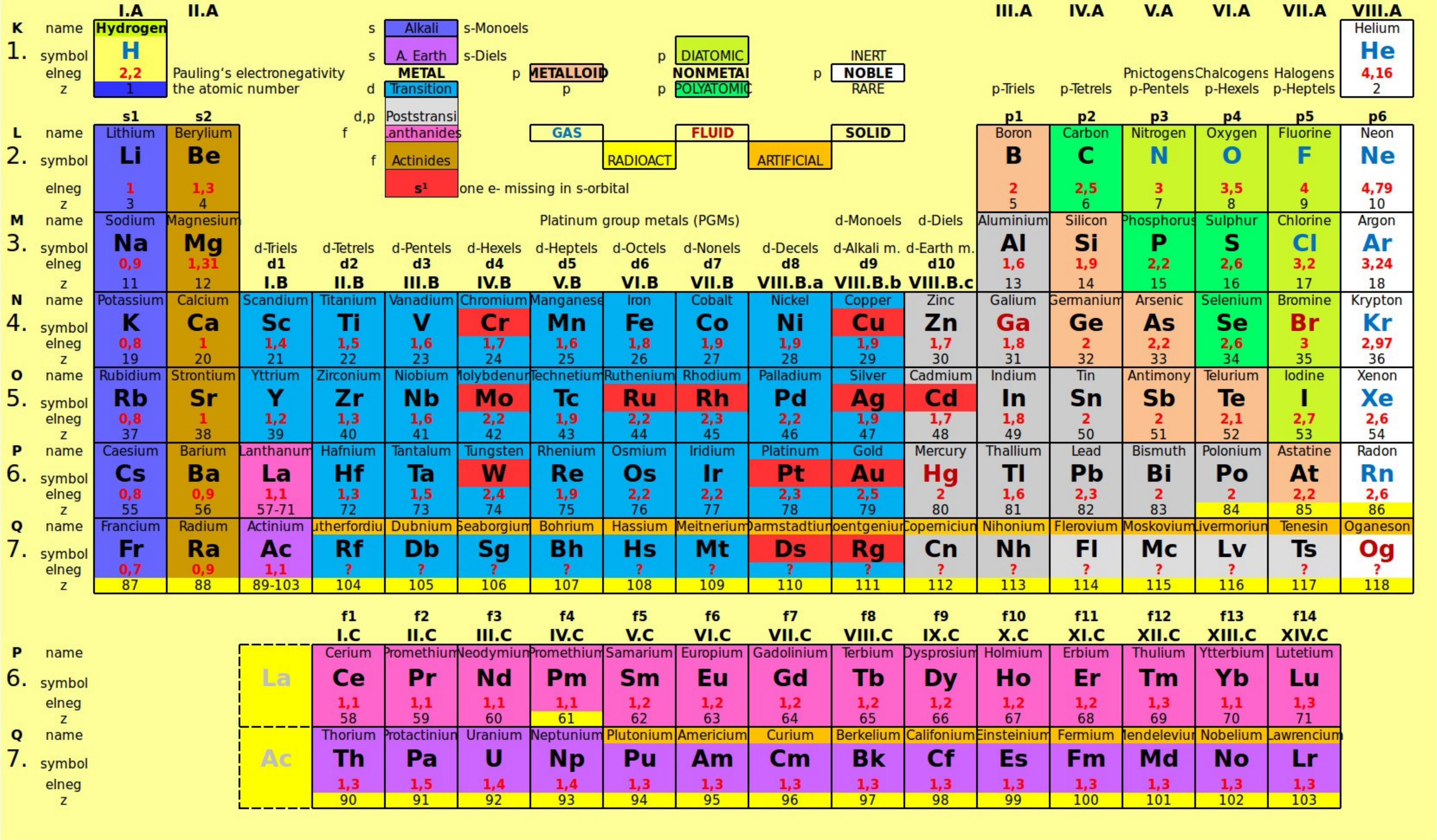
Introduction to Inorganic Chemistry



s Alkali s-Monoels
s A. Earth s-Diels
METAL
d Transition
d,p Poststransi
f Lanthanides
f Actinides
s^1 one e- missing in s-orbital

p METALLOID
p

p DIATOMIC
NONMETAL
p POLYATOMIC

INERT
p NOBLE
RARE

GAS RADIOACT FLUID ARTIFICIAL SOLID

elneg: Pauling‘s electronegativity
z: the atomic number

Platinum group metals (PGMs)

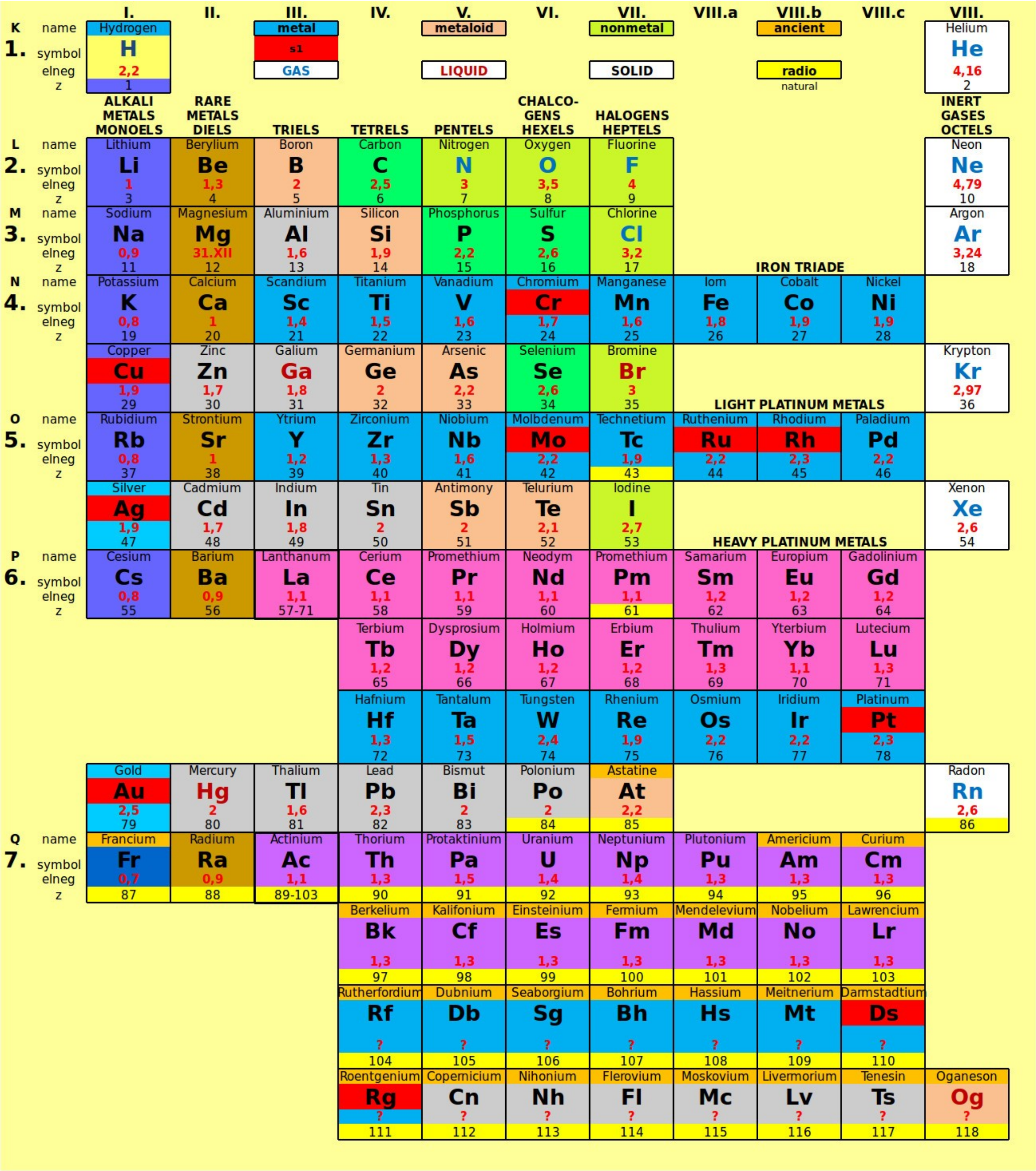
		I.A	II.A	I.B	II.B	III.B	IV.B	V.B	VI.B	VII.B	VIII.B.a	VIII.B.b	VIII.B.c	III.A	IV.A	V.A	VI.A	VII.A	VIII.A
		s1	s2	d1	d2	d3	d4	d5	d6	d7	d8	d9	d10	p1	p2	p3	p4	p5	p6
				d-Triels	d-Tetrels	d-Pentels	d-Hexels	d-Heptels	d-Octels	d-Nonels	d-Decels	d-Monoels d-Alkali m.	d-Diels d-Earth m.	p-Triels	p-Tetrels	Pnictogens p-Pentels	Chalcogens p-Hexels	Halogens p-Heptels	
K 1.	name symbol elneg z	Hydrogen H 2,2 1																	Helium He 4,16 2
L 2.	name symbol elneg z	Lithium Li 1 3	Berylium Be 1,3 4											Boron B 2 5	Carbon C 2,5 6	Nitrogen N 3 7	Oxygen O 3,5 8	Fluorine F 4 9	Neon Ne 4,79 10
M 3.	name symbol elneg z	Sodium Na 0,9 11	Magnesium Mg 1,31 12											Aluminium Al 1,6 13	Silicon Si 1,9 14	Phosphorus P 2,2 15	Sulphur S 2,6 16	Chlorine Cl 3,2 17	Argon Ar 3,24 18
N 4.	name symbol elneg z	Potassium K 0,8 19	Calcium Ca 1 20	Scandium Sc 1,4 21	Titanium Ti 1,5 22	Vanadium V 1,6 23	Chromium Cr 1,7 24	Manganese Mn 1,6 25	Iron Fe 1,8 26	Cobalt Co 1,9 27	Nickel Ni 1,9 28	Copper Cu 1,9 29	Zinc Zn 1,7 30	Galium Ga 1,8 31	Germanium Ge 2 32	Arsenic As 2,2 33	Selenium Se 2,6 34	Bromine Br 3 35	Krypton Kr 2,97 36
O 5.	name symbol elneg z	Rubidium Rb 0,8 37	Strontium Sr 1 38	Yttrium Y 1,2 39	Zirconium Zr 1,3 40	Niobium Nb 1,6 41	lolybdenur Mo 2,2 42	Technetium Tc 1,9 43	Ruthenium Ru 2,2 44	Rhodium Rh 2,3 45	Palladium Pd 2,2 46	Silver Ag 1,9 47	Cadmium Cd 1,7 48	Indium In 1,8 49	Tin Sn 2 50	Antimony Sb 2 51	Telurium Te 2,1 52	Iodine I 2,7 53	Xenon Xe 2,6 54
P 6.	name symbol elneg z	Caesium Cs 0,8 55	Barium Ba 0,9 56	Lanthanum La 1,1 57-71	Hafnium Hf 1,3 72	Tantalum Ta 1,5 73	Tungsten W 2,4 74	Rhenium Re 1,9 75	Osmium Os 2,2 76	Iridium Ir 2,2 77	Platinum Pt 2,3 78	Gold Au 2,5 79	Mercury Hg 2 80	Thallium Tl 1,6 81	Lead Pb 2,3 82	Bismuth Bi 2 83	Polonium Po 2 84	Astatine At 2,2 85	Radon Rn 2,6 86
Q 7.	name symbol elneg z	Francium Fr 0,7 87	Radium Ra 0,9 88	Actinium Ac 1,1 89-103	utherfordiu Rf ? 104	Dubnium Db ? 105	eaborgium Sg ? 106	Bohrium Bh ? 107	Hassium Hs ? 108	Meitnerium Mt ? 109	armstadtiun Ds ? 110	oentgeniur Rg ? 111	Copemiciun Cn ? 112	Nihonium Nh ? 113	Flerovium Fl ? 114	Moskovium Mc ? 115	ivermoriun Lv ? 116	Tenesin Ts ? 117	Oganeson Og ? 118

			f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12	f13	f14
			I.C	II.C	III.C	IV.C	V.C	VI.C	VII.C	VIII.C	IX.C	X.C	XI.C	XII.C	XIII.C	XIV.C
P 6.	name symbol elneg z	La	Cerium Ce 1,1 58	Promethium Pr 1,1 59	Neodymiun Nd 1,1 60	Promethium Pm 1,1 61	Samarium Sm 1,2 62	Europium Eu 1,2 63	Gadolinium Gd 1,2 64	Terbium Tb 1,2 65	Dysprosiun Dy 1,2 66	Holmium Ho 1,2 67	Erbium Er 1,2 68	Thulium Tm 1,3 69	Ytterbium Yb 1,1 70	Lutetium Lu 1,3 71
Q 7.	name symbol elneg z	Ac	Thorium Th 1,3 90	Protactiniun Pa 1,5 91	Uranium U 1,4 92	Neptunium Np 1,4 93	Plutonium Pu 1,3 94	Americium Am 1,3 95	Curium Cm 1,3 96	Berkelium Bk 1,3 97	Califonium Cf 1,3 98	Einsteinium Es 1,3 99	Fermium Fm 1,3 100	lendeleviur Md 1,3 101	Nobelium No 1,3 102	awrencium Lr 1,3 103

