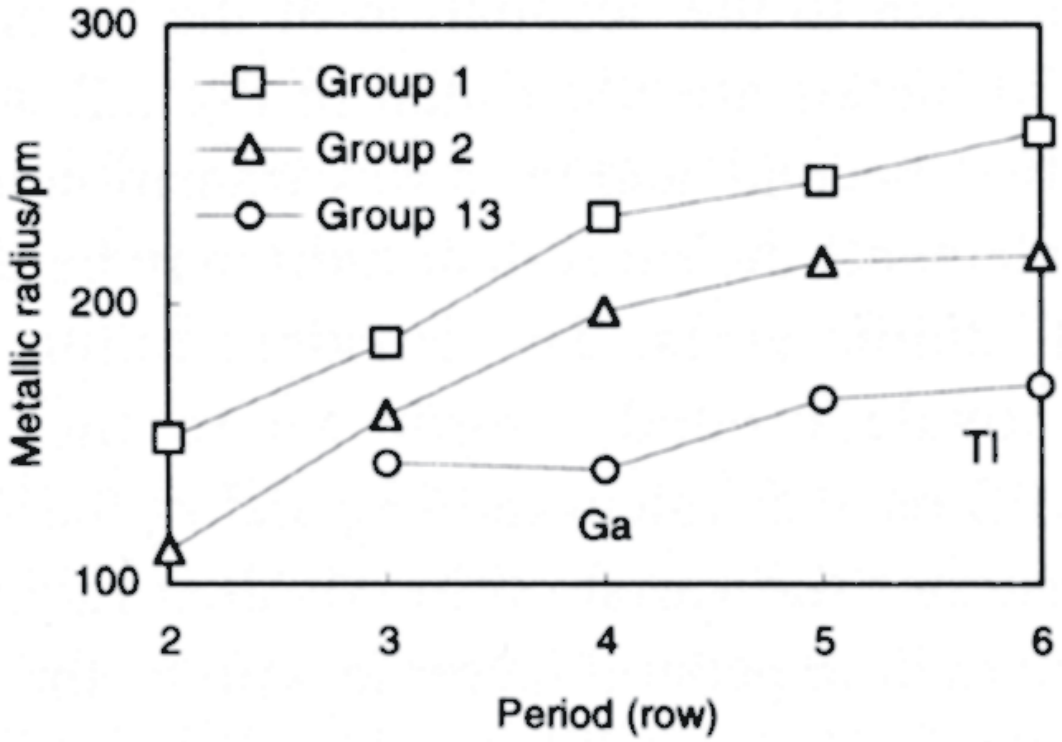


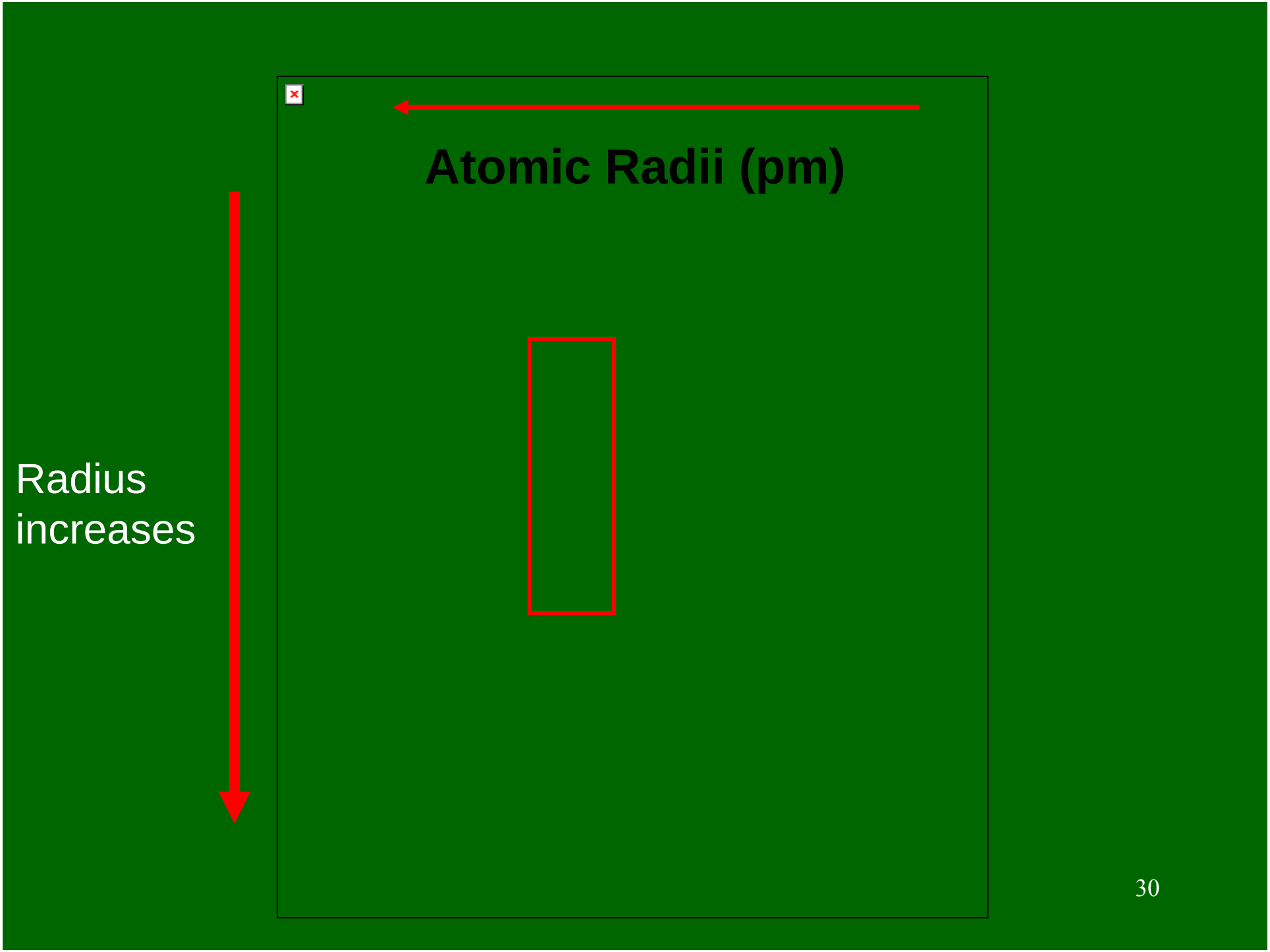
Radius of maximum electron density



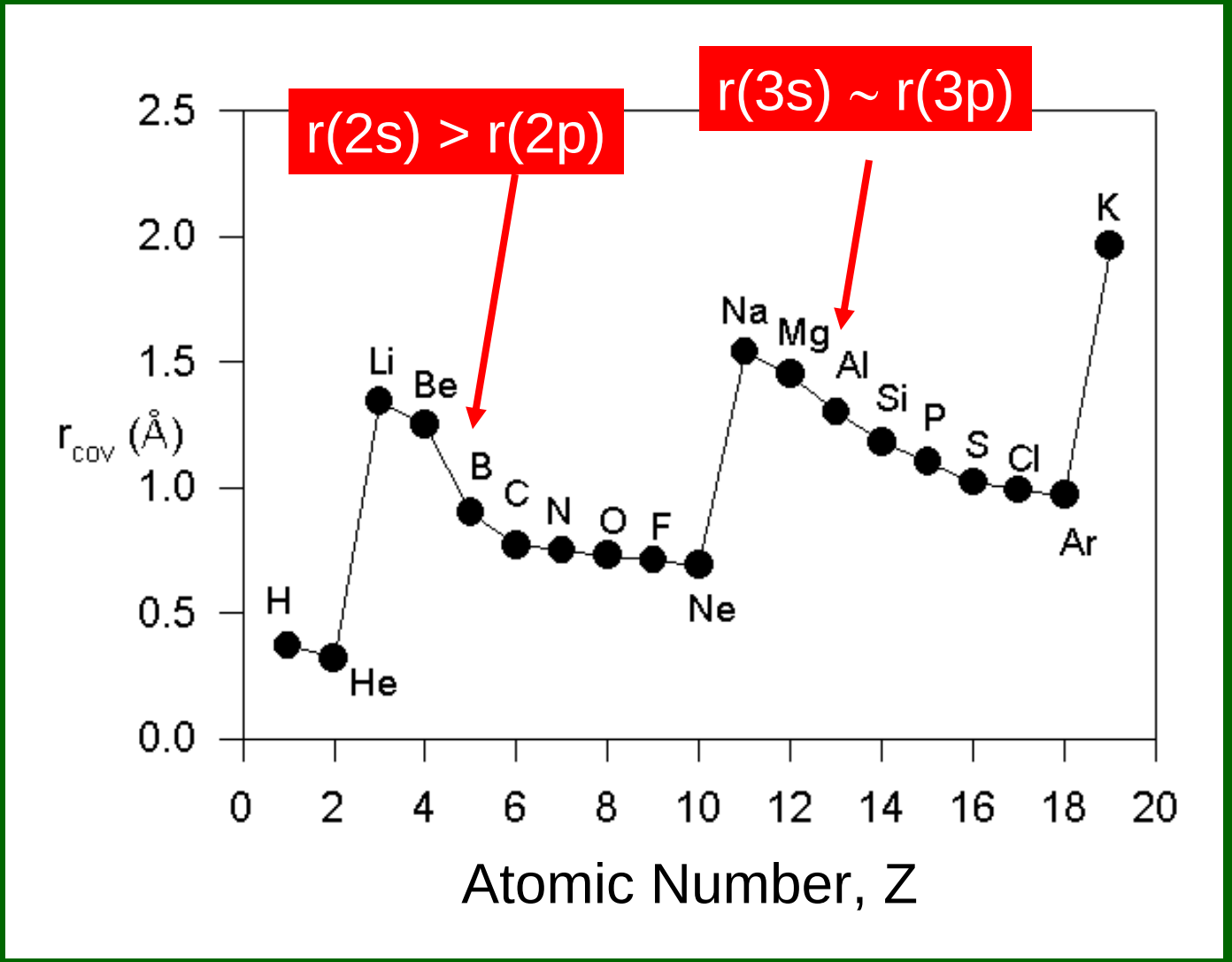
Size of Atoms

Radius




Atomic Radii (pm)
Radius increases

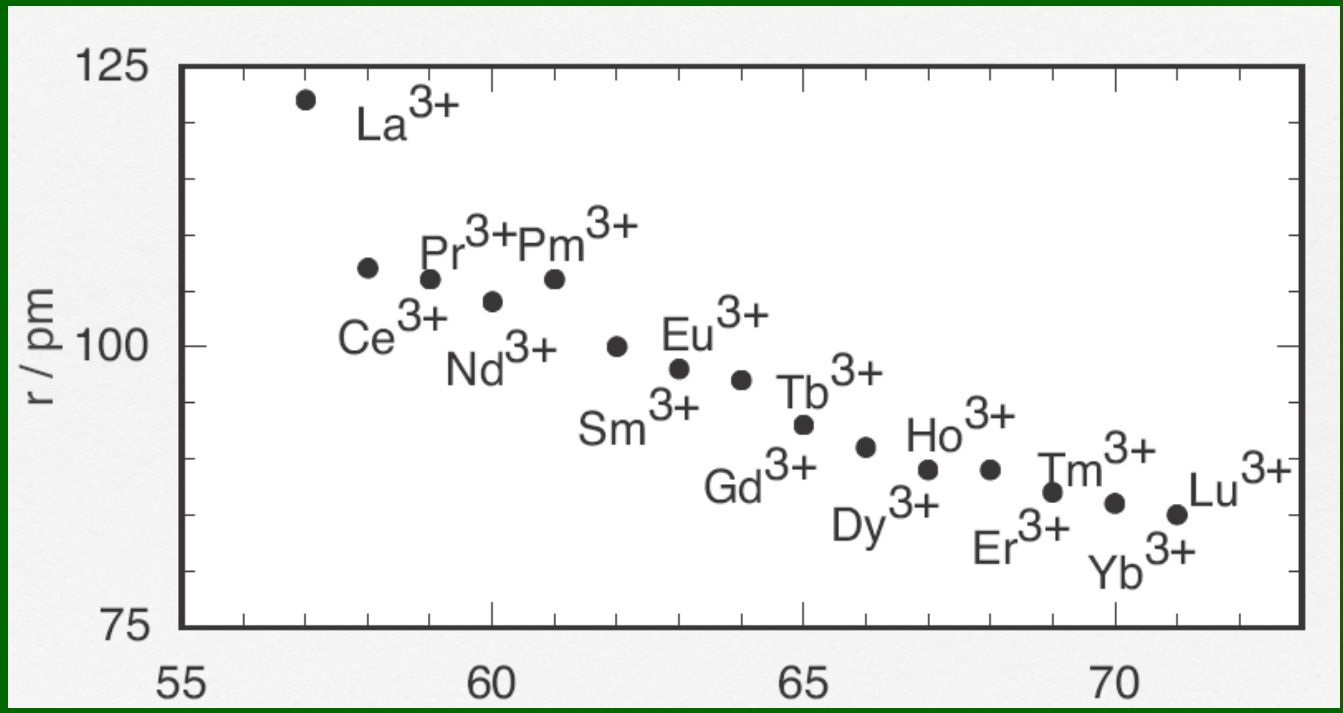
Covalent Radii, r_{cov} (Å)



Size of Atoms

Atomic radii decrease along the periods: electrons added to orbitals with the same *n*, increasing Z – positive nuclear charge contracts electron shell