The Recent Periodic Table of Elements

UNIVERZITA J. E. PURKYNĚ V ÚSTÍ NAD LABEM

The Amazing Vertical Form Of The Periodic Table of Elements



		I.	II.	III.	IV.	V.	VI.	VII.	VIII.a	VIII.b	VIII.c	VIII.
K 1.	name symbol elneg z	Hydrogen H 2,2 1		metal s1 GAS		metaloid LIQUID		nonmetal SOLID		ancient radio natural		Helium He 4,16 2
		ALKALI METALS MONOELS	RARE METALS DIELS	TRIELS	TETRELS	PENTELS	CHALCO-GENS HEXELS	HALOGENS HEPTELS				INERT GASES OCTELS
L 2.	name symbol elneg z	Lithium Li 1 3	Beryllium Be 1,3 4	Boron B 2 5	Carbon C 2,5 6	Nitrogen N 3 7	Oxygen O 3,5 8	Fluorine F 4 9				Neon Ne 4,79 10
M 3.	name symbol elneg z	Sodium Na 0,9 11	Magnesium Mg 31.XII 12	Aluminium Al 1,6 13	Silicon Si 1,9 14	Phosphorus P 2,2 15	Sulfur S 2,6 16	Chlorine Cl 3,2 17	IRON TRIADE			Argon Ar 3,24 18
N 4.	name symbol elneg z	Potassium K 0,8 19	Calcium Ca 1 20	Scandium Sc 1,4 21	Titanium Ti 1,5 22	Vanadium V 1,6 23	Chromium Cr 1,7 24	Manganese Mn 1,6 25	Iom Fe 1,8 26	Cobalt Co 1,9 27	Nickel Ni 1,9 28	
		Copper Cu 1,9 29	Zinc Zn 1,7 30	Gallium Ga 1,8 31	Germanium Ge 2 32	Arsenic As 2,2 33	Selenium Se 2,6 34	Bromine Br 3 35	LIGHT PLATINUM METALS			Krypton Kr 2,97 36
O 5.	name symbol elneg z	Rubidium Rb 0,8 37	Strontium Sr 1 38	Ytrium Y 1,2 39	Zirconium Zr 1,3 40	Niobium Nb 1,6 41	Molbdenum Mo 2,2 42	Technetium Tc 1,9 43	Ruthenium Ru 2,2 44	Rhodium Rh 2,3 45	Paladium Pd 2,2 46	
		Silver Ag 1,9 47	Cadmium Cd 1,7 48	Indium In 1,8 49	Tin Sn 2 50	Antimony Sb 2 51	Telurium Te 2,1 52	Iodine I 2,7 53	HEAVY PLATINUM METALS			Xenon Xe 2,6 54
P 6.	name symbol elneg z	Cesium Cs 0,8 55	Barium Ba 0,9 56	Lanthanum La 1,1 57-71	Cerium Ce 1,1 58	Promethium Pr 1,1 59	Neodym Nd 1,1 60	Promethium Pm 1,1 61	Samarium Sm 1,2 62	Europium Eu 1,2 63	Gadolinium Gd 1,2 64	
					Terbium Tb 1,2 65	Dysprosium Dy 1,2 66	Holmium Ho 1,2 67	Erbium Er 1,2 68	Thulium Tm 1,3 69	Yterbium Yb 1,1 70	Lutecium Lu 1,3 71	
					Hafnium Hf 1,3 72	Tantalum Ta 1,5 73	Tungsten W 2,4 74	Rhenium Re 1,9 75	Osmium Os 2,2 76	Iridium Ir 2,2 77	Platinum Pt 2,3 78	
		Gold Au 2,5 79	Mercury Hg 2 80	Thalium Tl 1,6 81	Lead Pb 2,3 82	Bismut Bi 2 83	Polonium Po 2 84	Astatine At 2,2 85				Radon Rn 2,6 86
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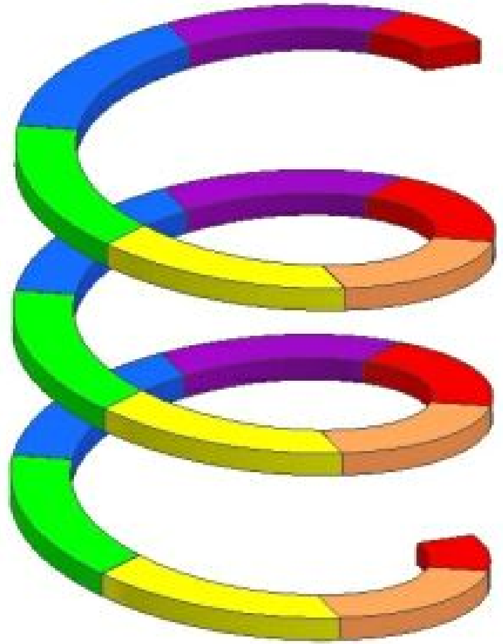
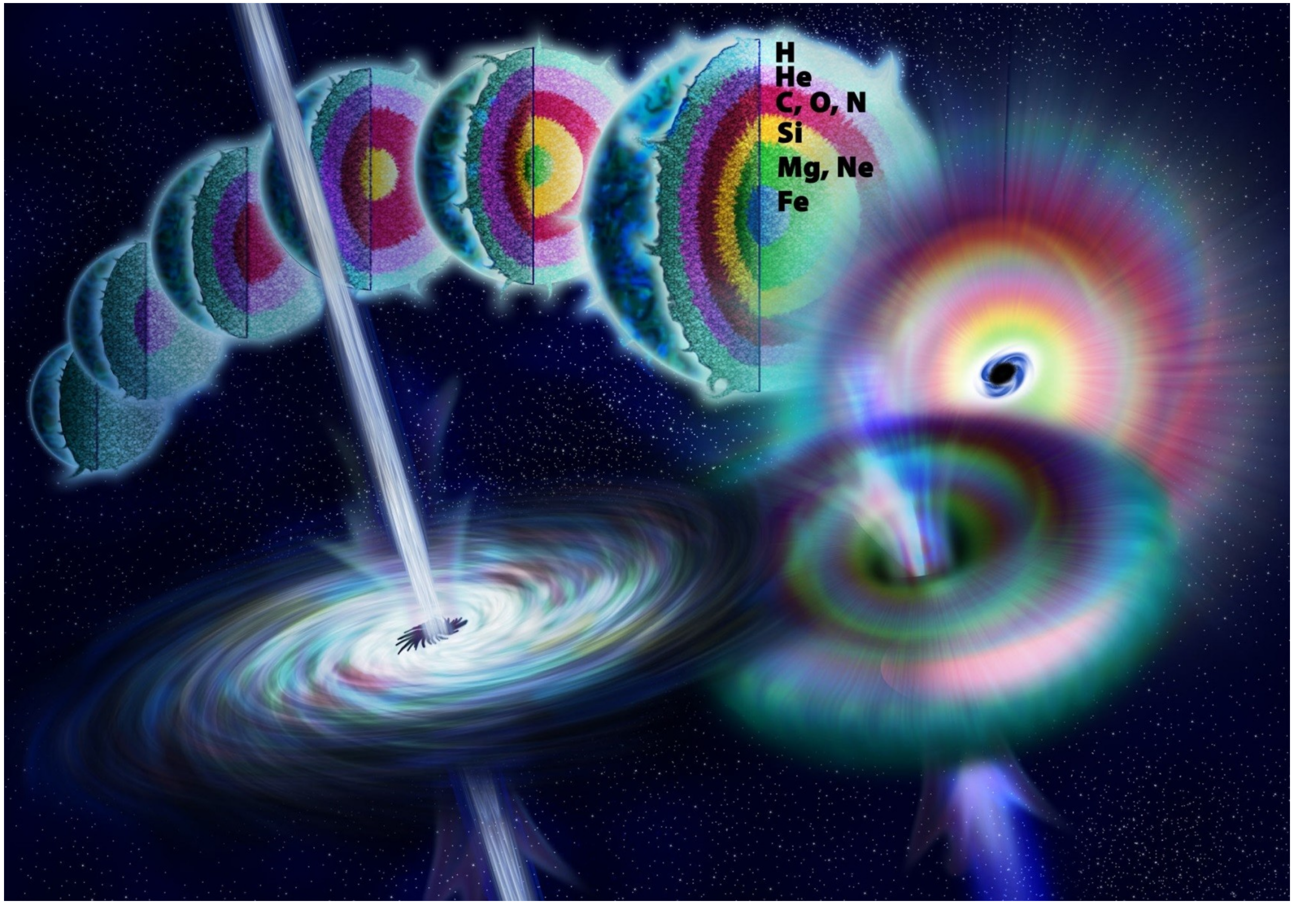
					Berkelium Bk 1,3 97	Kalifonium Cf 1,3 98	Einsteinium Es 1,3 99	Fermium Fm 1,3 100	Mendelevium Md 1,3 101	Nobelium No 1,3 102	Lawrencium Lr 1,3 103	
					Rutherfordium Rf ? 104	Dubnium Db ? 105	Seaborgium Sg ? 106	Bohrium Bh ? 107	Hassium Hs ? 108	Meitnerium Mt ? 109	Darmstadtium Ds ? 110	
					Roentgenium Rg ? 111	Copernicium Cn ? 112	Nihonium Nh ? 113	Flerovium Fl ? 114	Moskovium Mc ? 115	Livermorium Lv ? 116	Tenesin Ts ? 117	Oganeson Og ? 118



http://www.jitrnizeme.cz/view.php?cisloclanku=2012030004

The origin of all chemical elements…



The Sun Star Stages	**Timescale**	**Temp. K**
H burning	7 bilion years	1-2.**10**^{7}
He burning	0.5 bilion years	2-3.**10**^{8}
C burning	600 years	6-8.**10**^{8}
Ne burning	1 year	1.**10**^{9}
O burning	6 months	2.**10**^{9}
Si burning	1 day	**3.10**^{9}

The Big Bang nucleosynthesis – **H, He**

Cosmic ray spallation – **Li, Be, B**

Stellar nucleosynthesis – from **C** to **Fe**, and Supernova and other nucleosynthesis – **all other chemical elements**

https://www.forbes.com/sites/startswithabang/2016/05/11/which-elements-will-never-be-made-by-our-sun/#654834ce1aba
https://geo.libretexts.org/Core/Geochemistry/The_Earth_and_its_Lithosphere/Origin_of_the_chemical_elements
E. M. Burbidge; G. R. Burbidge; W. A. Fowler; F. Hoyle (1957). "Synthesis of the Elements in Stars". Reviews of Modern Physics. 29 (4): 547–650.

Atom

Results of the Ernest **Rutherford's experiment** (Thin Gold foil, alpha particles irradiation):

There is very small and heavy **nucleus** in the centre of each atom, composed from **nucleones** = positively charged protones (**p^+**) and zero charged neutrones (**n^0**). Each atomic nuclei in electroneutral atom is surrounded by very light negatively charged electrones (**e^-**) in the **core**.

Electrones are located in so called atomic orbitals (**AO**) - „statistically the most probable place of the electrone occurence in the core of the atom".

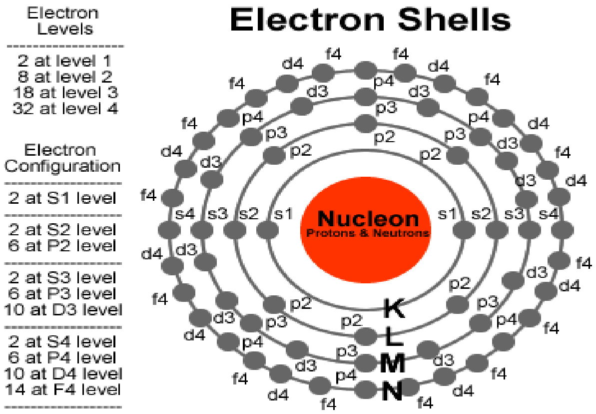
The **number** of protones in the nuclei and electrones in the core of the electroneutral atom must be equal.

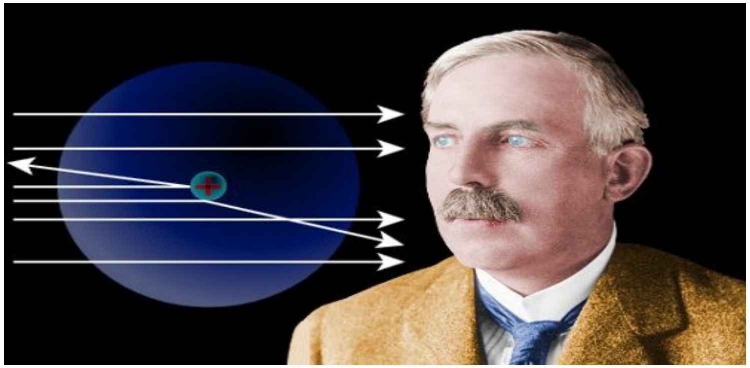
The **magnitude** of the atom is at about 10.000 times greater than the magnitude of the nuclei.

There is a lot of space in the core layer. All the smallest particles behave realativistic, the particle-wave dualism, have their own magnetic movement moment (spin).

The subject of Physics is to study transformations of **enormous nuclear energies** and nuclear transmutations.

Chemistry focuses on study of much smaller energies, which allow to make huge number of chemical **bonds** between atoms, elements.



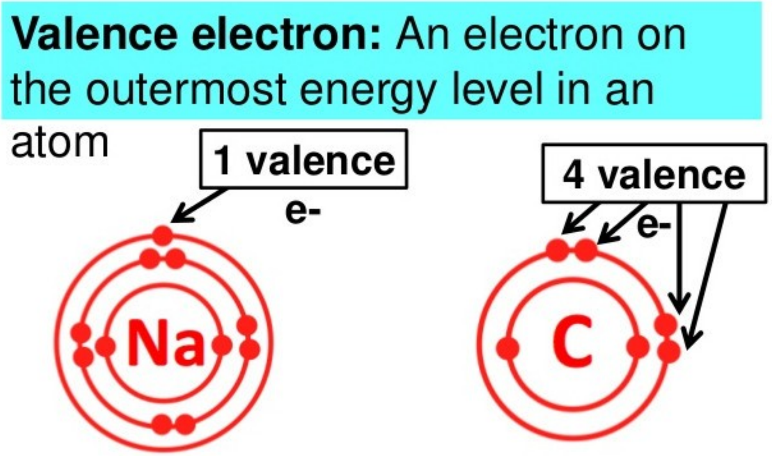


Ernest Rutherford (1871 - 1937)

https://www.famousscientists.org/ernest-rutherford/; http://animatedphysics.com/energylevels/2d_atomic_orbitals.gif

Valence shell electronic configuration

Elements use only the last (valence) shell of electrones to make chemical bonds !!!