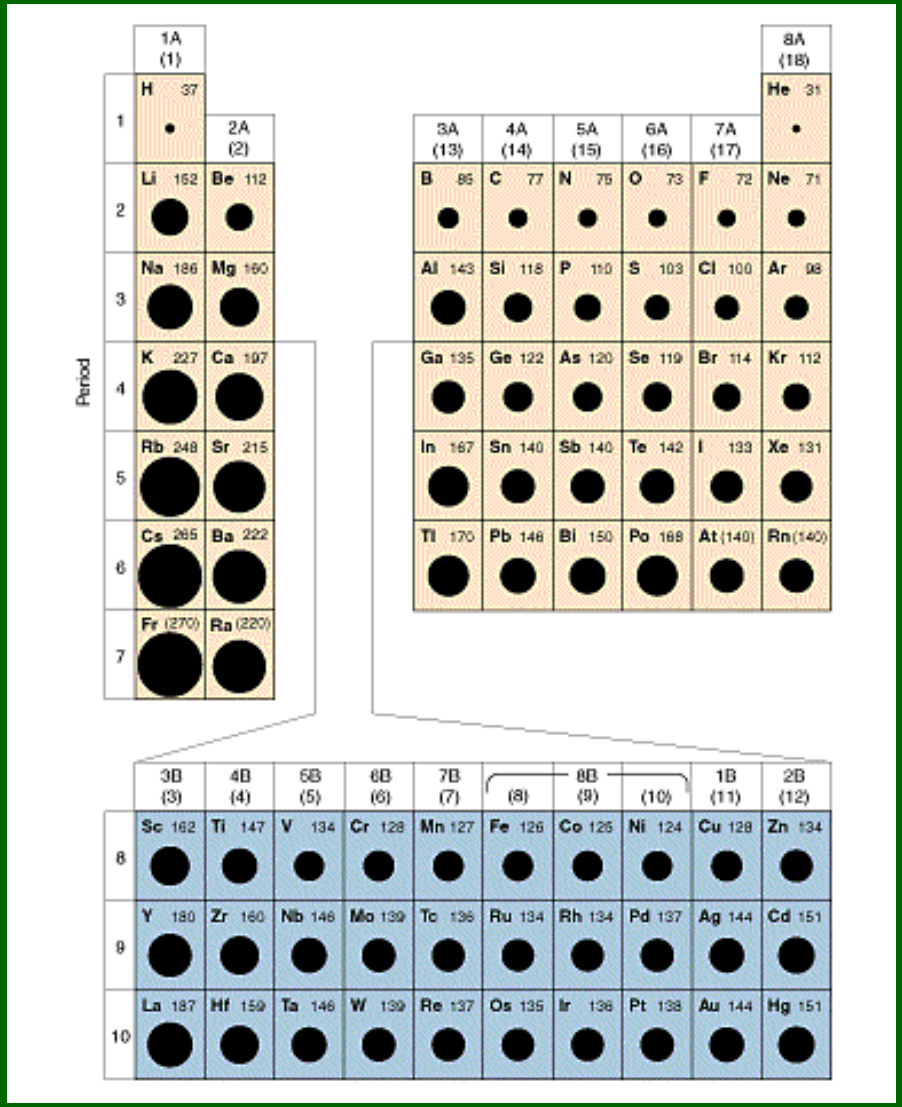
Lanthanide Contraction



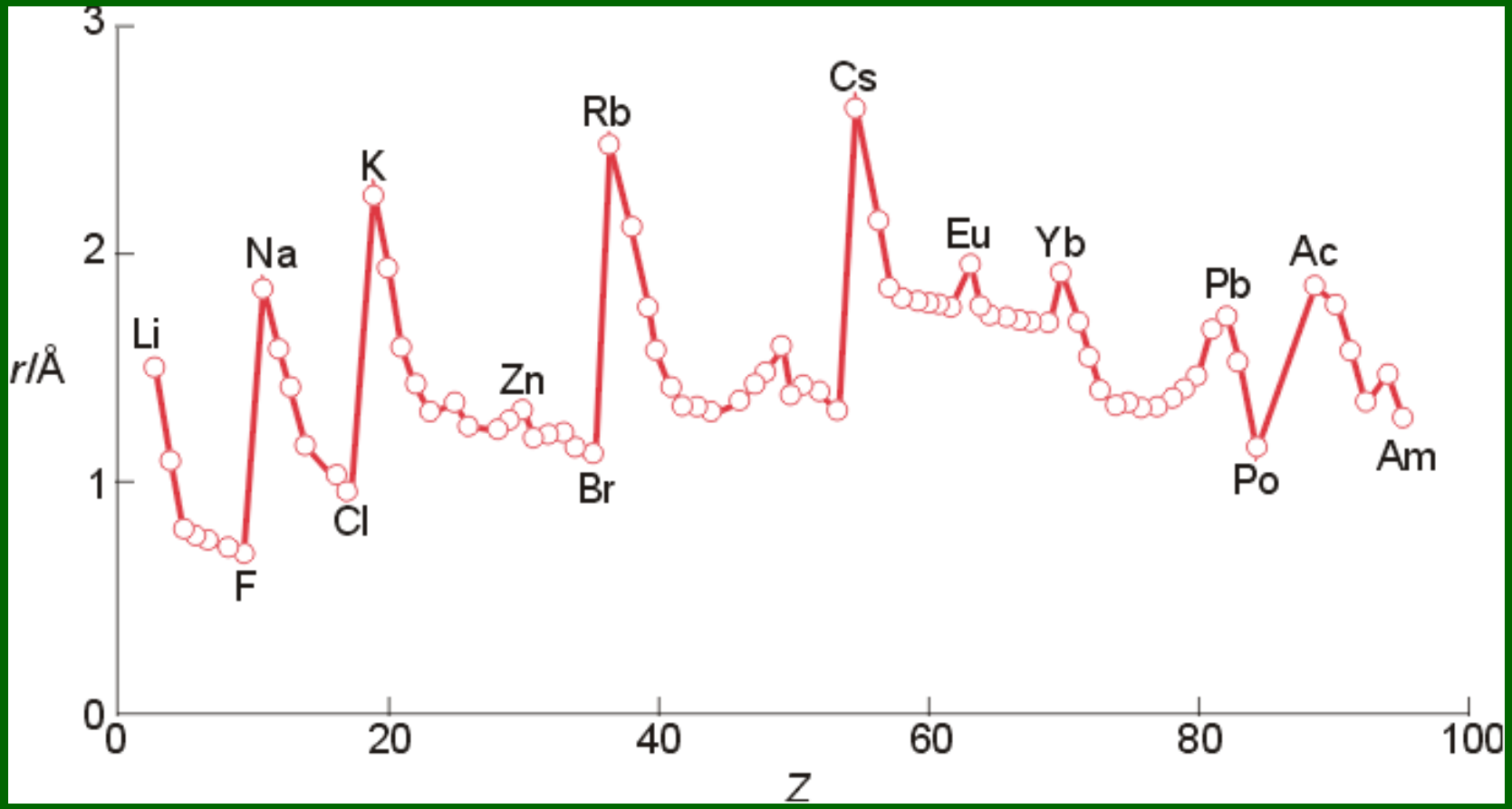
Lanthanide Contraction: outer orbital is 6s, electrons filled to 4f, increasing Z,

Radii decrease from La 169 pm to Lu 153 pm

Atomic Radii, pm

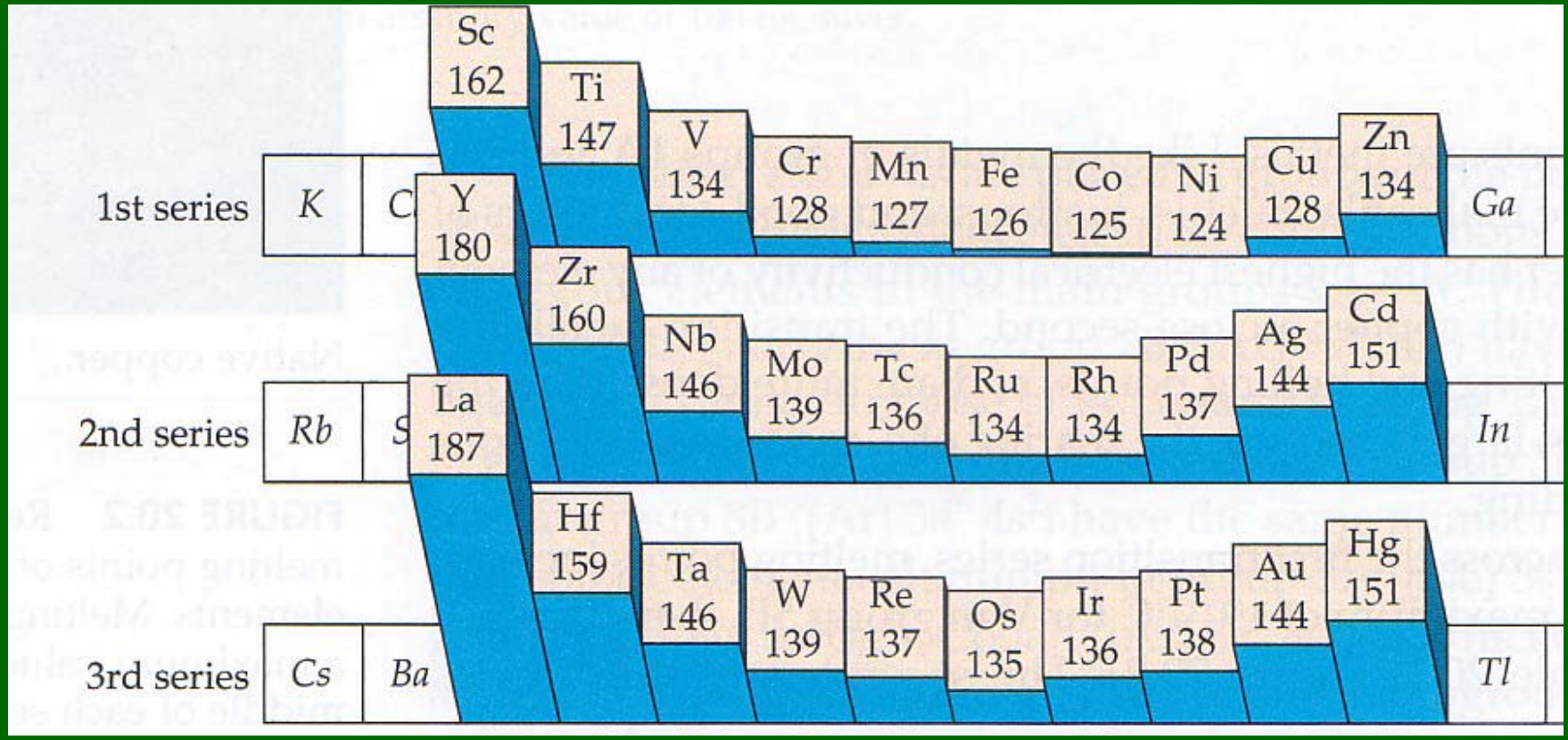


Atomic Radii, Å

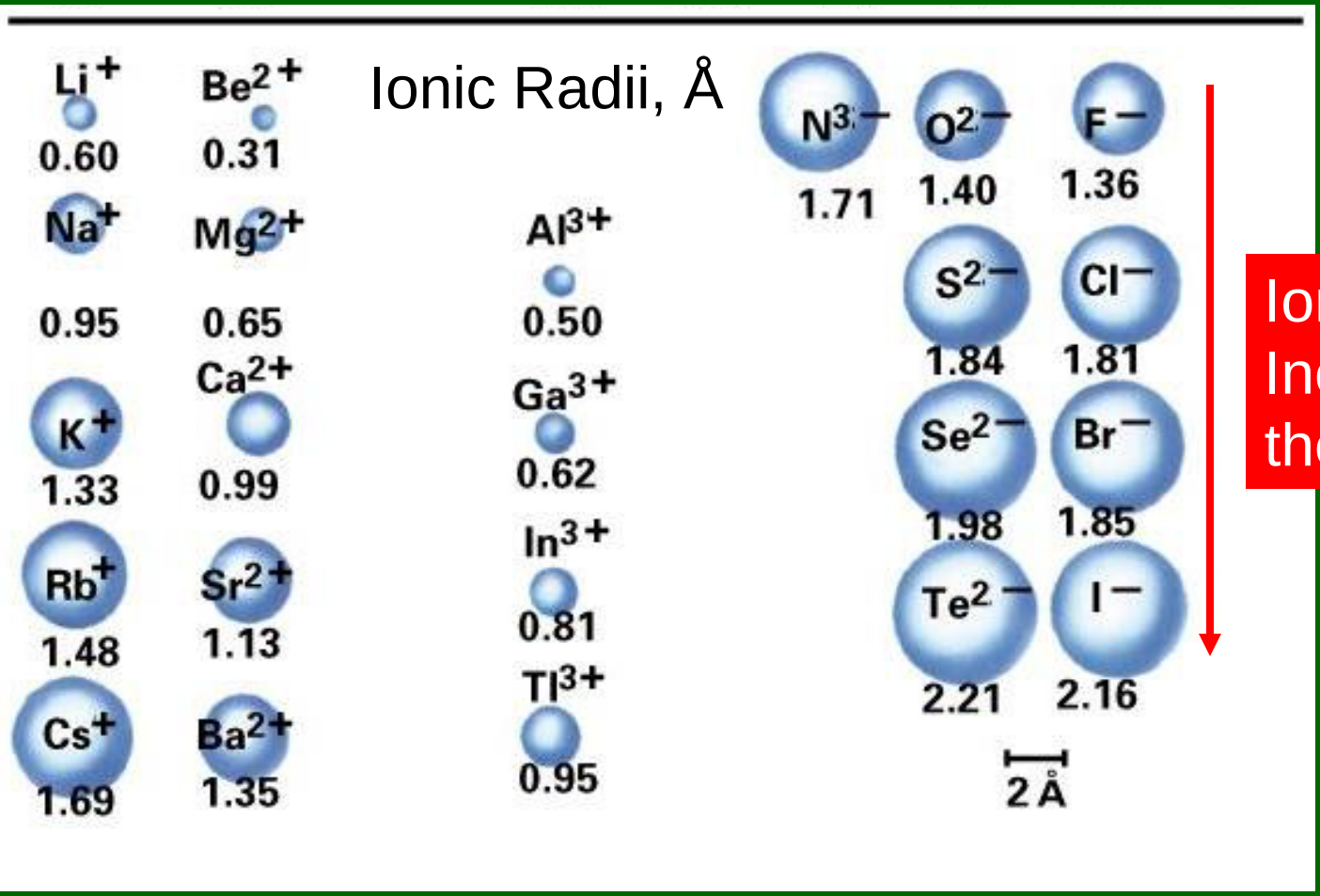


Atomic Radius, Z

Atomic Radii of Transition Elements, pm



Ionic Radii



Ionic Radii Increase down the group

Ionic Radii

Isoelectronic ions: **$N^{3-} > O^{2-} > F^{-} > Na^{+} > Mg^{2+} > Al^{3+}$**

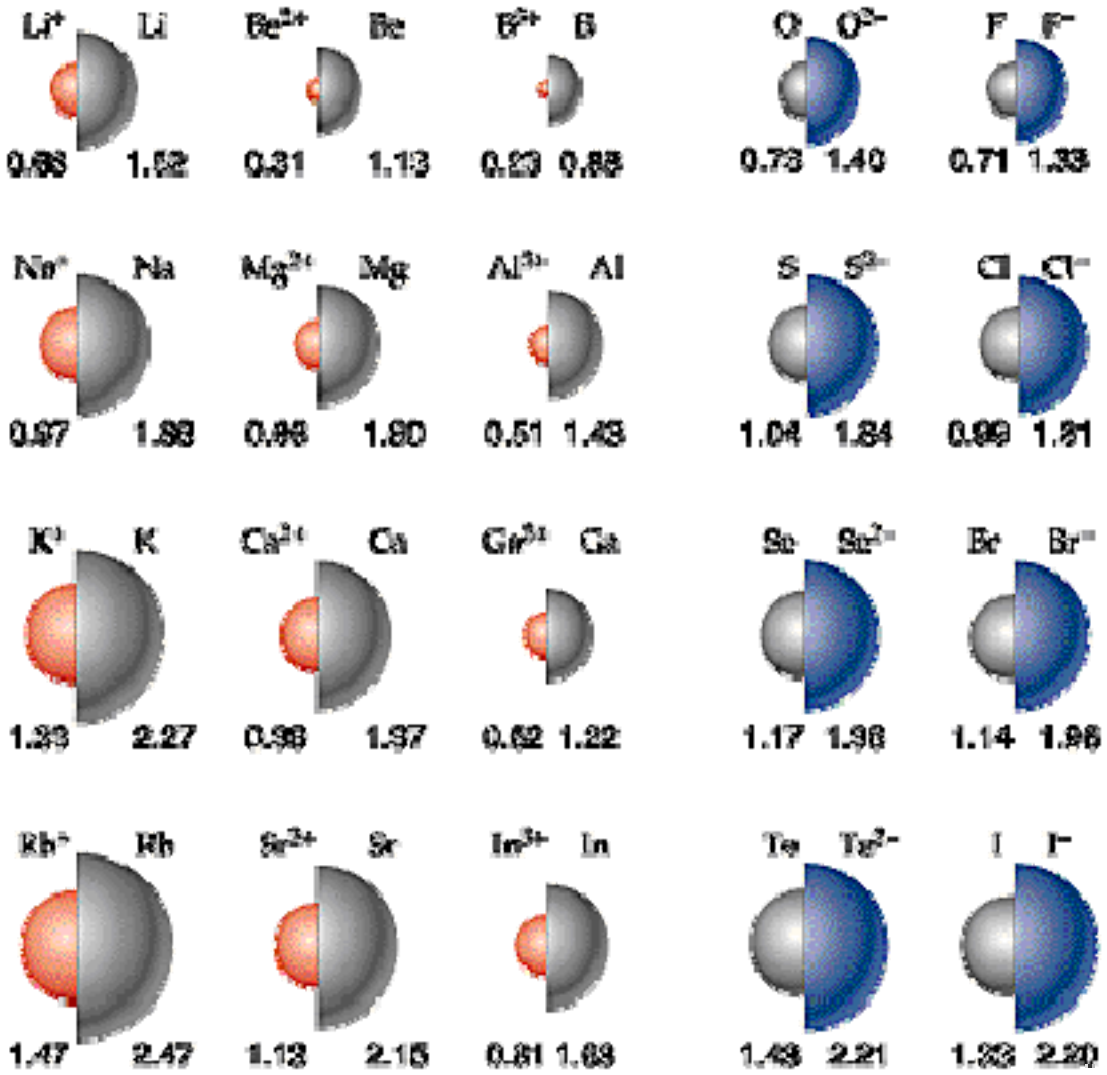
With increasing Z and increasing positive charge
radii decrease

Cations smaller than neutral atoms
Anions bigger than neutral atoms

$Fe^{2+} > Fe^{3+}$ **$Pb^{2+} > Pb^{4+}$**

With increasing positive charge, radii decrease

Ionic and Atomic Radii, Å



Ionization

Ionization = removal of an electron from an atom (or ion)
Spent energy = always endothermic

Electron further from nucleus is torn off most easily, wekly bound

Removing second electron from a cation even more energetically demanding:

Removing electron – decrease of e-e repulsion, radius decreases

Cations smaller than neutral atoms
Anions bigger than neutral atoms

Ionization Energy, IE

IE = energy for removing the weakest bound electron from an atom in a gas phase (at 0 K) [kJ mol^{-1}].

Electron bonding in a given orbital

$M_{(g)} \longrightarrow M_{(g)}^{+} + e^{-}$ First IE IE1 > 0 [kJ mol^{-1}]

$M_{(g)}^{+} \longrightarrow M_{(g)}^{2+} + e^{-}$ Second IE IE2 >> 0 [kJ mol^{-1}]

1. IE < 2. IE < 3. IE < 4. IE < .....

Subsequent ionization is more demanding energetically :
same Z, smaller number of e is held more tightly,
charge separation is disadvantageous

Ionization Energy, IE

[kJ mol^{-1}]

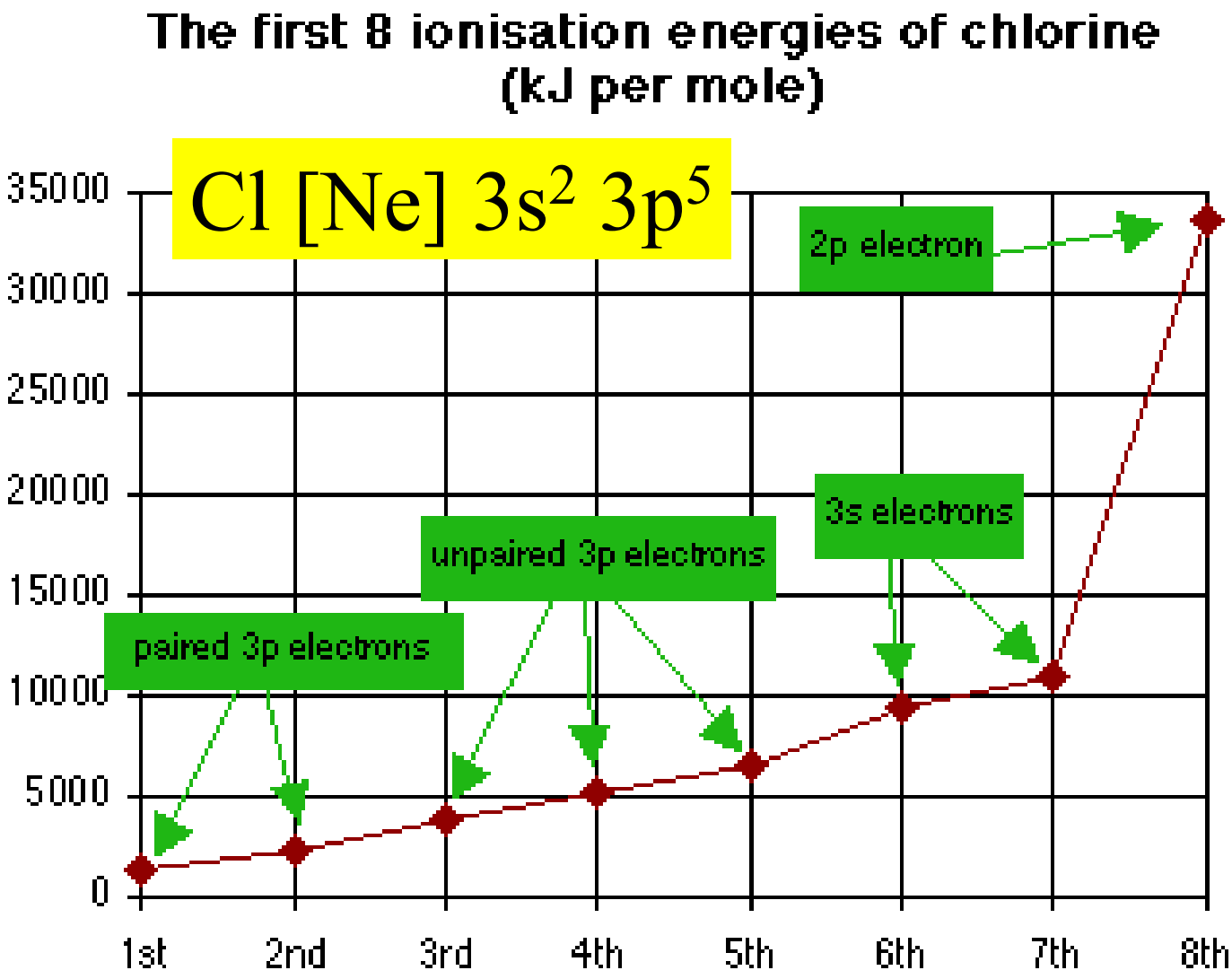
Element	I_1	I_2	I_3	I_4	I_5	I_6	I_7
Na	495	4560					
Mg	735	1445	7730				
Al	580	1815	2740	11,600			
Si	780	1575	3220	4350	16,100		
P	1060	1890	2905	4950	6270	21,200	
S	1005	2260	3375	4565	6950	8490	27,000
Cl	1255	2295	3850	5160	6560	9360	11,000
Ar	1527	2665	3945	5770	7230	8780	12,000

Uzavřené elektronové slupky

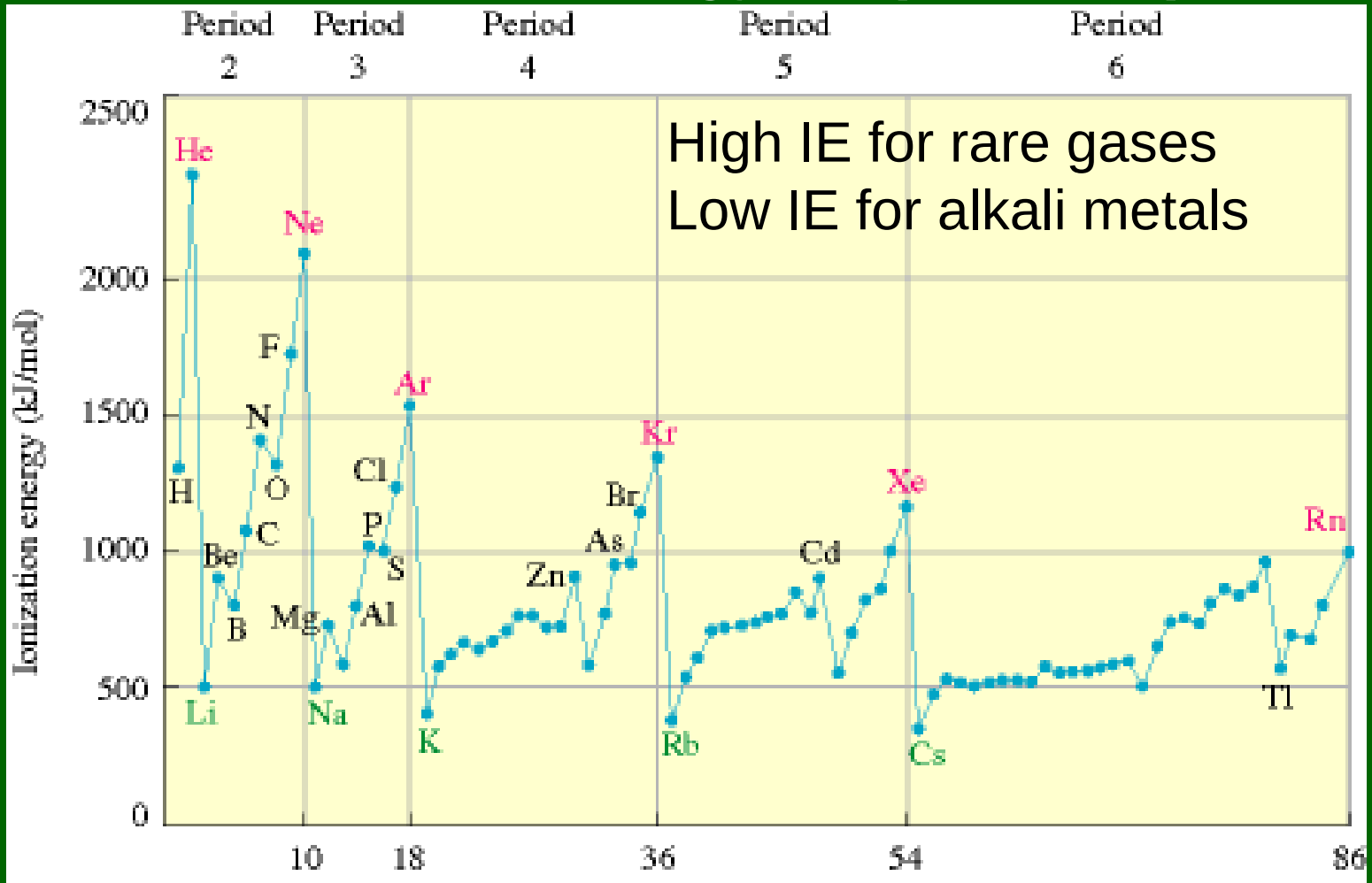
*Note the large jump in ionization energy in going from removal of valence electrons to removal of core electrons.