Valence electron: An electron on the outermost energy level in an atom

https://www.slideshare.net/beb7714/lesson-1-37179816

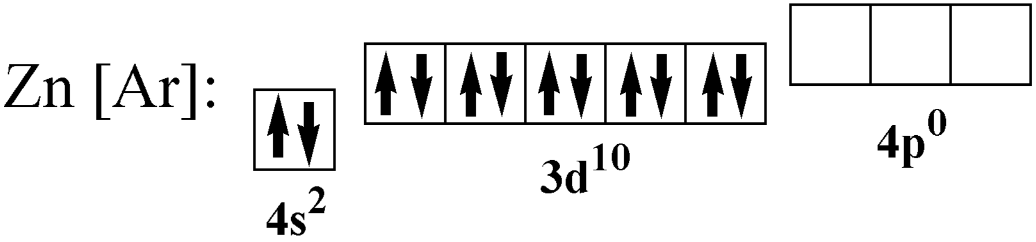


Fig. 2 – The example of the valence shell electronic configuration of Zinc atom using the **genial learning concept:** frame drawings of orbitals with vertical arrows as electrones.

Rules for filling of orbitals:

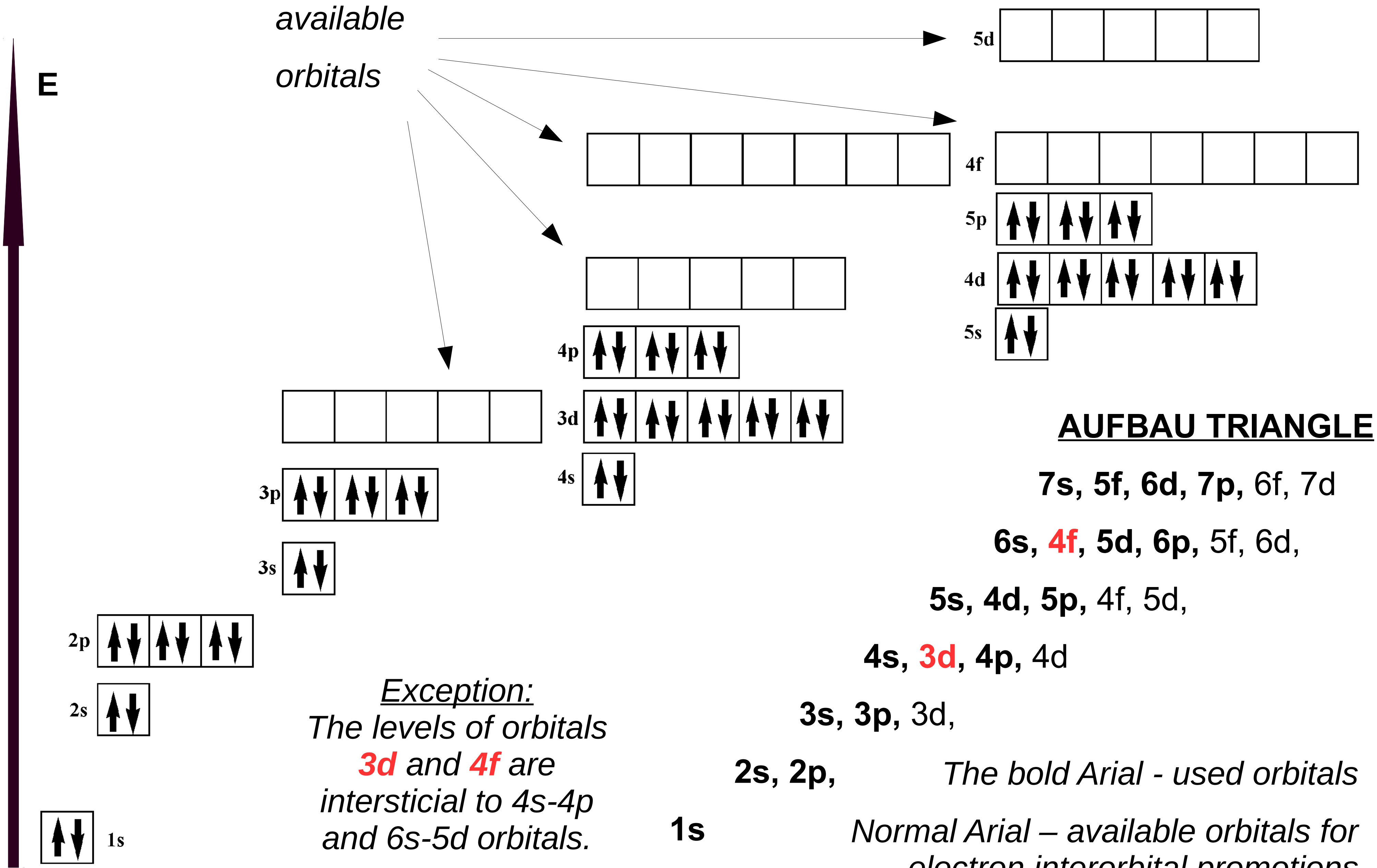
Aufbau principle – a maximum of two electrons are put into orbitals in the order of increasing orbital energy: the lowest-energy orbitals are filled before electrons are placed in higher-energy orbitals.

Hund‘s rule: electrones with the same quantum of energy can occupie each suborbital of energetically degenerated p, d, f, g.. orbitals (means suborbitals at the same energy level!) independently electrones occupie each suborbital at the same energy level independently.

Pauli‘s rule: Each orbital could be filled by one or two electrones. No two electrons in the same atom can have the same values of the four quantum numbers. Paired electrones must differ in their spins (+1/2, -1/2) of each orbital at least.

https://en.wikipedia.org/wiki/Electron_configuration

Aufbau principle on the Noble gases example



AUFBAU TRIANGLE

7s, 5f, 6d, 7p, 6f, 7d

6s, 4f, 5d, 6p, 5f, 6d,

5s, 4d, 5p, 4f, 5d,

4s, 3d, 4p, 4d

3s, 3p, 3d,

2s, 2p,

1s

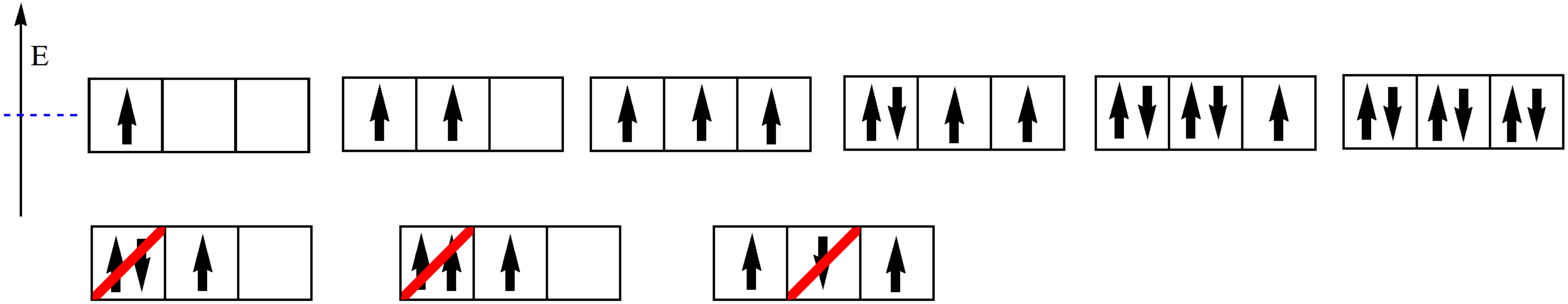
The bold Arial - used orbitals

Normal Arial – available orbitals for electron interorbital promotions

Exception:
The levels of orbitals
3d and 4f are
interstitial to 4s-4p
and 6s-5d orbitals.

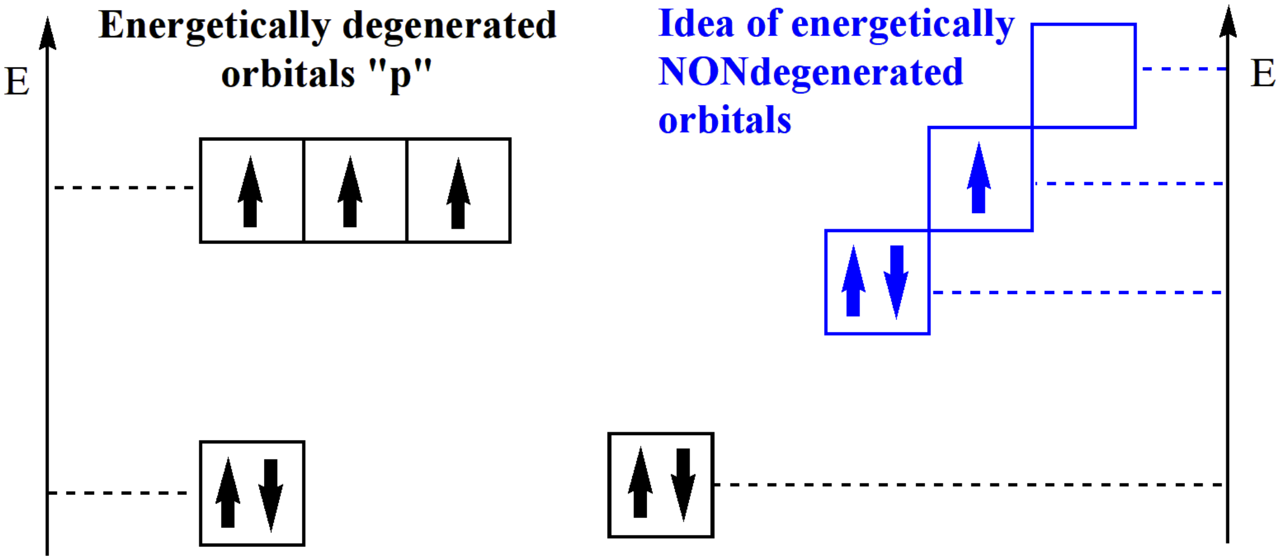
An graphical description of some allowed energetical quants of electrones.

Hund‘s rule



- The principles of the electron filling using the Hund‘s rule shown on the examples of various p-orbitals.
- There are **energetically degenerated** (on the same energy level) **p, d, f.. orbitals**, each have got 3, 5, 7...suborbitals, that can be filled by 0-6, 0-10, 0-14...electrones using the Hund‘s rule.
- Hund‘s rule say, that these type of orbitals could be occupied **at first by single electrones** only, and after that could be respective electrone couples paired as shown on the picture above.
- All electrones filling **the same** energetically degenerated orbital have **the same** quantum of energy, **equal** to the energy level of the orbital.
- Couples making electrones (s = -1/2) are waking up the **electronic repulsion** (both have negative charge!) in the orbital, so the pairing of electrones need some small extra energy.

What could happen with degenerated orbitals when the spherical s-orbitals should be mentioned only?



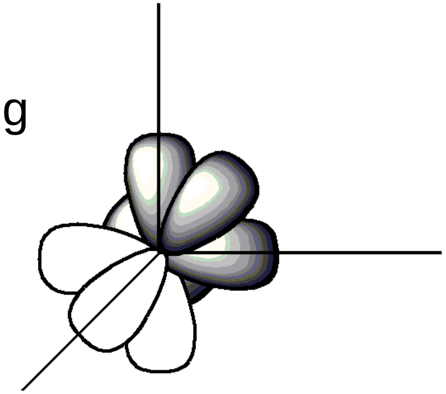
Energetically degenerated orbitals "p"

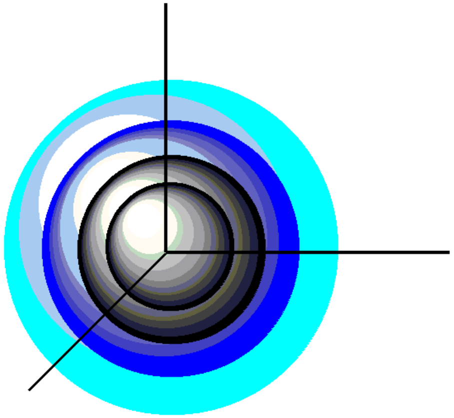
Idea of energetically NONdegenerated orbitals

Energetically NONdegenerated orbitals "s"

space saving

space optimizing





Pauli‘s rule

Zero, one or two spin different electrons may occupie each atomic orbital only.

In the same atom there could not exist two electrons with the same set of quantum numbers (n, l, m, s).

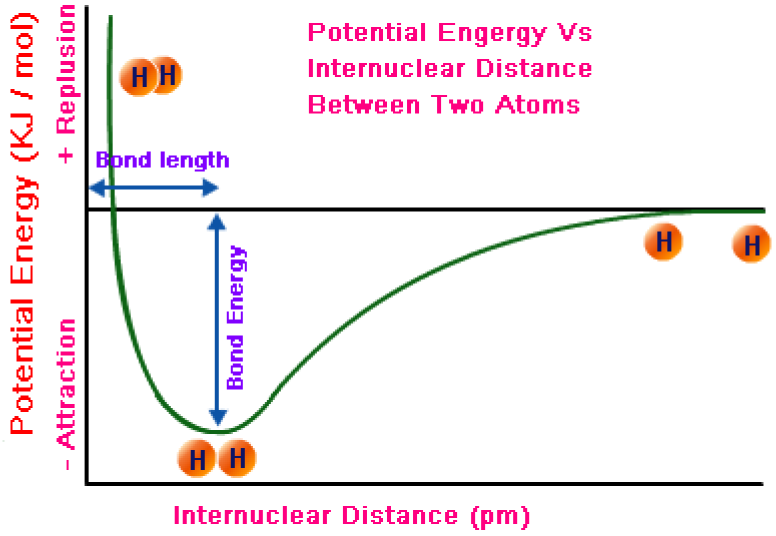
They must so differ minimally in their spin numbers (+1/2, -1/2).