General decrease

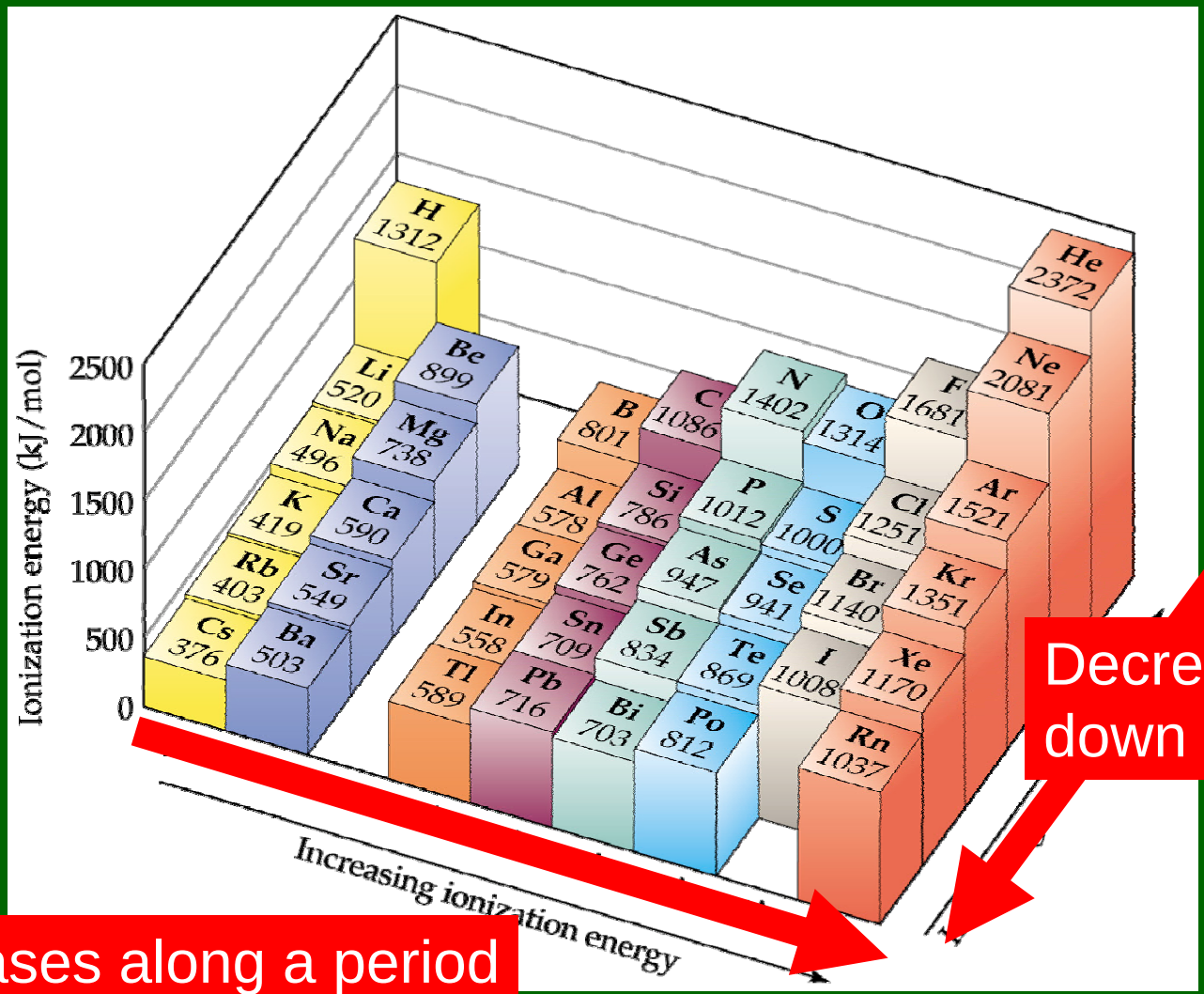
General increase


The first 8 ionisation energies of chlorine
(kJ per mole)
Cl [Ne] 3s2 3p5
35000
30000
25000
20000
15000
10000
5000
0
1st
2nd
3rd
4th
5th
6th
7th
8th
2p electron
3s electrons
unpaired 3p electrons
paired 3p electrons

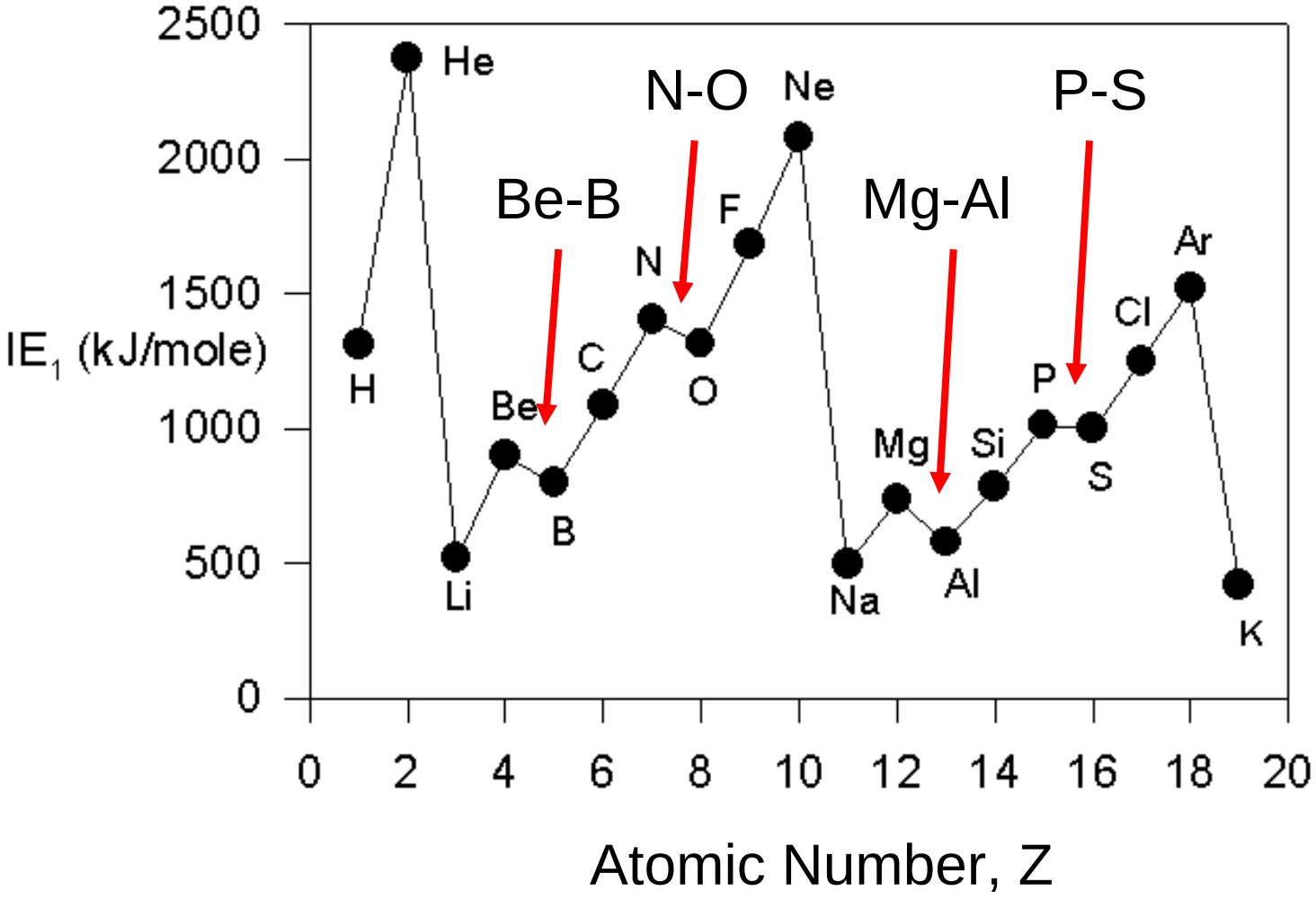
Ionization Energy, IE (kJ mol^{-1})



Ionization Energy, IE (kJ mol^{-1})



First Ionization Energy, IE (kJ mol^{-1})



Electron Affinity, EA

EA = Electron affinity released (EA < 0) or absorbed (EA > 0) during attachment of an electron to an atom or an ion in gas phase (at 0 K).

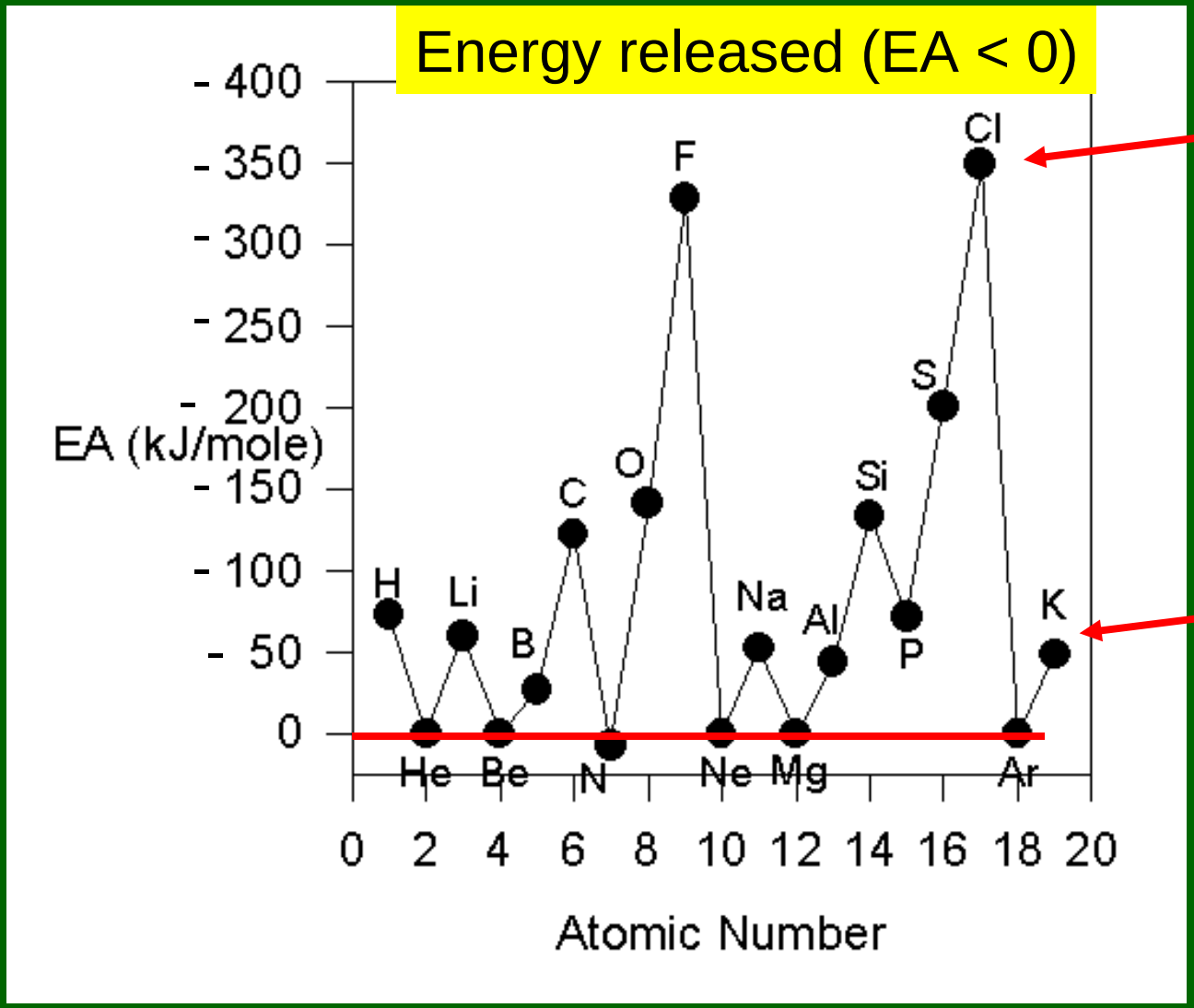
First EA generally < 0, except Be, N, ….. Why?

Second EA always > 0, attachment of an e^- to anion is unfavorable by energy, compensated by lattice energy release

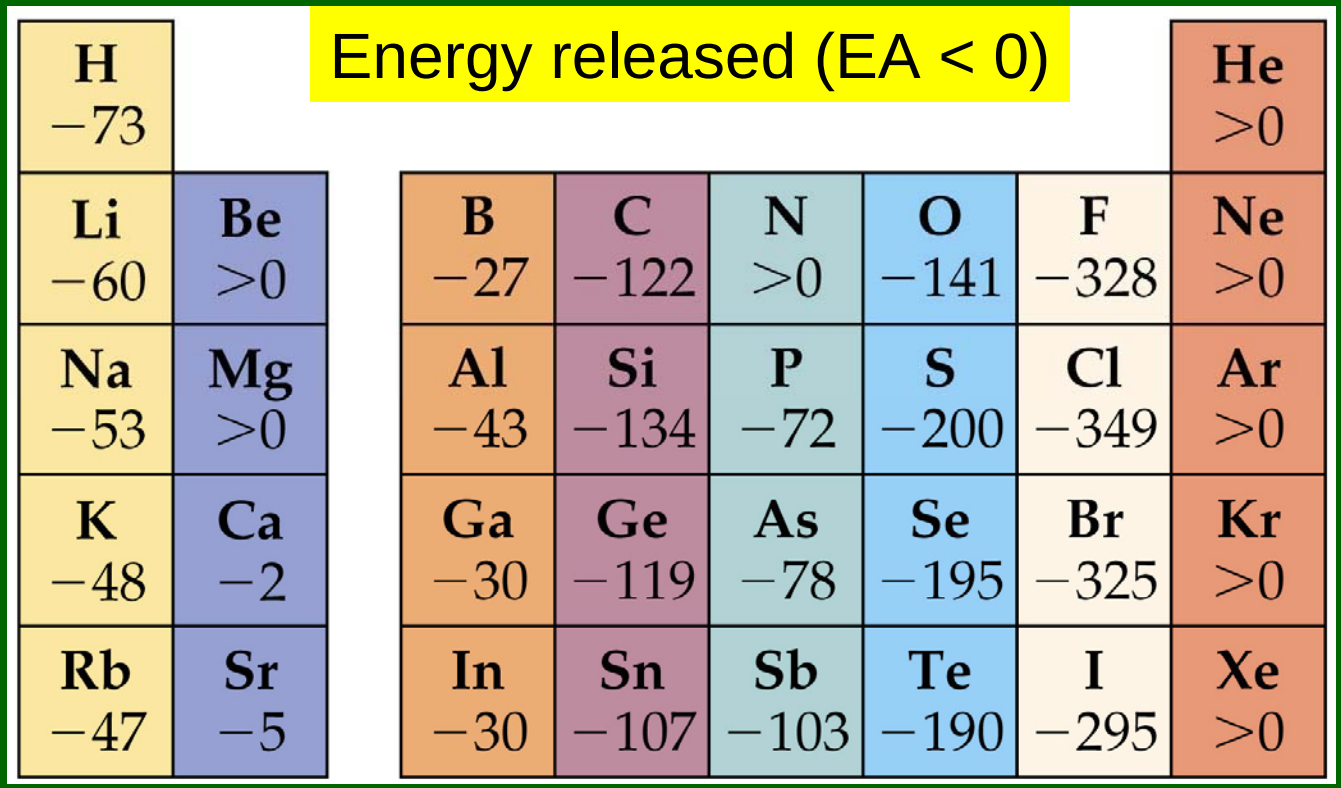
Oxides, O^{2-}

$EA_1(O) < 0$
$EA_2(O) > 0$

First Electron Affinity, EA (kJ mol^{-1})



First Electron Affinity, EA (kJ mol^{-1})



Pauling's Electronegativity

Ability of an atom to attract bonding electrons in covalent bond

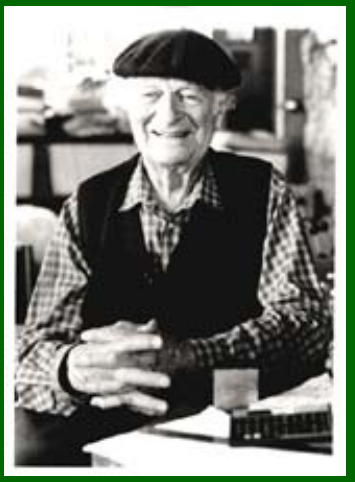
Dissociatin energy of a polar bond A–B is higher than an average of dissociation energies of nonpolar bonds A–A and B–B

$$E_D(AB) = \{E_D(AA) \times E_D(BB)\}^{1/2} + \Delta$$

$$\Delta = 96.48\ (\chi_A - \chi_B)^2$$

χ_F = 4.0 Pauling

χ_F = 3.98 today's value



Linus Pauling (1901-1994)

NP in Chemistry 1954, Peace 1963

Pauling's Electronegativity

Dissociation energy from experiments

$E_D(F_2) = 154.8$ kJ mol^{-1}

$E_D(Br_2) = 192.5$ kJ mol^{-1}

$E_D(BrF) = 238.5$ kJ mol^{-1}

$E_D(BrF) = \{E_D(F_2) \times E_D(Br_2)\}^{½} + \Delta$

$\Delta = 96.48\ (\chi_A - \chi_B)^2$

$\chi_F = 3.98$

$\chi_{Br} = ?$

$$\chi_B = \sqrt{\frac{\Delta}{96.48}} - \chi_A$$

Square root of energy??

Pauling's Electronegativity

A-B	E_D(A-B) kJ mol^{-1}	½ E_D(AA) kJ mol^{-1}	½ E_D(BB) kJ mol^{-1}	Δ	$\chi_B - \chi_A$	% ionicity
HF	565	218	77	270	1.9	43
HCl	432	218	122	92	0.9	17
HBr	367	218	96	53	0.7	13
HI	297	218	75	4	0.4	7

Mulliken's Electronegativity

Orbital electronegativities – s, p, d, hybrid

$\chi_M = 3.15\ \chi_P$

$$\chi_M = \frac{IE + EA}{2}$$

SOME MULLIKEN ELECTRONEGATIVITIES (eV)

H							
s 7.2							
Li	Be	B	C	N	O	F	
s 3.1	di^2 4.8	tr^3 6.4	$di^2\pi^2$ 10.4, 5.7	$di^3\pi^2$ 15.7, 7.9	$tr^4\pi^2$ 16.8	*s* 31.3	
p 1.8	te^2 3.9	te^3 6.0	$tr^3\pi$ 8.8, 5.6	$tr^4\pi$ 12.9, 8.0	te^6 15.3	*p* 12.2	
			te^4 8.0	te^5 11.6			
Na	Mg	Al	Si	P	S	Cl	
s 2.9	di^2 4.1	tr^3 5.5	$di^2\pi^2$ 9.0, 5.7	$di^3\pi^2$ 11.3, 6.7	$tr^4\pi^2$ 10.9	*s* 19.3	
p 1.6	te^2 3.3	te^3 5.4	$tr^3\pi$ 7.9, 5.6	$tr^4\pi$ 9.7, 6.7	te^6 10.2	*p* 9.4	
			te^4 7.3	te^5 8.9			
K	Ca	Ga	Ge	As	Se	Br	
s 2.9	di^2 3.4	tr^3 6.0	$di^2\pi^2$ 9.8, 6.5	$di^3\pi^2$ 9.0, 6.5	$tr^4\pi^2$ 10.6	*s* 18.3	
p 1.8	te^2 2.5	te^3 6.6	$tr^3\pi$ 8.7, 6.4	$tr^4\pi$ 8.6, 7.0	te^6 9.8	*p* 8.4	
			te^4 8.0	te^5 8.3			
Rb	Sr	In	Sn	Sb	Te	I	
s 2.1	di^2 3.2	tr^3 5.3	$di^2\pi^2$ 9.4, 6.5	$di^3\pi^2$ 9.8, 6.3	$tr^4\pi^2$ 10.5	*s* 15.7	
p 2.2	te^2 2.2	te^3 5.1	$tr^3\pi$ 8.4, 6.5	$tr^4\pi$ 9.0, 6.7	te^6 9.7	*p* 8.1	
				te^5 8.5			

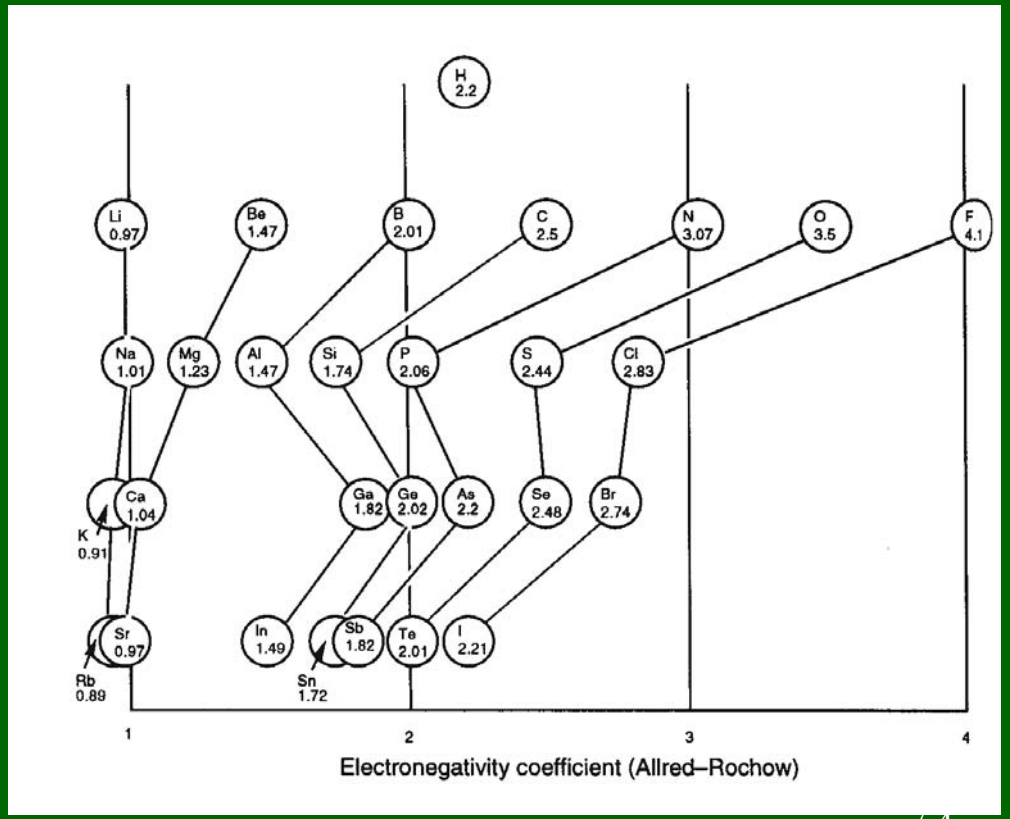
Values can be computed only for orbitals holding 1 electron. For the carbon and nitrogen families it is possible to have both hybrid and π atomic orbitals half-filled. *di*gonal $\equiv$ *sp* hybrid, *tri*gonal $\equiv$ sp^2 hybrid, *te*trahedral $\equiv$ sp^3 hybrid.

Allred and Rochow's Electronegativity

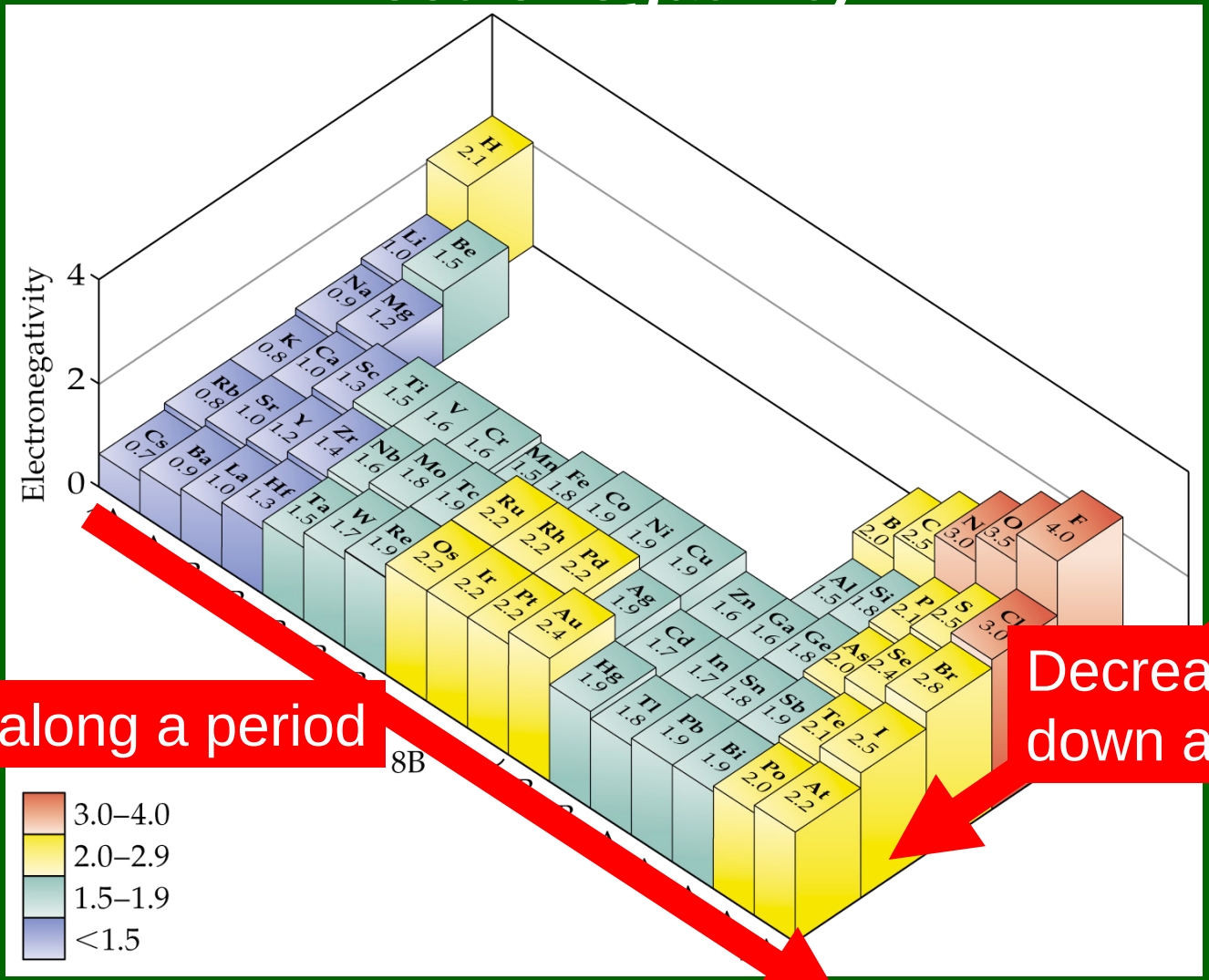
Coulombic force – nucleus attracts bonding electrons