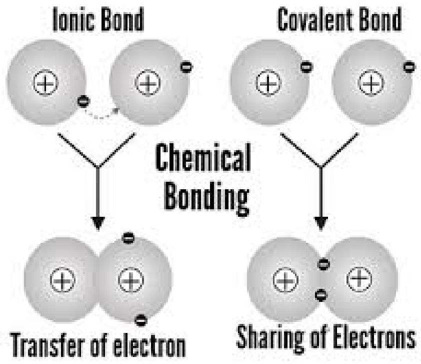
Chemical bond

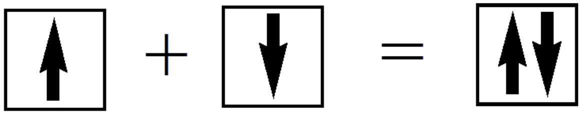
is the **attractive force interaction** of atoms assemble into molecules.

There are significant changes of bonding particles in energies of **the valence shell** electrones and orbitals.

The System wants **to minimize the energy content** – isolated atoms have got higher energies than molecules. **Bond energy** dissipate into surrounding in order to minimalise the Energy of the System.

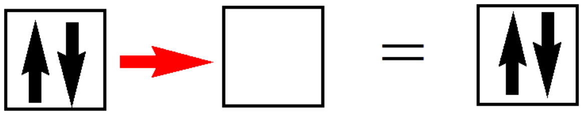






COVALENT BOND

equally share electrones and orbitales

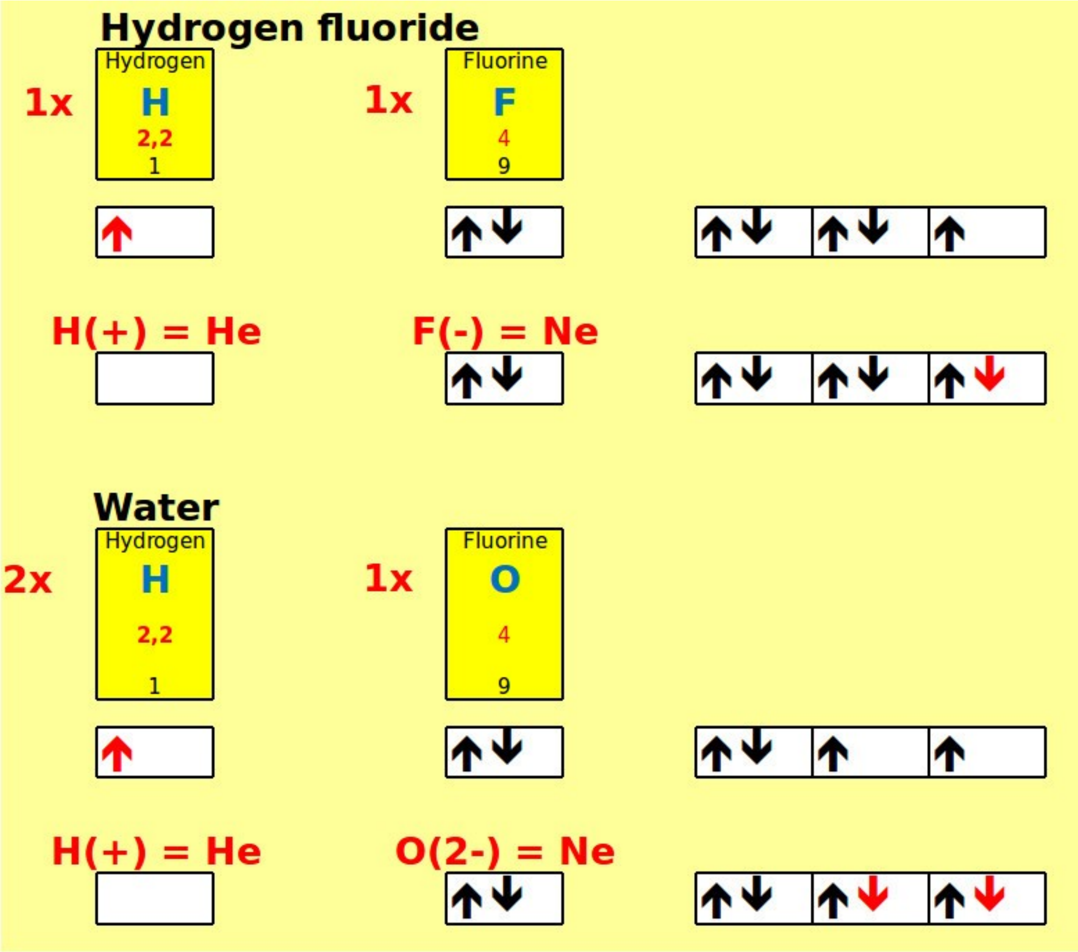


DONOR-ACCEPTOR BOND

donation of **the electron pair** to acceptor with the vacant (electron free) orbital

1. http://chemistry.tutorvista.com/organic-chemistry/chemical-bonds.html 2. http://myassignmenthelp.net

How elements reacts together?



Hydrogen fluoride

1x Hydrogen H 2,2 1

1x Fluorine F 4 9

H(+) = He

F(-) = Ne

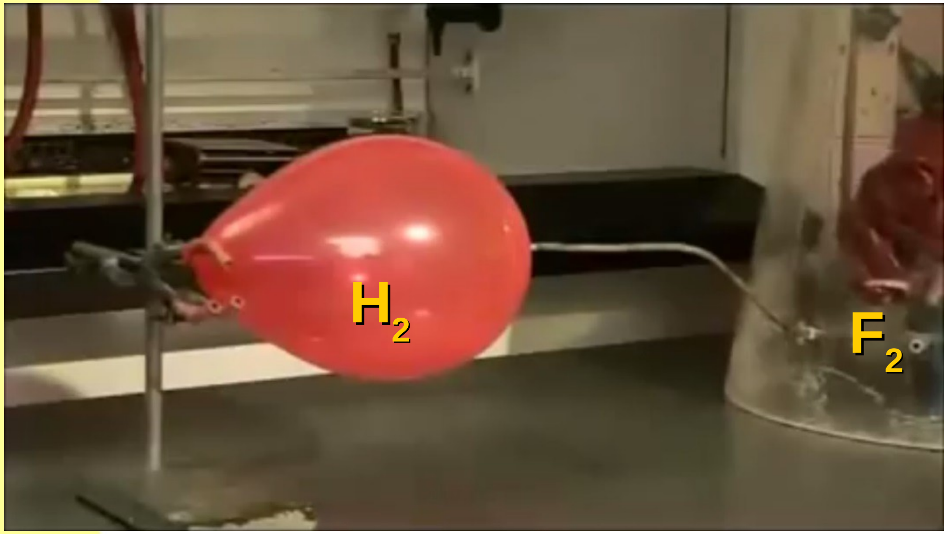
Water

2x Hydrogen H 2,2 1

1x Fluorine O 4 9

H(+) = He

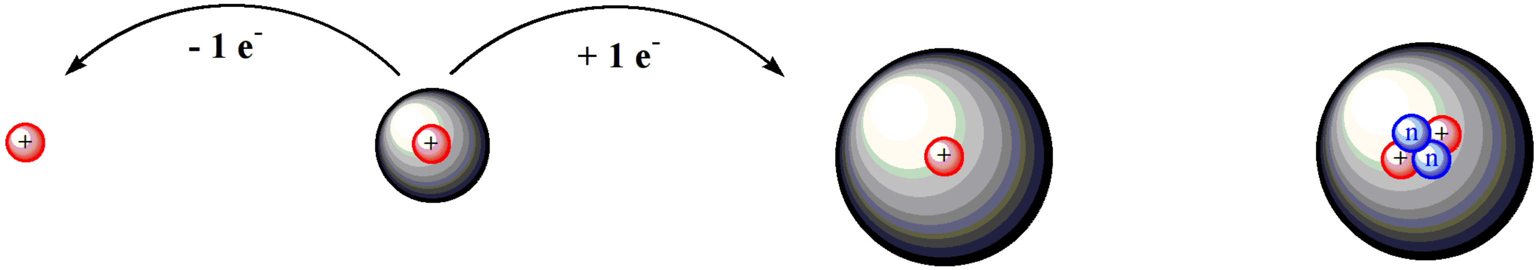
O(2-) = Ne



https://www.youtube.com/watch?v=rDpM9_G3Giw

https://www.youtube.com/watch?v=ce6imsXTkGQ

How looks like the simplest stable atom/molecule and their electronic configuration?



$_{1}H^{+1}\ \boxed{}$

$1\,s^{0}$

"Protone" cation

$_{1}H^{0} - 1\ e^{-} = {}_{1}H^{+1}$

One e^{-} ionized, excited by ionization quantum of energy! Free (vacant) orbital.

The simplest cation, Lewis acid, central atom, electrophile.

$^{1}_{1}H^{0}\ \boxed{\uparrow}$

$1\,s^{1}$

Hydrogen gas - "protium"

The simplest, lightest neutral atom, chemical element. $_{1}H$ is very reactive, right form H_2! Looking for the stable electron configuration =

free (e^{-} donor) or fully filled (e^{-} acceptor)

valence atomic orbitals (mimic el. config. of He)

$_{1}H^{-1}\ \boxed{\uparrow\downarrow}$

$1\,s^{2}$

"Hydridic" anion

$_{1}H^{0} + 1\ e^{-} = {}_{1}H^{-1}$

when absorb 1 e^{-}. During that process emit Electrone affinity energy. Full atomic orbital. Electron pair!

The simplest anion, Lewis base, ligand, nucleophile.

$_{2}He^{0}\ \boxed{\uparrow\downarrow}$

$1\,s^{2}$

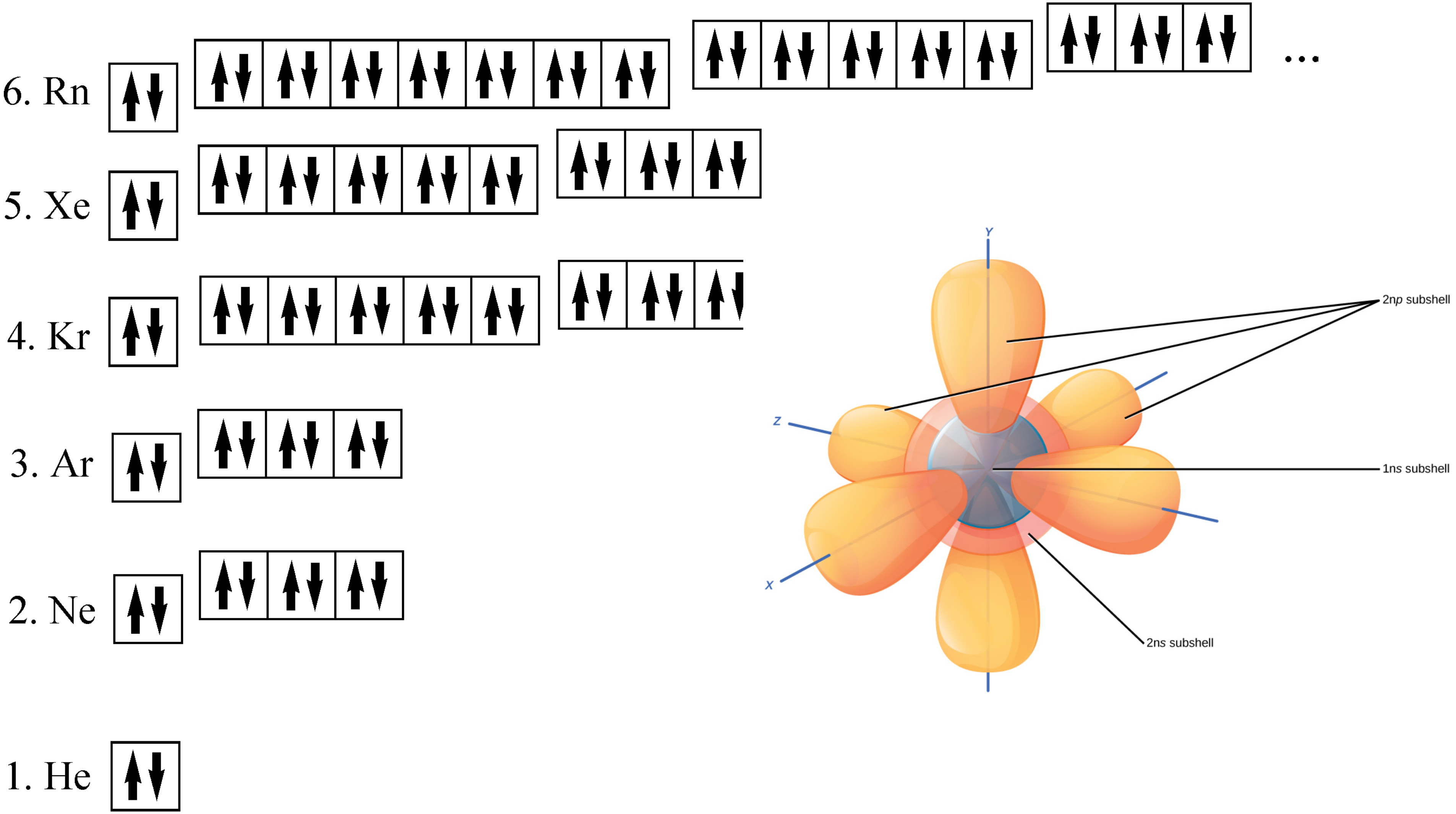
Helium

1st stable, nonreactive neutral atom.

Full atomic orbital, electron pair. 1st non reactive, inert, noble, rare gas! The standard of the most stable electronic configuration!