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Z^{eff}e}{r^2}$$

$$\chi_{AR} = A\frac{Z^{eff}}{r^2} + B$$



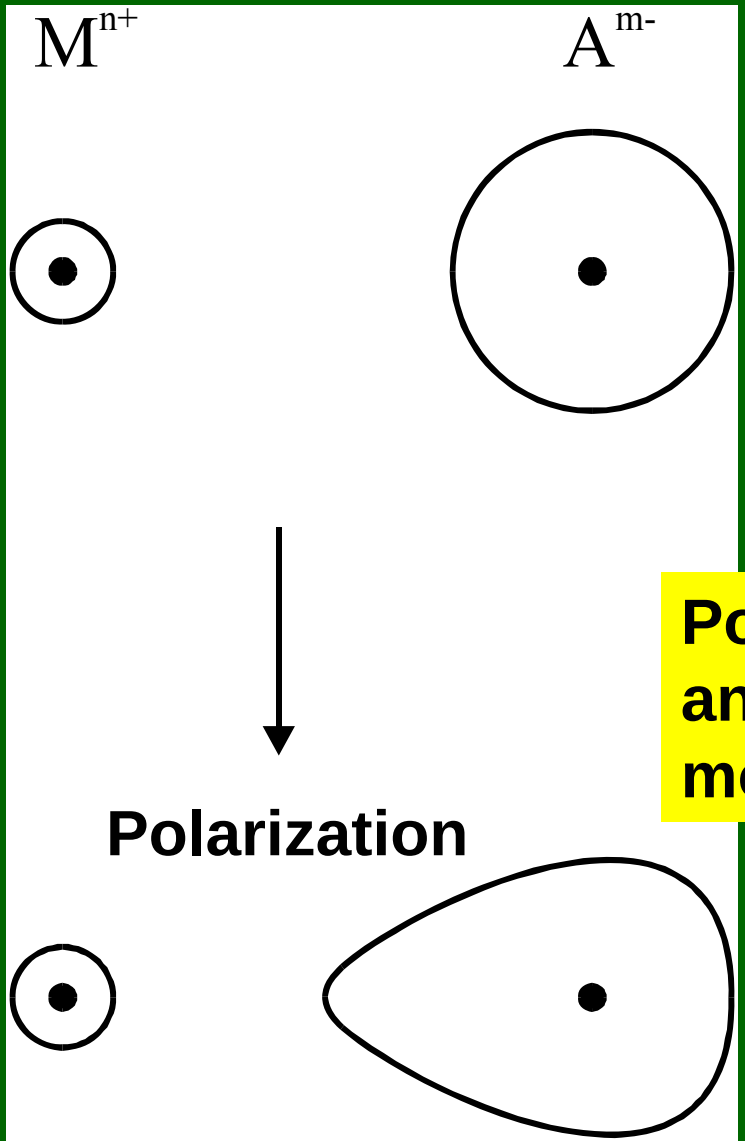
Electronegativity



Increases along a period

Decreases down a group

Mutual Polarization of Ions



Polarization power of a cation

Polarizibility of an anion, an atom, or a molecule

Polarizibility, α [m^3]

Deformation of electronic density in an atom or an ion by external electric field (other charged particles)

Change of volume of electron cloud, α [m^3]

Value of α depends on strength of electron bonding by a nucleus, atomic size, number of electrons

Soft atom (ion, molecule) = easy to deform
Hard atom (ion, molecule) = resists deformation

Polarizibility of Atoms, 10^6 pm^3

Atom	α	Atom	α	Atom	α	Atom	α
		H	0.408	C(4)	1.027	He	0.20
Li	24.0	F	0.321	C(3)	1.329	Ne	0.39
Na	24.4	Cl	2.317	C(2)	1.419	Ar	1.62
K	41.6	Br	3.465	C(ar)	1.322	Kr	2.46
Rb	43.7	I	5.530			Xe	3.99
Cs	52.9						

Polarization Power

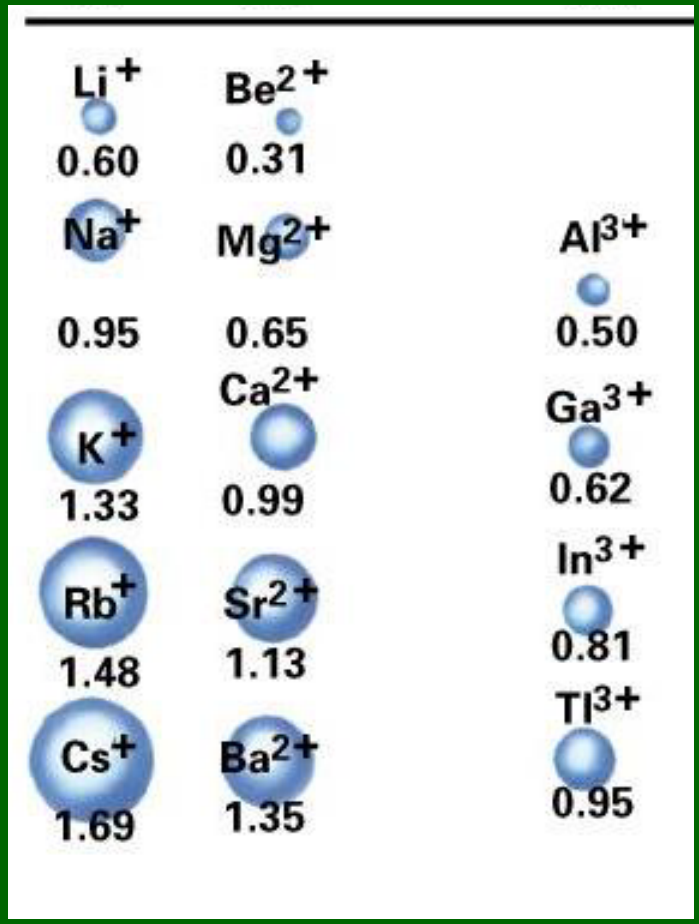
Increases with increasing charge

Increases with decreasing radius

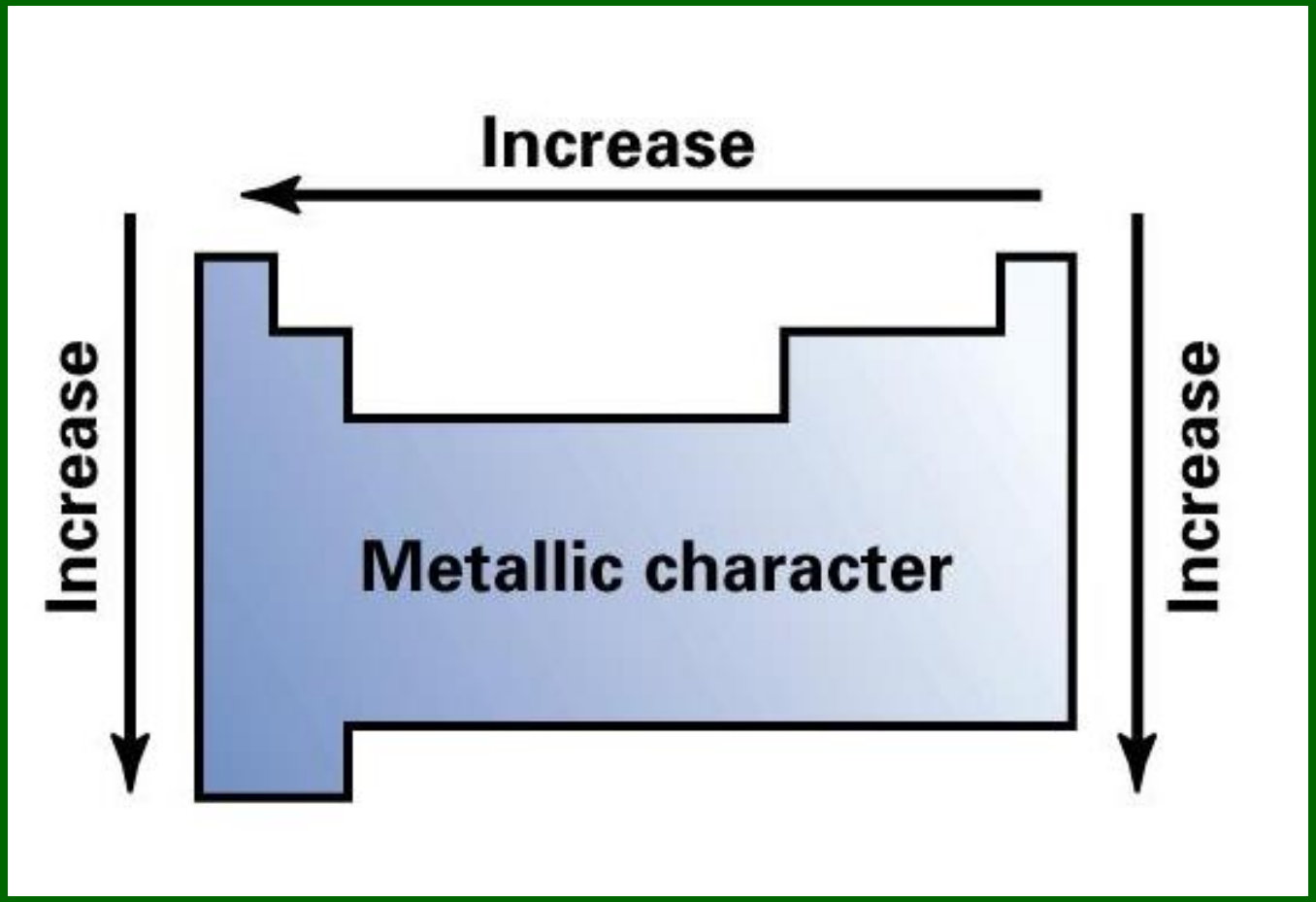
q/r charge density

Al^{3+} hard cation

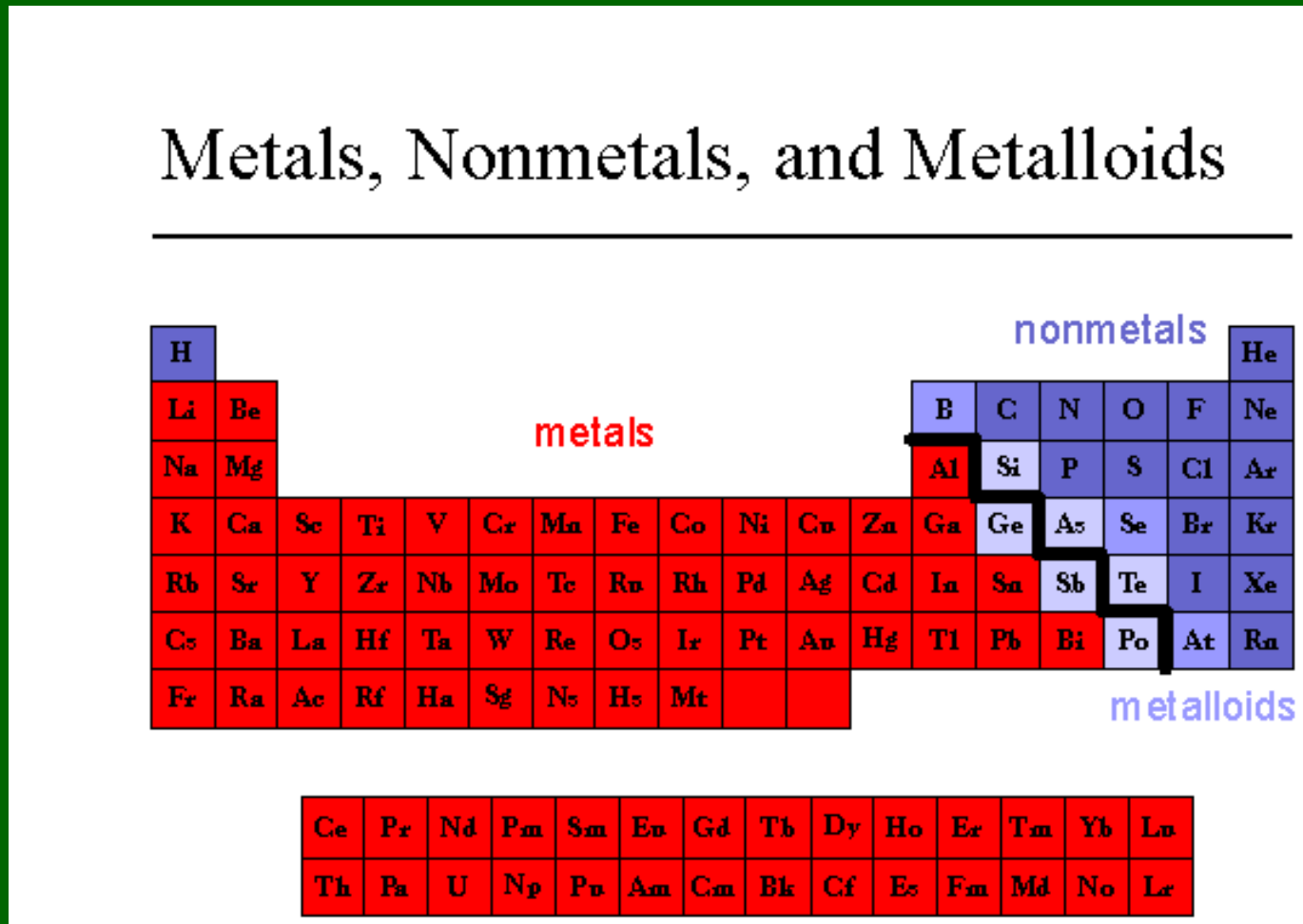
Cs^{+} soft cation

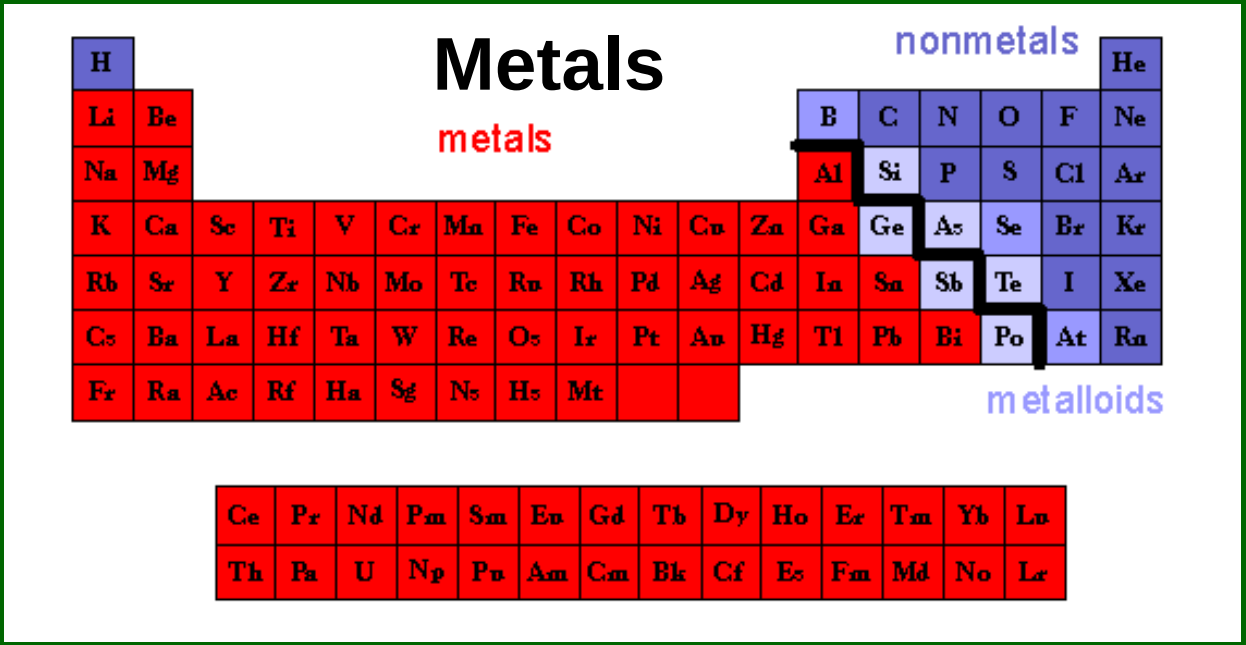


Metallic – Nonmetallic Properties

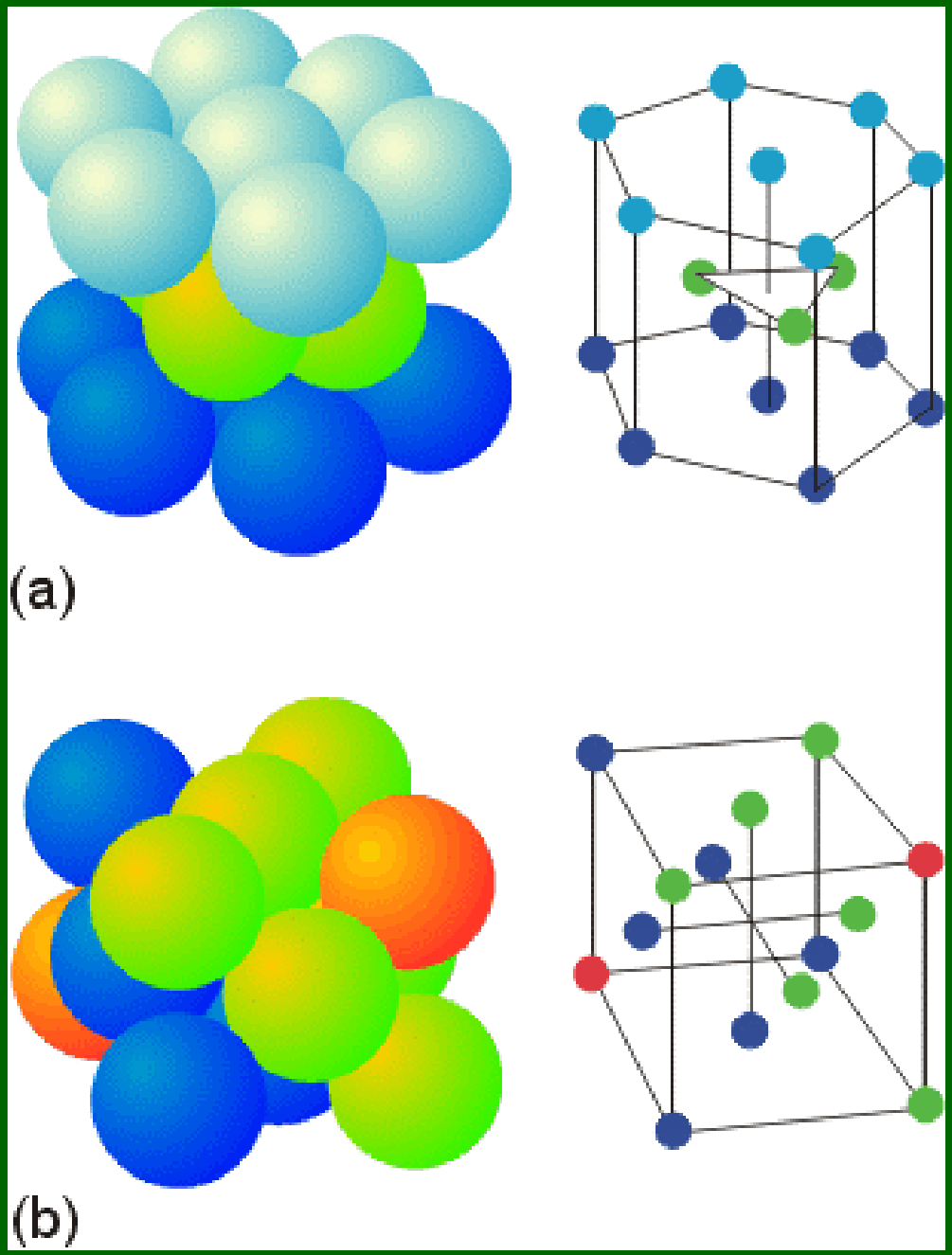


Metallic – Nonmetallic Properties

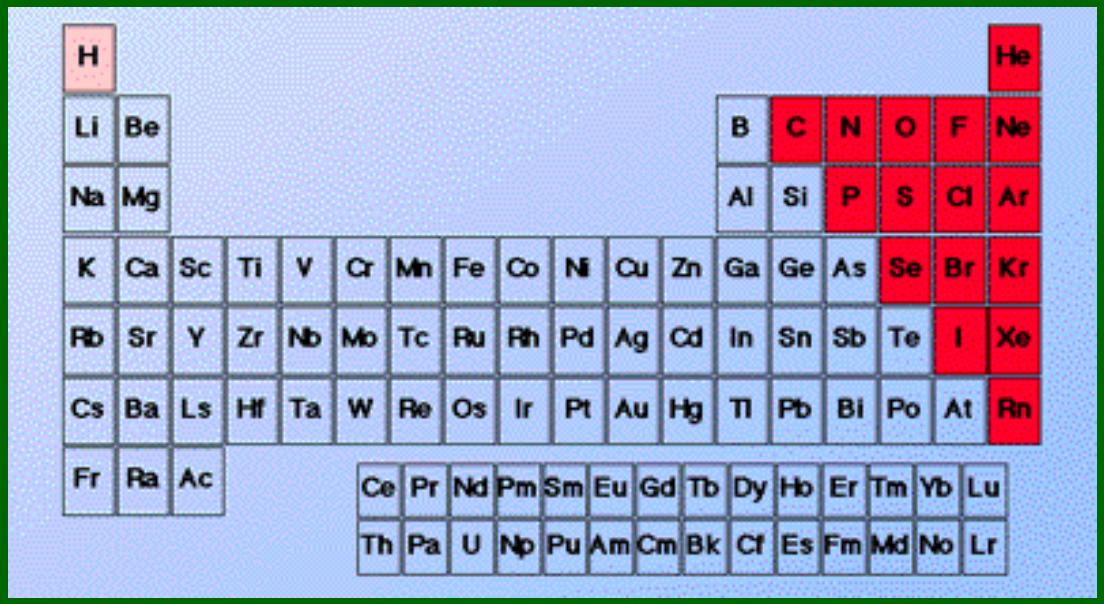




Close-packed structures
High coordination numbers (12)
Large atoms
Low ionization energies
High polarisibility
Omnidirectional metallic bonging

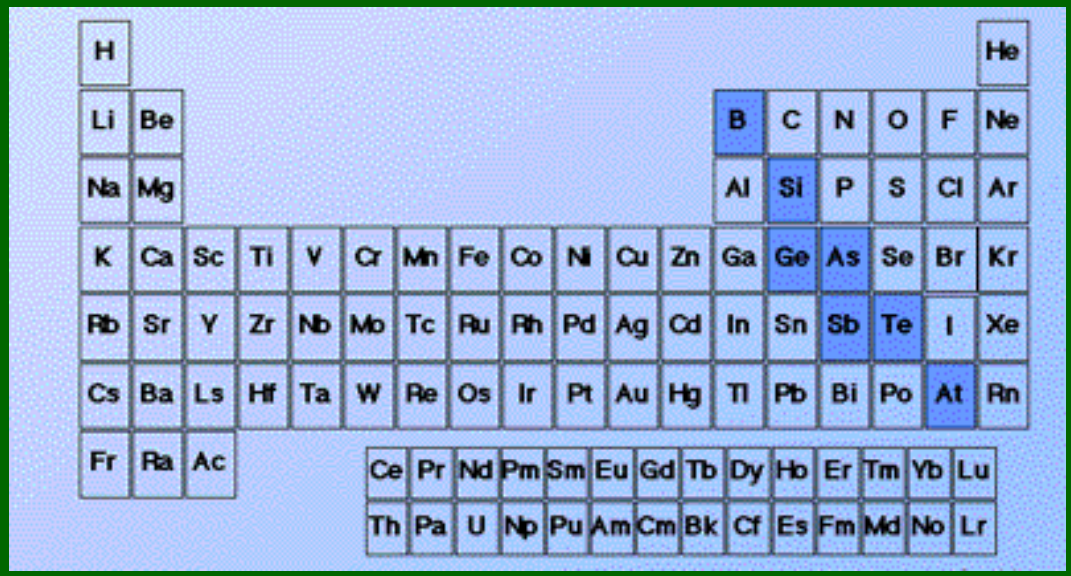

(a)
(b)

Nonmetals



Covalent bonds strong and directional
Good orbital overlap
Small atoms
High ionization energies, low polarizibility
Weak vdW interactions