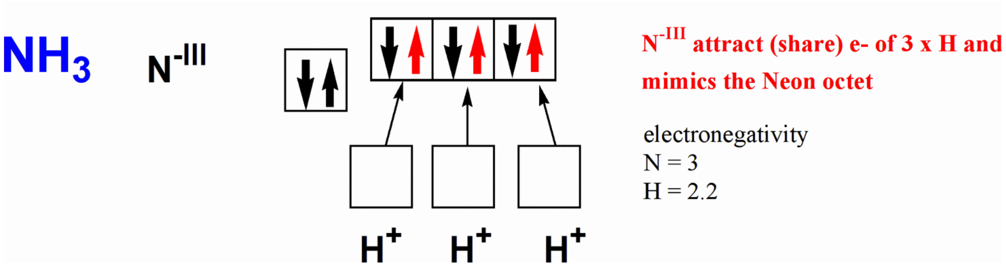
Can not form He_2 molecules.

Why Noble gases exist as independent atoms and do not form molecules as H_2, O_2, N_2 etc.?



Why elements reacts together?

„**<u>The Stable Octet Rule</u>**“ – all other elements than Noble gases want **to mimic** their extremely stable („fullfilled“) electronic configuration by the reaction with other elements - „octet“ generally means valence orbitals filled with all electrones



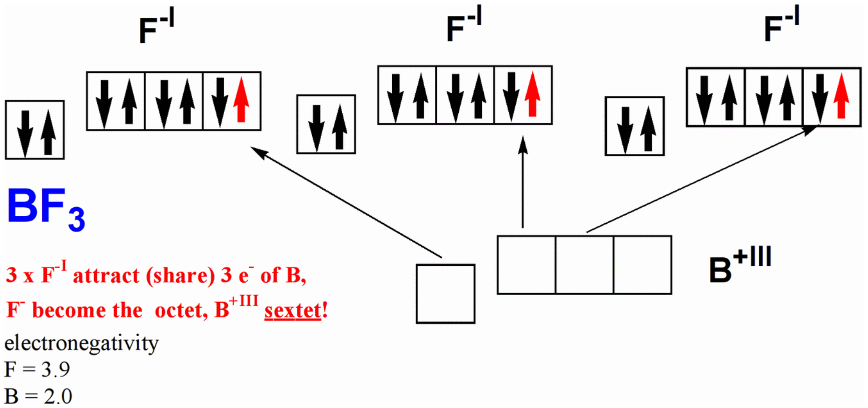
N^{-III} attract (share) e- of 3 x H and mimics the Neon octet

electronegativity
N = 3
H = 2.2

<u>Exceptions from the Octet Rule:</u>

HYPOvalency – less than octet

3 valence e^- - only **6** shared e^-!

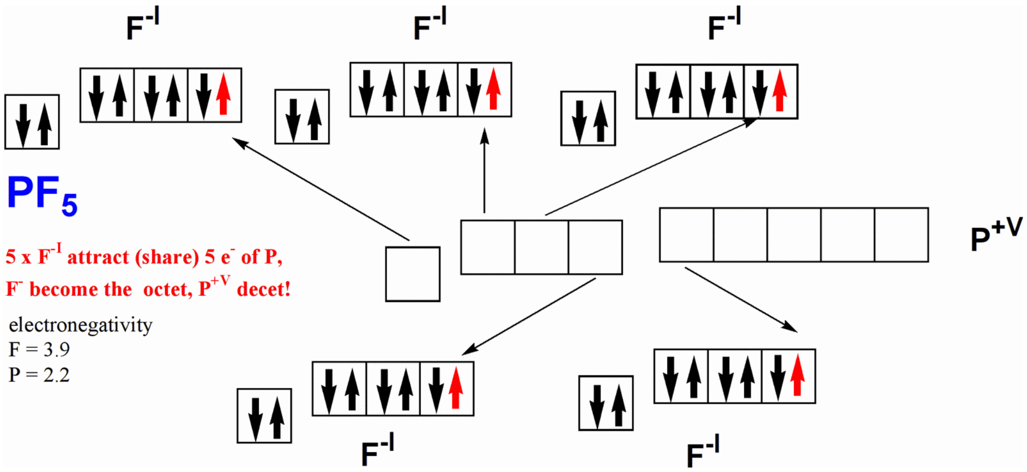


3 x F^{-I} attract (share) 3 e^- of B,
F^- become the octet, B^{+III} <u>sextet</u>!

electronegativity
F = 3.9
B = 2.0

HYPERvalency – more than octet

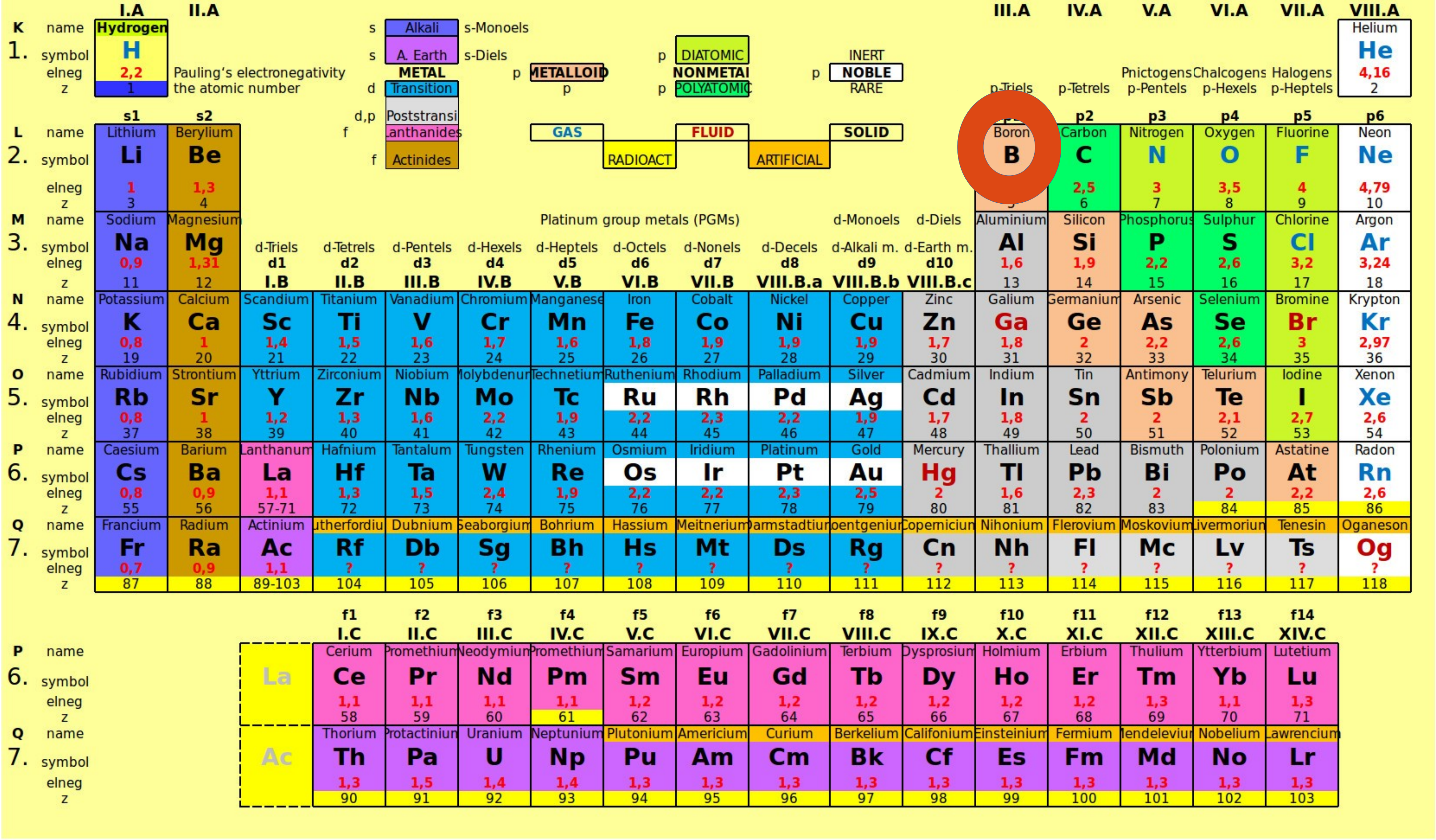
5 valence e^- means **10** shared e^-!



5 x F^{-I} attract (share) 5 e^- of P,
F^- become the octet, P^{+V} decet!

electronegativity
F = 3.9
P = 2.2

How to recognize the most stable compound of each element?



s Alkali s-Monoels
s A. Earth s-Diels
METAL
d Transition
d,p Poststransi
f Lanthanides
f Actinides
p METALLOID p
p DIATOMIC
NONMETAL
p POLYATOMIC
INERT
p NOBLE
RARE
GAS
RADIOACT
FLUID
ARTIFICIAL
SOLID

Pauling's electronegativity
the atomic number

Platinum group metals (PGMs)

		I.A s1	II.A s2	d-Triels d1 I.B	d-Tetrels d2 II.B	d-Pentels d3 III.B	d-Hexels d4 IV.B	d-Heptels d5 V.B	d-Octels d6 VI.B	d-Nonels d7 VII.B	d-Decels d8 VIII.B.a	d-Monoels d-Alkali m. d9 VIII.B.b	d-Diels d-Earth m. d10 VIII.B.c	III.A p-Triels	IV.A p-Tetrels p2	V.A Pnictogens p-Pentels p3	VI.A Chalcogens p-Hexels p4	VII.A Halogens p-Heptels p5	VIII.A p6
K 1.	name symbol elneg z	Hydrogen H 2,2 1																	Helium He 4,16 2
L 2.	name symbol elneg z	Lithium Li 1 3	Berylium Be 1,3 4											Boron B	Carbon C 2,5 6	Nitrogen N 3 7	Oxygen O 3,5 8	Fluorine F 4 9	Neon Ne 4,79 10
M 3.	name symbol elneg z	Sodium Na 0,9 11	Magnesium Mg 1,31 12											Aluminium Al 1,6 13	Silicon Si 1,9 14	Phosphorus P 2,2 15	Sulphur S 2,6 16	Chlorine Cl 3,2 17	Argon Ar 3,24 18
N 4.	name symbol elneg z	Potassium K 0,8 19	Calcium Ca 1 20	Scandium Sc 1,4 21	Titanium Ti 1,5 22	Vanadium V 1,6 23	Chromium Cr 1,7 24	Manganese Mn 1,6 25	Iron Fe 1,8 26	Cobalt Co 1,9 27	Nickel Ni 1,9 28	Copper Cu 1,9 29	Zinc Zn 1,7 30	Galium Ga 1,8 31	Germanium Ge 2 32	Arsenic As 2,2 33	Selenium Se 2,6 34	Bromine Br 3 35	Krypton Kr 2,97 36
O 5.	name symbol elneg z	Rubidium Rb 0,8 37	Strontium Sr 1 38	Yttrium Y 1,2 39	Zirconium Zr 1,3 40	Niobium Nb 1,6 41	olybdenu Mo 2,2 42	Technetium Tc 1,9 43	Ruthenium Ru 2,2 44	Rhodium Rh 2,3 45	Palladium Pd 2,2 46	Silver Ag 1,9 47	Cadmium Cd 1,7 48	Indium In 1,8 49	Tin Sn 2 50	Antimony Sb 2 51	Telurium Te 2,1 52	Iodine I 2,7 53	Xenon Xe 2,6 54
P 6.	name symbol elneg z	Caesium Cs 0,8 55	Barium Ba 0,9 56	Lanthanum La 1,1 57-71	Hafnium Hf 1,3 72	Tantalum Ta 1,5 73	Tungsten W 2,4 74	Rhenium Re 1,9 75	Osmium Os 2,2 76	Iridium Ir 2,2 77	Platinum Pt 2,3 78	Gold Au 2,5 79	Mercury Hg 2 80	Thallium Tl 1,6 81	Lead Pb 2,3 82	Bismuth Bi 2 83	Polonium Po 2 84	Astatine At 2,2 85	Radon Rn 2,6 86
Q 7.	name symbol elneg z	Francium Fr 0,7 87	Radium Ra 0,9 88	Actinium Ac 1,1 89-103	utherfordiu Rf ? 104	Dubnium Db ? 105	eaborgium Sg ? 106	Bohrium Bh ? 107	Hassium Hs ? 108	Meitnerium Mt ? 109	armstadtiu Ds ? 110	oentgeniu Rg ? 111	Coperniciu Cn ? 112	Nihonium Nh ? 113	Flerovium Fl ? 114	Moskovium Mc ? 115	ivermoriu Lv ? 116	Tenesin Ts ? 117	Oganeson Og ? 118

			f1 I.C	f2 II.C	f3 III.C	f4 IV.C	f5 V.C	f6 VI.C	f7 VII.C	f8 VIII.C	f9 IX.C	f10 X.C	f11 XI.C	f12 XII.C	f13 XIII.C	f14 XIV.C
P 6.	name symbol elneg z	La	Cerium Ce 1,1 58	Promethium Pr 1,1 59	Neodymiu Nd 1,1 60	Promethium Pm 1,1 61	Samarium Sm 1,2 62	Europium Eu 1,2 63	Gadolinium Gd 1,2 64	Terbium Tb 1,2 65	Dysprosium Dy 1,2 66	Holmium Ho 1,2 67	Erbium Er 1,2 68	Thulium Tm 1,3 69	Ytterbium Yb 1,1 70	Lutetium Lu 1,3 71
Q 7.	name symbol elneg z	Ac	Thorium Th 1,3 90	Protactiniu Pa 1,5 91	Uranium U 1,4 92	Neptunium Np 1,4 93	Plutonium Pu 1,3 94	Americium Am 1,3 95	Curium Cm 1,3 96	Berkelium Bk 1,3 97	Californium Cf 1,3 98	Einsteinium Es 1,3 99	Fermium Fm 1,3 100	endeleviu Md 1,3 101	Nobelium No 1,3 102	Lawrencium Lr 1,3 103

How to recognize the most stable compound of each element?

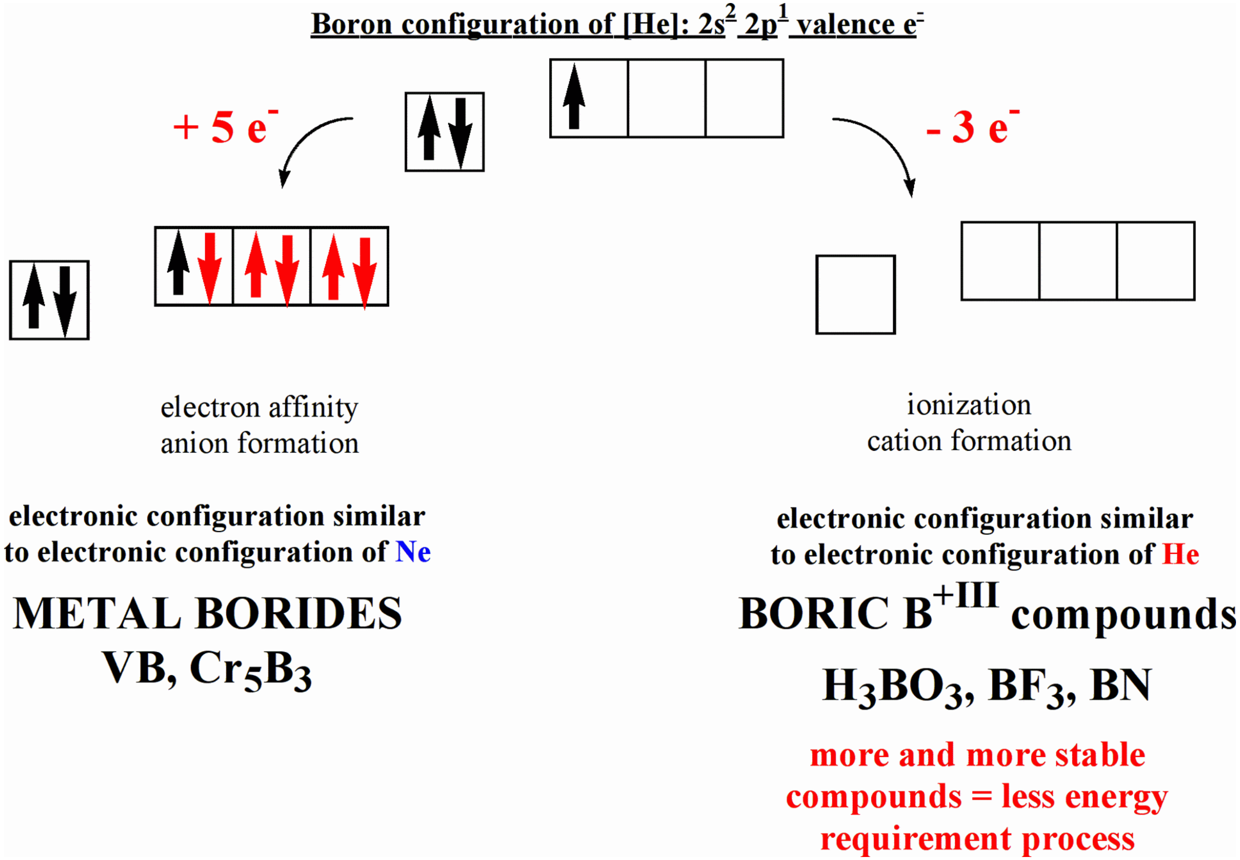
H_3BO_3 – primary source of B element in the nature

$H^{+}_{3}B^{+III}O^{-II}_{3}$ – boron has 3 valence e^- in 4 valence atomic orbitals (1 x s AO, 3 x p AO)

Strategy of boron to mimic the stable electronic configuration of a nearest Noble gas element:

1. choice – B release all **3 e^-**, originate B^{+III} (boric acid, borax etc.)

2. choice – B involve most **5 e^-**, originate B^{-I}, B^{-III}, B^{-V} (varoius metal borides)



Boron configuration of [He]: $2s^2$ $2p^1$ valence e^-

+ 5 e^-

- 3 e^-

electron affinity
anion formation

ionization
cation formation

electronic configuration similar to electronic configuration of Ne

METAL BORIDES
VB, Cr_5B_3

electronic configuration similar to electronic configuration of He

BORIC B^{+III} compounds

H_3BO_3, BF_3, BN

more and more stable compounds = less energy requirement process

Chemical elements with the odd (even) numbers of valence electrones PREFERE to build stable compounds with the same odd (even) oxidation number.

3 e^- B = BCl_3 (B^{+III})

4 e^- C = CO (C^{+II}), CO_2 (C^{+IV})

5 e^- N = N_2O (N^{+I}), N_2O_5 (N^{+V})

How to recognize acid, base, salt or complex?

The ARRHENIUS Theory	**The BRØNSTED-LOWRY Theory**	**The LEWIS Theory**
Acids are substances that contain hydrogen **H**. Bases are substances that contain hydroxyl **OH**, group.	An acid is a proton **donor (H+)**. A base is a proton acceptor.	Acids are **electron pair** acceptors. Bases are **electron pair** donors.
HCl and **NaOH**	$\mathbf{NH_3}$ and $\mathbf{H_2O}$	$\mathbf{BF_3}$ and $\mathbf{NH_3}$
neutralization $HCl + NaOH = H_2O + NaCl$ + heat	**neutralization** $\mathbf{NH_3} + H_2O = NH_4^+ + \mathbf{OH^-}$ $\mathbf{NH_3} + HCl = NH_4^+ + \mathbf{Cl^-}$	**neutralization** $\mathbf{BF_3 + NH_3 = BF_3.NH_3}$ **complex !!!**
$H^+ + OH^- = H_2O$ Limited use only.	$H_2O + H_2O = H_3O^+ + OH^-$ Solvent Dependent Theory!	Nearly Universal Theory.

BA – Brønsted acid

LA – Lewis acid

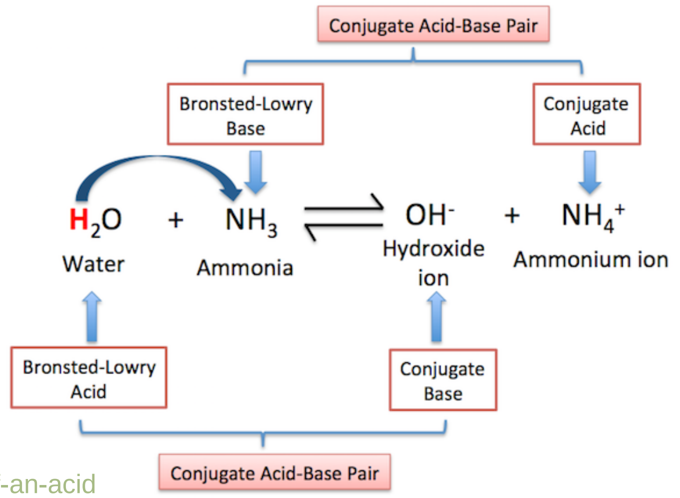
BB – Brønsted base

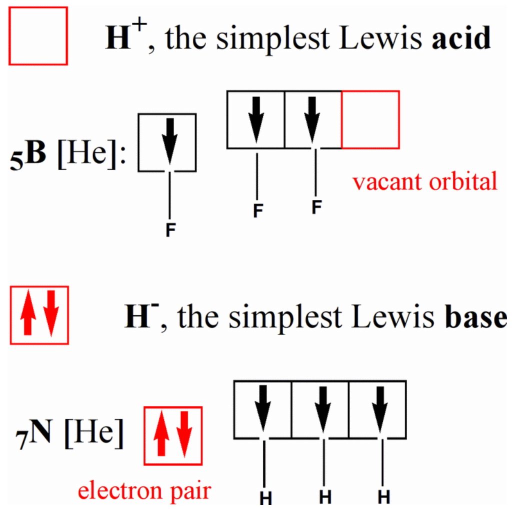
LB – Lewis base

S - salt

C - complex

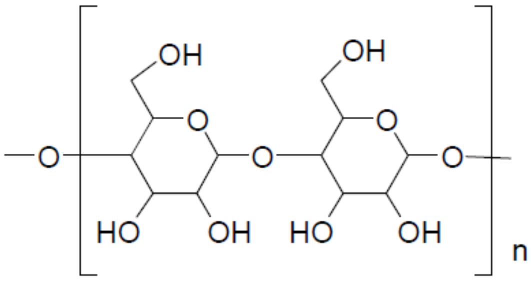
https://www.quora.com/What-are-the-charactericis-of-an-acid





1. The similar can dissolve similar! The non/polar solute attract/dissolve compounds of the similar polarity.

Water dissolve NaCl, sugar, acids,
and water attract water, acids...



celulosa

2. Polar solute is being repulsed on the nonpolar (hydrophobic) surface, nonpolar analyte on the polar surface (hydrophilic).

celulose = polar surface (many of -OH groups)
celulose knows how to separate some nonpolar drugs...

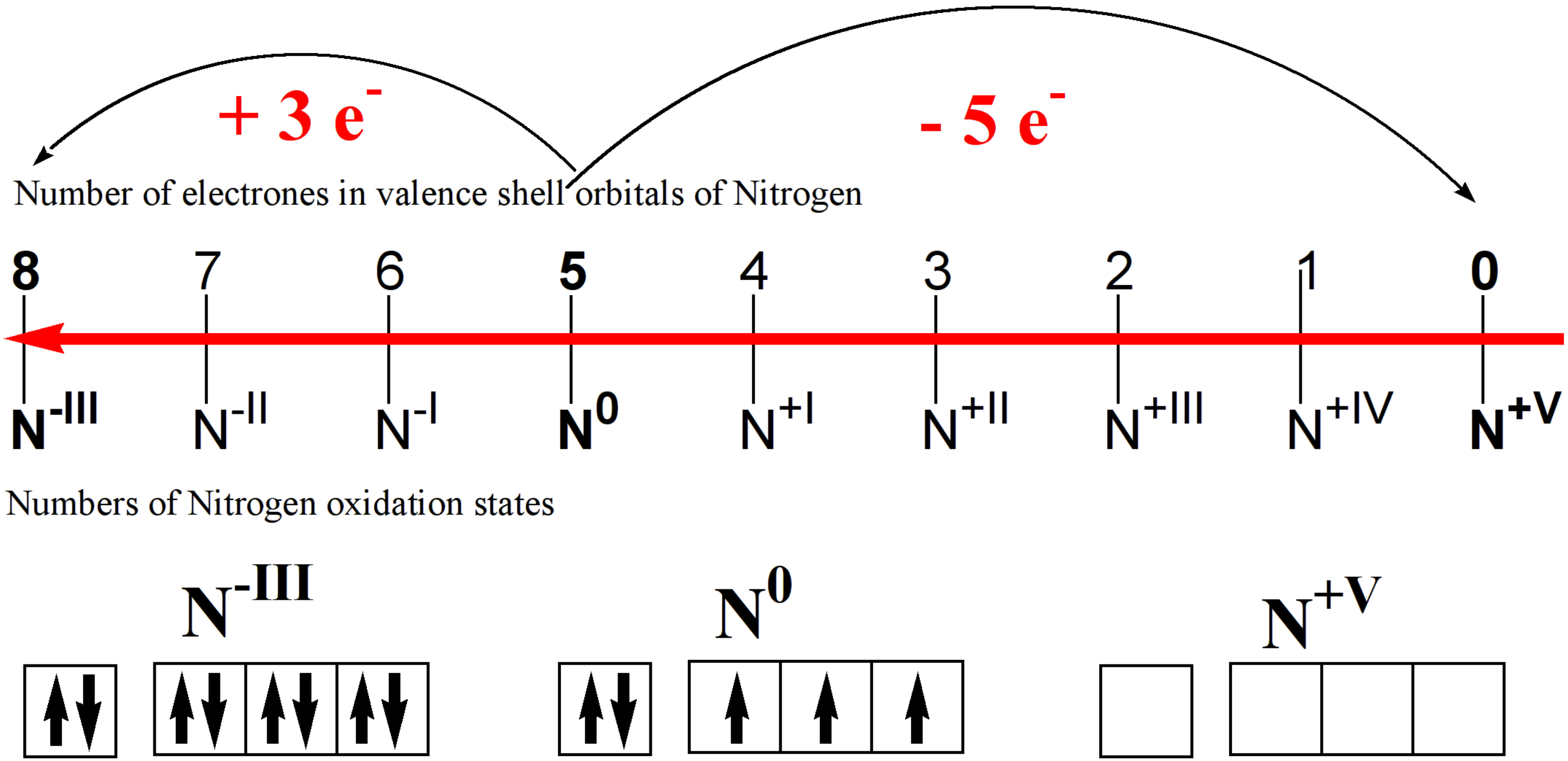
H_2O...H-O-H...OH_2 ...hydrogen bond O...H-O

H_2O polar O-H (differencial electronegativities counts 1,3)

Is there any important practical application?