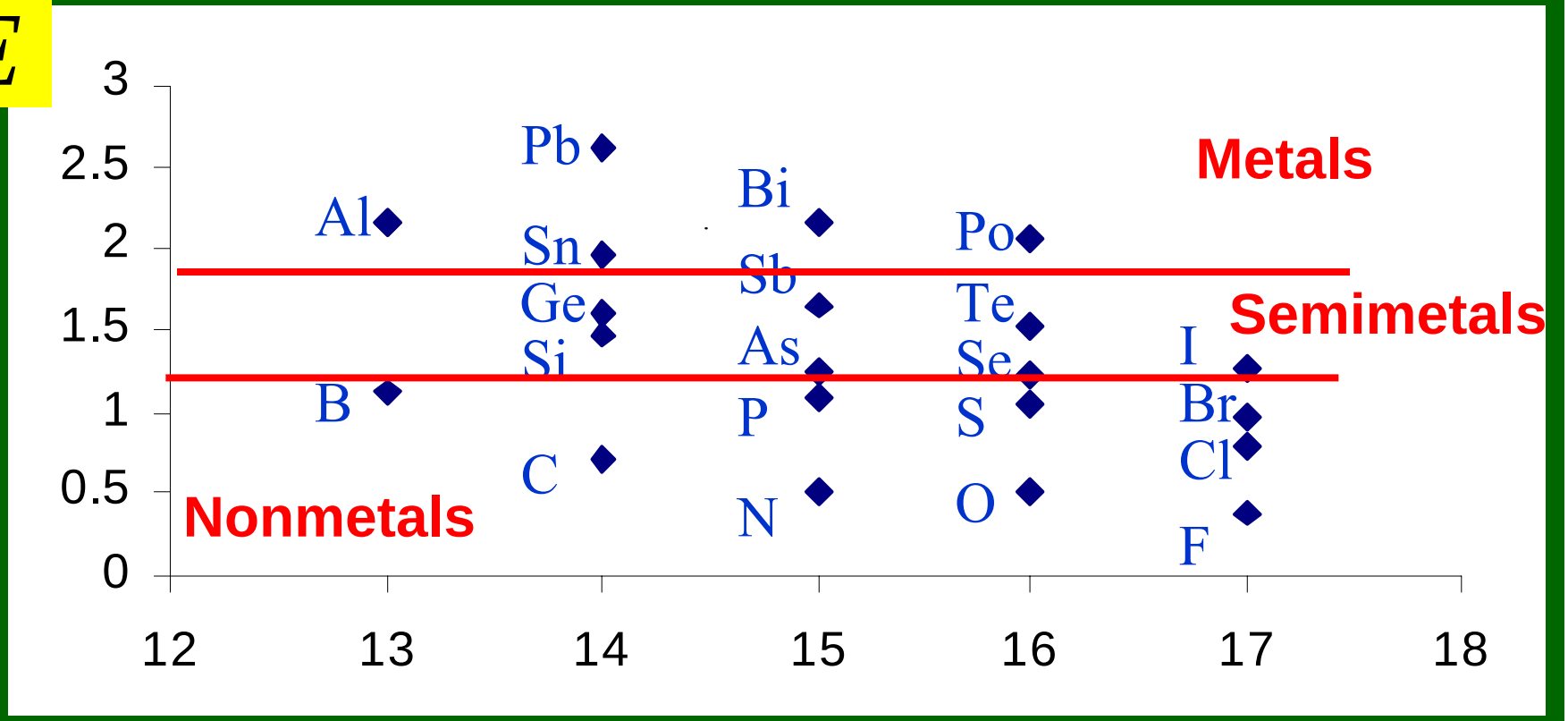
Metalloids - Semimetals



Weaker covalent bonds
vdW interactions
Secondary bonds

Metalloids - Semimetals

$$\frac{r}{IE}$$



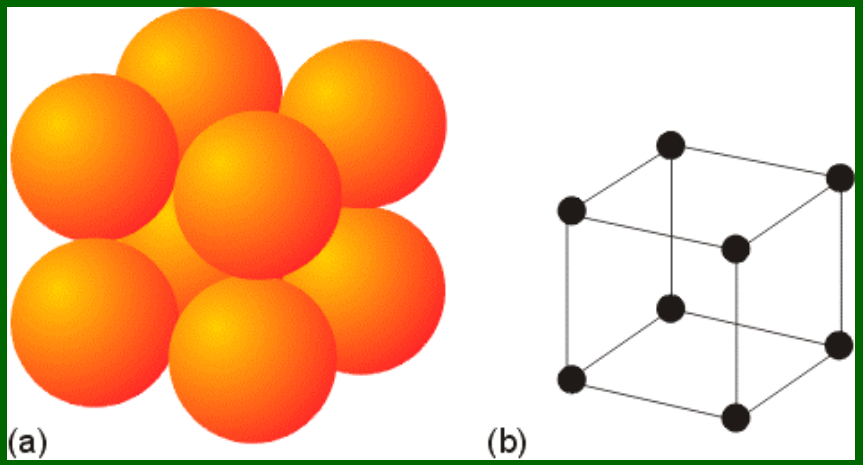
16th Group

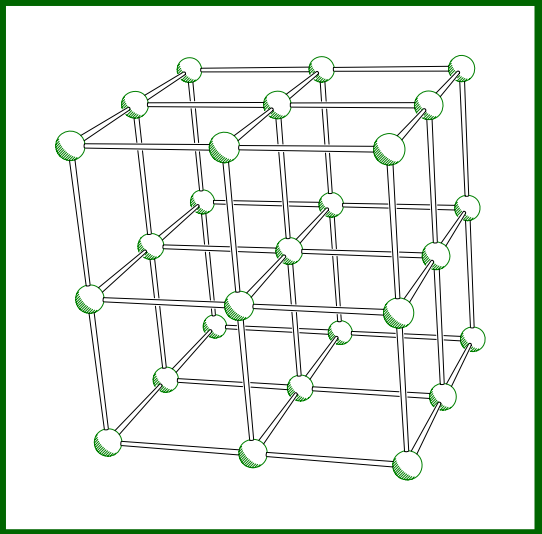
O and S - nonmetals

Se - nonmetallic and semimetallic modifictions (allotropes)

Te - semimetallic

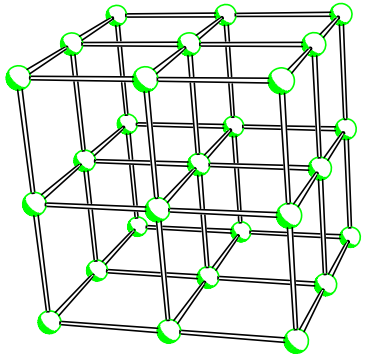
Po - metallic with a rare structure

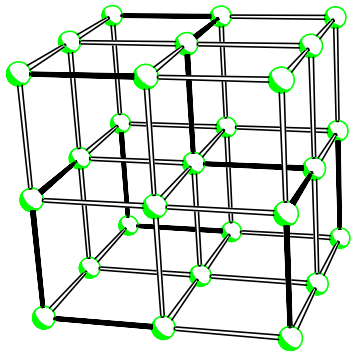


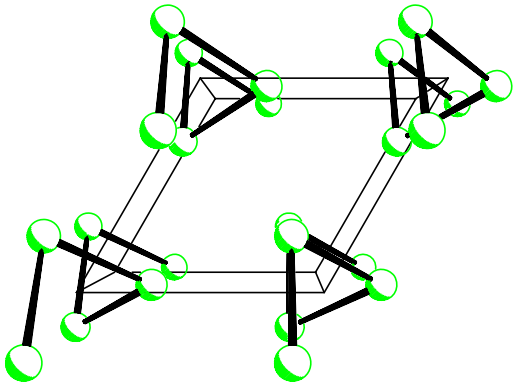


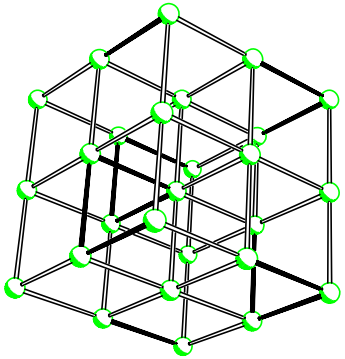
16th Group

Po - metal

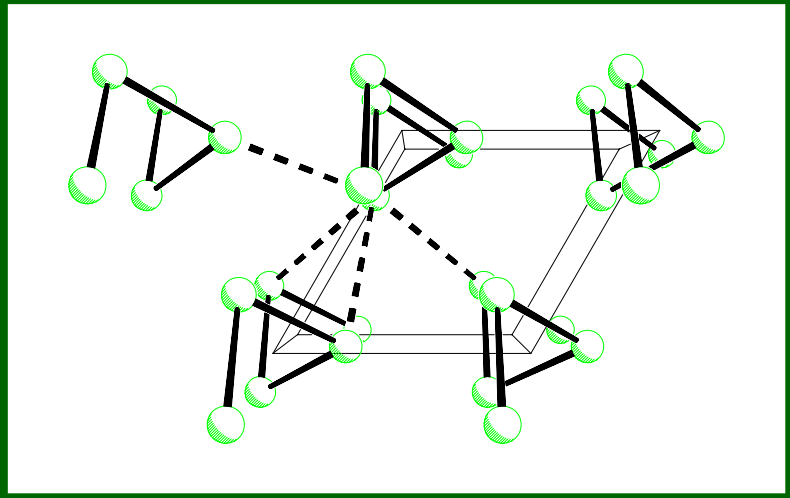








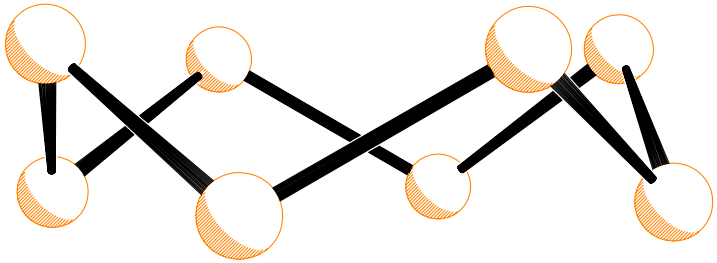
Te



Te - semimetal

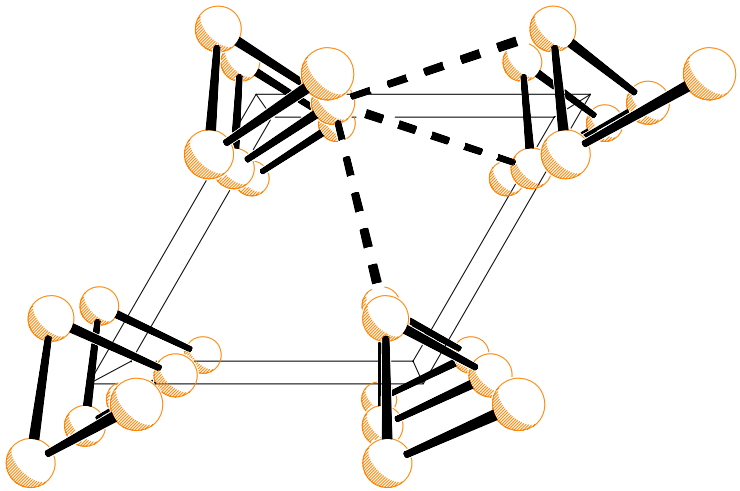
Se

Red selenium

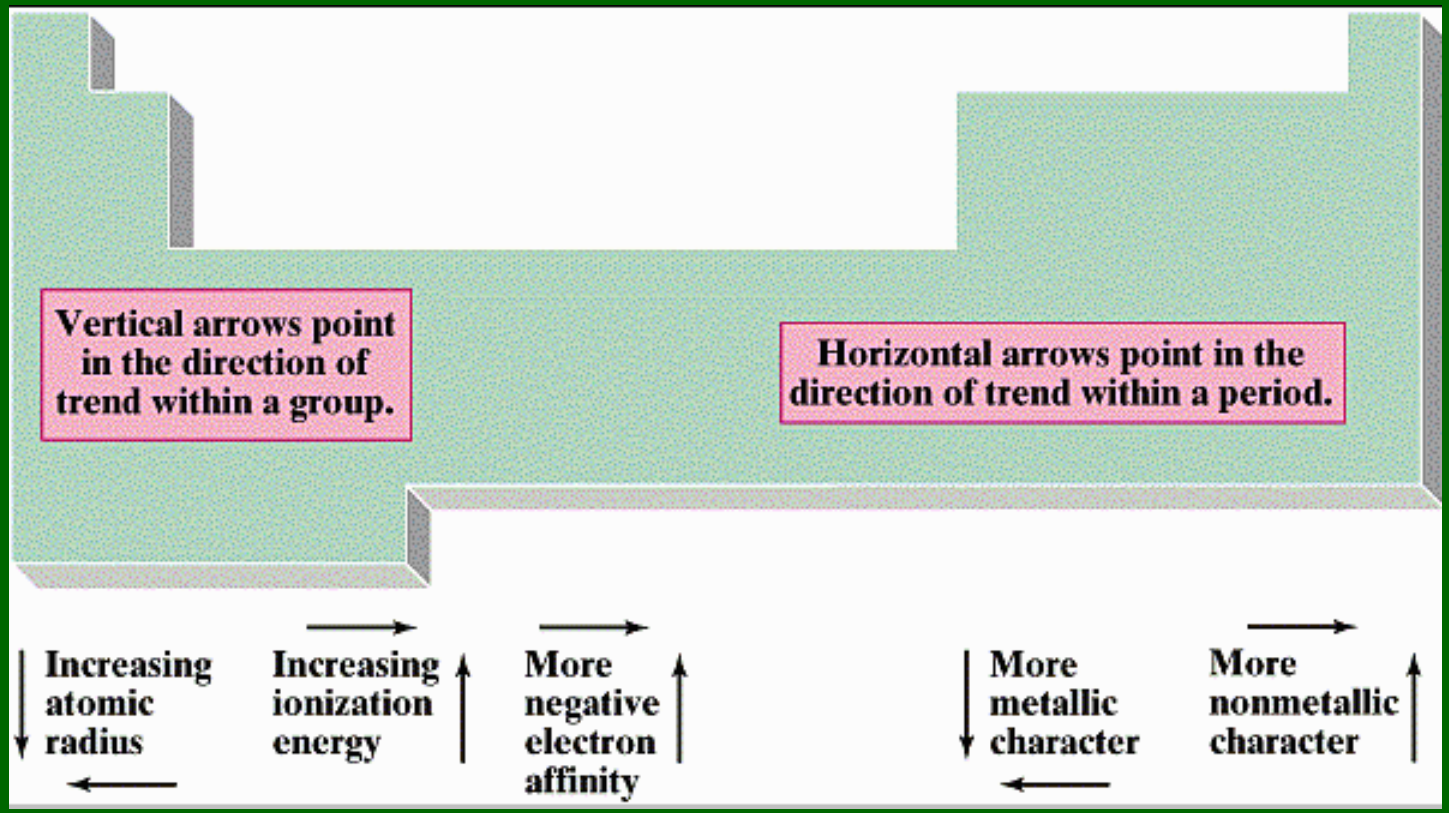


Se_8 nonmetal

Gray selenium



semimetal


Vertical arrows point in the direction of trend within a group.
Horizontal arrows point in the direction of trend within a period.
Increasing atomic radius
Increasing ionization energy
More negative electron affinity
More metallic character
More nonmetallic character