CHROMATOGRAPHY

Reduction................Oxidation



$+3\,e^-$

$-5\,e^-$

Number of electrones in valence shell orbitals of Nitrogen

8	7	6	**5**	4	3	2	1	**0**
N^{-III}	N^{-II}	N^{-I}	N^{0}	N^{+I}	N^{+II}	N^{+III}	N^{+IV}	N^{+V}

Numbers of Nitrogen oxidation states

N^{-III}

the most reduced form
strong REDUCTION reagent
i.e. NH_3

N^{0}

N^{+V}

the most oxidized form
strong OXIDATION reagent
i.e. HNO_3

Standard electrode potentials of metals

lithium	−3,0401
cesium	−3,026
rubidium	−2,98
potassium	−2,931
barium	−2,912
strontium	−2,899
calcium	−2,868
sodium	−2,71
magnesium	−2,372
beryllium	−1,85
aluminium	−1,66
titanium	−1,63
manganese	−1,185
zinc	−0,7618
chromium	−0,74
iron	−0,44
cadmium	−0,40
indium	−0,34
thallium	−0,34
cobalt	−0,28
nickel	−0,25
tin	−0,13
lead	−0,13
hydrogen	**0**

hydrogen	**0**
copper	+0,34
bismut	+0,2
osmium	
ruthenium	+0,3
silver	+0,7996
mercury	+0,8
platinum	+1,188
gold	+1,52

Metals with more negative standard electrode potential can spontaneously substitute the metals with more positive standard electrode potencial.

$2\ Na + MgCl_2 = 2\ NaCl + \mathbf{Mg}$

$Mg + 2\ AgNO_3 = Mg(NO_3)_2 + \mathbf{Ag}$

$Al + Fe_2O_3 = Al_2O_3 + \mathbf{Fe}$

$Fe + CuSO_4 = \mathbf{Cu} + FeSO_4$

$Zn + 2[Au(CN)_2](OH) = 2\ \mathbf{Au} + [Zn(CN)_4](OH)_2$

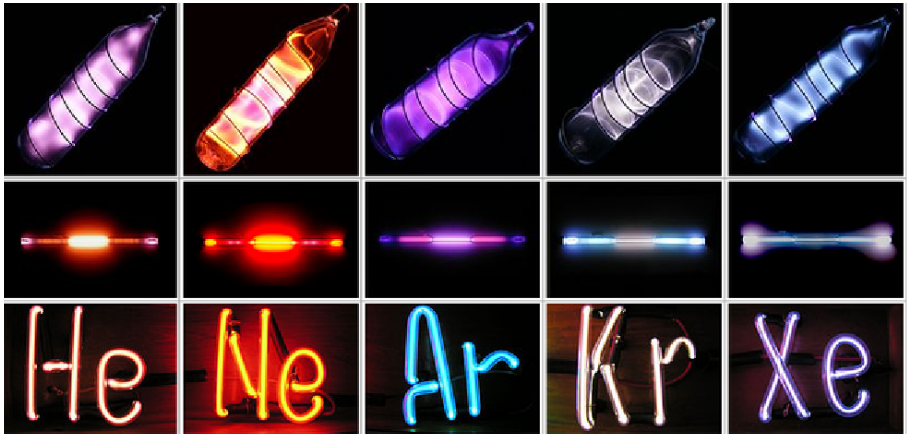
H_2 is evolved during the acidic hydrogen substitution.

$Zn + 2\ HCl = ZnCl_2 + \mathbf{H_2}$

$Zn + 2\ NaOH + 2\ H_2O = Na_2[Zn(OH)_4] + \mathbf{H_2}$

https://en.wikipedia.org/wiki/Standard_electrode_potential_(data_page)

Noble / Inert Gases „p-Octels“ (8 val. e^-)



He – Helium gas, cca 3% in the natural gas mixture
atomic gas, inert gas, He **balloons** – lighter than air mixture,
collision gas in **MS detectors**, **carrier gas in GC** etc.
Ne – Neon (0,0018 %), neon red lighting,
Ar – Argon (1 %), laboratory and industrial **inert atmosphere**
Kr – Krypton (0,0001 %), light.
Xe – Xenon (0,000 005 %), **car lights**, **anesthetic**
Rn – Radon, **radioactive**! Use the air ventilation of home!
Og – Oganesson, manmade radioactive liquid.

Reactivity of Noble Gases:

1962 – $Xe^+[PtF_6]^-$ – 1st Noble gas containing compounc

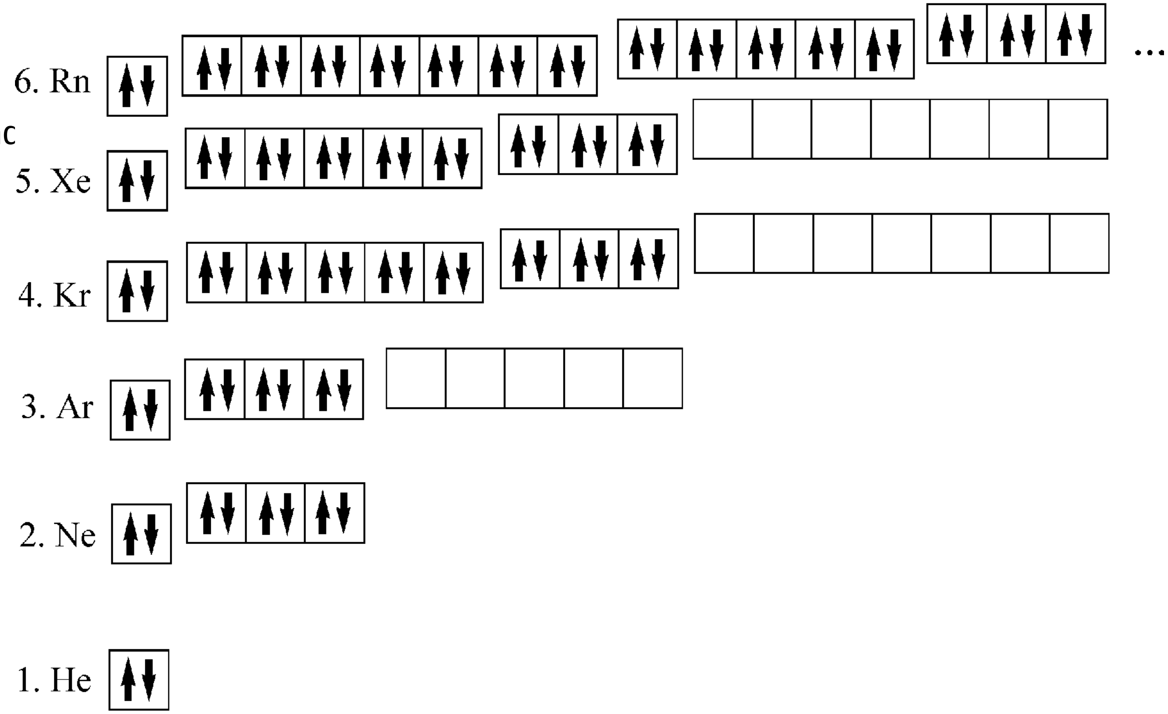
XeF_2 XeF_4 XeF_6

strong fluorination agents

melting points 129 117 49°C

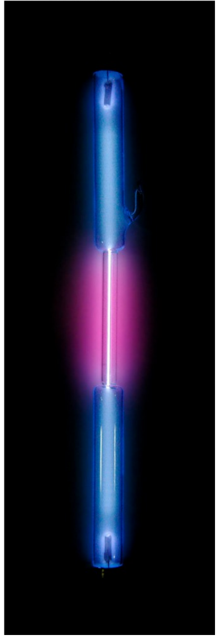
$XeF_6 + H_2O = HF + XeO_3$ ...strong oxidizing agent

Why these elements are so noble and inert?
Because they have got electrones filled into
all available atomic orbitals.



https://www.evolvingsciences.com/Group%200%20Noble%20gases%20.html

$_1$H: Hydrogen (1 val. e$^-$)



☐ **H^+: $1s^0$ protone**, hydrogen cation: **the simplest Lewis acid = electron free, vacant AO**

Compounds: H_3O^+hydroxonium cation, all acids: HF, H_2SO_4...,

↑ **H: $1s^1$ hydrogen: the simplest, lightest, the most reactive element**

Compounds: H_2, H_2O, CH_4, SiH_4, NH_3...

↑↓ **H^-: $1s^2$ hydridic anion: the simplest Lewis base = full electrone pair AO**

Compounds: OH^- hydroxide anion, all metal hydrides - LiH, CaH_2, B_2H_6, PtH_x

THE SIMPLEST NEUTRALIZATION REACTION

$H^+ + H^- = H_2$ (salt) + heat

$H_3O^+ + OH^- = 2\ H_2O$ (salt) + heat

Methods of useful laboratory preparations:

3 HCl + Al = **H_2** + $AlCl_3$

4 NaOH + Al = **H_2** + $Na[Al(OH)_4]$

sodium tetrahydroxidoaluminate

H_2O =electrolysis= **H_2** + O_2

A large scale production methods:

1. dehydrogenation of hydrocarbons (petrochemistry)
2. $CH_4 + H_2O$ (heat) = **H_2** + CO
3. H_2O =electrolysis = **H_2** + O_2 (solar energy)

Preparation of various metal hydrides:

H_2 + 2 Na = 2 **NaH**

X H_2 + Pt = **PtHx**

(intersticial nonstoichiometric hydrides)

Typical use of metal hydrides:

NaH + C_2H_5OH = C_2H_5ONa + **H_2**

PtH_x + substrate = Pt + hydrogenated substrate

<u>Reactivity - important reactions:</u>

$H_2 + F_2 = 2\ HF$ explosion under 30 K

$2\ H_2 + O_2 = 2\ H_2O$ explosion after iniciation

$3\ H_2 + N_2 = 2\ NH_3$ heat, pressure and catalyst needed!

Haber-Bosch process – megatons of NH_3 per year!

$WO_3 + 3\ H_2 = W + 3\ H_2O$ reduction of metal

https://en.wikipedia.org/wiki/Hydrogen#/media/File:Hydrogen_discharge_tube.jpg

Alkali metals (1 val. e^-)

The most electrondeficient and reactive metals, low melting points.

Li, Na, K, Rb, Cs, Fr

The common „octet“ oxidation state: **+1, odd**

Metal cations with a free orbitals in the valence shell react with bases as acids

Lithium batteries; many Li compounds are soluble in organic solvents

Baking, cleaning „soda“, sodalime, Na-K channels…

Flame ionization (excitation) – characteristic colors in the flame!

Fireworks.

$2 Li + H_2 = 2 LiH$ **lithium hydride**

$Li + N_2 = Li_3N$ **lithium nitride** (unique reaction - occurs at standard conditions!!!)

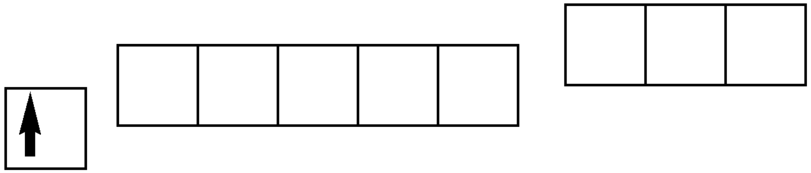
$Li_3N + H_2O = LiOH + NH_3$ **lithium hydroxide**

1\. step $4 Li + O_2 = 2 Li_2O$ dilithium **oxide**

1\. step $2 Na + O_2 =$ **Na_2O_2** sodium **peroxide** (orange)

2\. step $Na_2O_2 + 2 Na = 2$ **Na_2O** (yellow) disodium oxide

1\. step $K + O_2 = KO_2$ potassium **hyperoxide** (the same for Rb, Cs)



$Na + H_2O = H_2 + NaOH$ sodium **hydroxide**

$Na_2O + H_2O = 2 NaOH$

$NaOH + CO_2 = Na_2CO_3 + H_2O$ **soda**

All alkali metals are good soluble in liquid ammonia NH_3 (-33°C).

https://www.quora.com/What-is-the-flame-test-and-what-are-its-applications

Alkaline Earth Metals (2 val. e^-)

The common „octet“ oxidation state: +2, even

Less reactive metals than alkali metals: **Be, Mg, Ca, Sr, Ba, Ra**

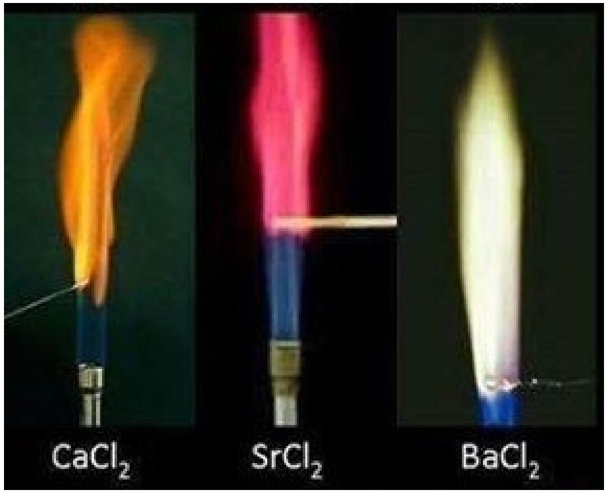
$Ca + H_2O = Ca(OH)_2 + H_2$

Characteristic colors in the flame (ionization). Fireworks.

Metal cations with a free orbitals in the valence shell react with bases as acids.

Ba – water soluble compounds are **toxic**, not soluble non-toxic

$Ba_2O_2 + H_2SO_4 = H_2O_2 + BaSO_4$…a white pigment



Mg – central atom in **chlorophyl** complexes with four pyrrol ligands

Mg,Al light hard **construction alloys** (airplanes, bikes etc.)

Grignard reagents – soluble in organic solvents

the Karst effect

$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2$ is more soluble in water

$CaCO_3$ is not soluble in pure water, but in the presents of slightly acidic CO_2 slowly react to more soluble acidic, but not so stable $Ca(HCO_3)_2$.

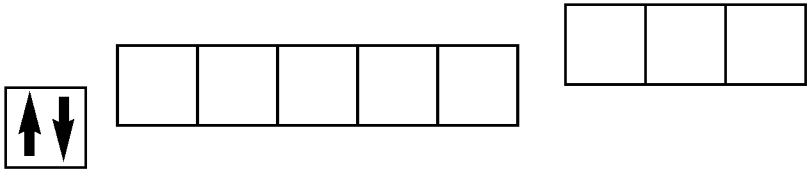
Building construction chemistry

$CaCO_3 = CaO + CO_2$ (after heating above 1000°C)

$CaO + H_2O = Ca(OH)_2$

$Ca(OH)_2 + CO_2 = CaCO_3$

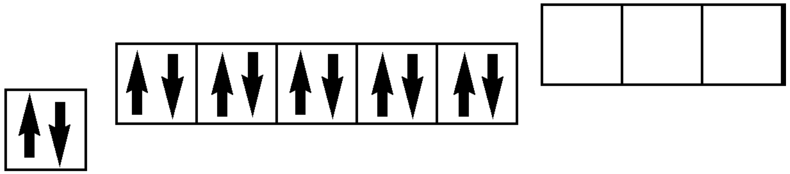
Desulfatation of exhalations $SO_2 + CaO = CaSO_3$



https://middleczech.kr-stredocesky.cz/cs/konepruske-jeskyne/

https://www.quora.com/What-is-the-flame-test-and-what-are-its-applications

Zinc metals (12 val. e^-)



- Transition metals: **Zn, Cd, Hg, Cp**

  Full d-AO (10 e^-), 2 e^- in s-AO ...**mimics Alkaline Earth Metals!**
- Stable oxidation states: **+2**

  metal cations with a free orbitals in the valence shell react with bases as acids
- $Zn + HCl = H_2 + ZnCl_2$

  ZnO_2 white pigment, **amphoteric oxide** = does not react with H_2O

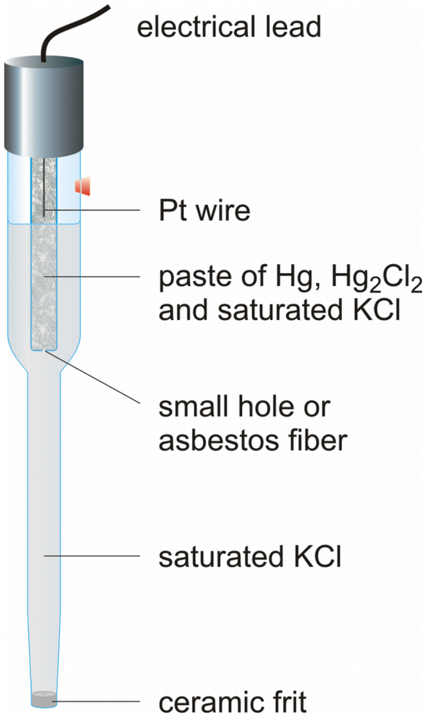
  ZnO_2 **+ HCl** = $ZnCl_2 + H_2O$

  ZnO_2 **+ 2KOH** = $K_2[Zn(OH)_4] + H_2O$
- $HgCl_2$ **(Hg^{+II})**– water soluble, very **toxic**!

  $HgCl_2 + Hg = Hg_2Cl_2$ **(2 Hg^{+I})**...white precipitate in water

  calomel referention electrodes in electrochemistry (ISE, pH)

  Hg liquid + metals = solid **amalgam alloys,** thermometers

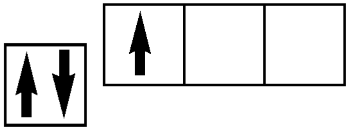


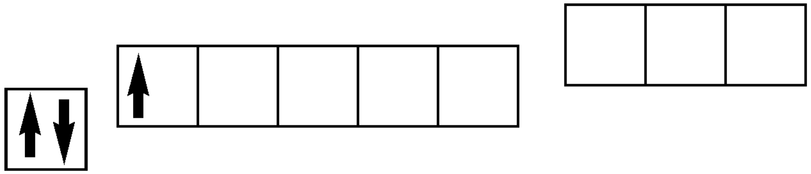
https://glossary.periodni.com/glossary.php?en=calomel+electrode

Triels, Scandium metals (3 val. e^-)

- p-Triels: **B – semiconductor, metalloid**
- **Green flame color, volatile esters**
- **Pyrex glass, peroxoborates**
- metals: **Al, Ga, In, Tl, Nh**
- d-Triels – Scandium metals: **Sc, Y, La, Ac**
- The common stable oxidation state: **+3**, odd
- **Thalium – „an inert s-pair“ (prefere Tl^{+I} before Tl^{+III})**
- Triel cations react with bases as **Lewis acids**
- $2\ BCl_3 + 3\ H_2O = 2\ H_3BO_3 + 6\ HCl$
- $H_3BO_3 + CH_3OH + H_2SO_4 = (CH_3O)_3B + H_2O$
- $Al^0 + NaOH = H_2^0 + Na[Al^{+III}(OH^{+I})_4]$
- Al_2O_3 not soluble in water – alumosilicates
- Al – construction metal, in alloys (airplanes)
- $Sc_2O_3 + HNO_3 = Sc(NO_3)_3 + H_2O$

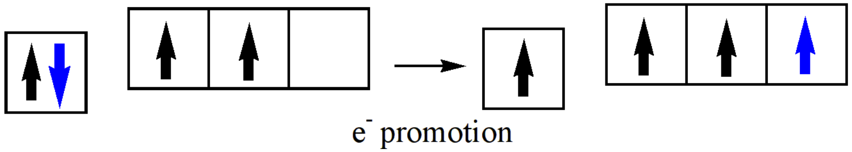

$(CH_3O)_3B$





https://www.quora.com/What-is-the-flame-test-and-what-are-its-applications

p-Tetrels, Titanium metals (4 val. e^-)



- p-Tetrels: **C** – nonmetal, alotrops (**graphite**, grafen **fullerene**, diamond, nanotubes...),
- **Si**, and **Ge** – metalloids, **semiconductors!**
- **Sn, Pb, Fl** – metals ...**Pb**$^{2+}$
- d-Tetrels: **Ti, Zr, Hf, Rf** - metals

The common stable oxidation state: -4, +4, even Pb^{+2} („an inert s-pair“)

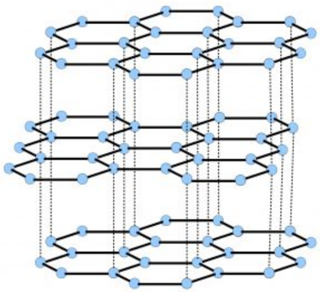
CO – toxic gas, triple bond between C and O

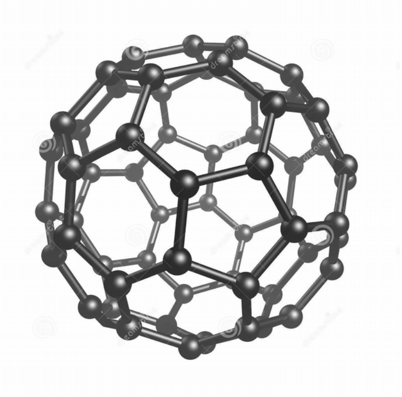
$CO_{2\,(g)}$, $SiO_{2\,(s)}$, $GeO_{2\,(s)}$, $SnO_{2\,(s)}$, $PbO_{2(s)}$$TiO_{2\,(s)}$, $ZrO_{2\,(s)}$

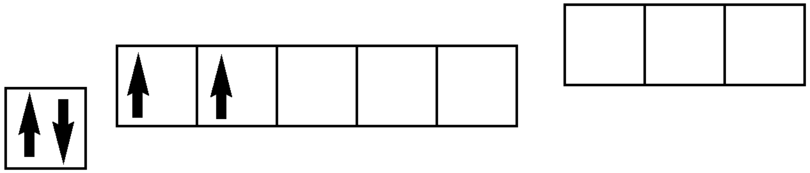
PbO, red Pb_3O_4 ($PbO + PbO_2$)

CS_2, $CaCO_3$ (Karst effect),

- Titanium alloys, steels
- ZrO_2 – modern ceramic, chromatography





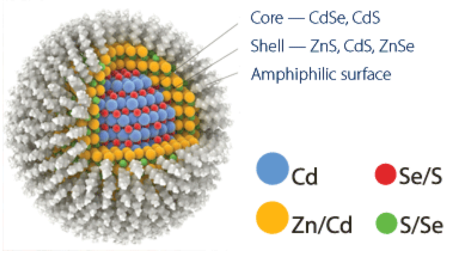


https://middleczech.kr-stredocesky.cz/cs/konepruske-jeskyne/

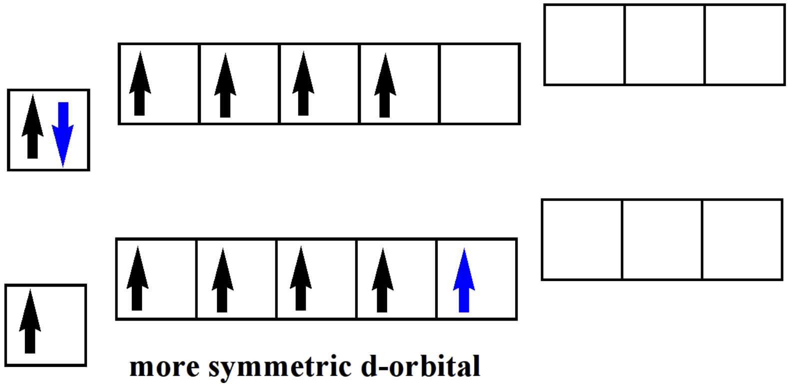
http://www.electroboom.com/?p=835

https://www.dreamstime.com/stock-photo-fullerene-c60-image23786180

Chalcogenes, Chromium metals (6 val. e^-)



- Chalkogenes: **O, S – nonmetals**
- **Se** - metalloid, **Te, Po, Lv** - metals
- Cr metals = **Cr, Mo, W, Sg** – an important exception in the valence shell electronic configuration: 1 e^- in s-AO and 5 e^- in d-AO (*symmetry preference!*)
- **The common stable oxidation states: (-2)** in oxides, sulfides, selenides, telurides, Cr^{+2}/Cr^{+3} salts, , **+6**, even **(+4)**
- H_2O; H_2O_2; O_2

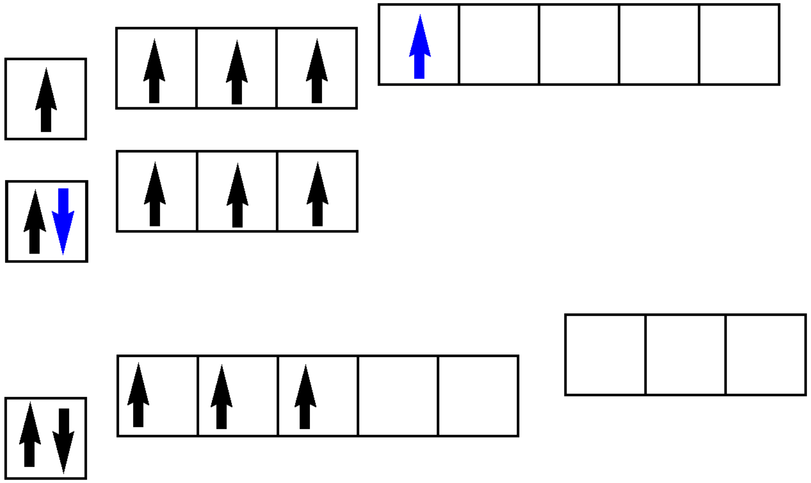


more symmetric d-orbital

http://www.taopatch.com/blog/quantum-dots-entangled-with-single-photons/

Pentels, Vanadium metals (5 val. e^-)

- p-Pentels: **N, P** – nonmetals
- **As** - metalloid, **Sb, Bi, Mc** - metals
- Vanadium metals: **V, Nb, Ta, Db**
- The common stable oxidation state: **-3, +5, odd**
- Bi^{+3} („an inert s-pair“)

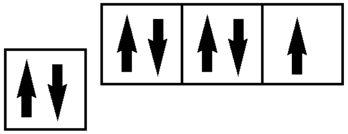


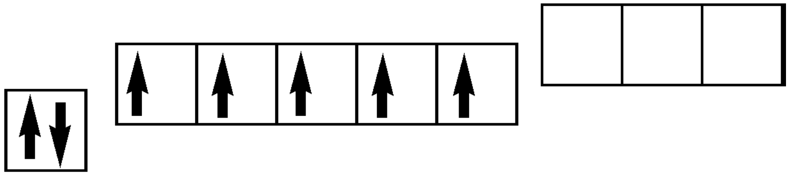
- $NH_3 + O_2$ –Cr_2O_3- NO
- $NO + O_2 = NO_2$
- $NO_2 + H_2O = \mathbf{HNO_3} + HNO_2$ $2\ HNO_2 = N_2O_3 + H_2O$
- $N_2O_3 = NO + NO_2$ disproportionation reaction (two oxidation states of the element in products)
- $P_4 + O_2 = P_4O_{10}$...dimer of P_2O_5
- $P_20_5 + H_2O = \mathbf{H_3PO_4}$
- $V_2O_5 + H_2O$ not react!

http://alloy-artifacts.org/armstrong-bros-p2.html

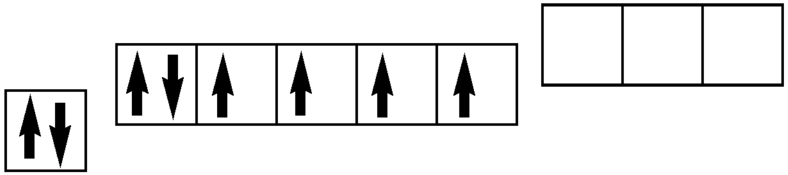
Halogenes, Manganese metals (7 val.e$^-$)

- p-Heptels = Halogenes: **F, Cl, Br, I, At, Ts**
- d-Heptels = **Mn, Tc, Re, Bh**
- The common stable oxidation state: -1,...+7, **odd**
- Compounds Cl: NaCl, NaClO, $NaClO_3$, $NaClO_4$
- Compounds Mn: $MnCl_2$, MnO_2, $KMnO_{4,}$
- Ferromangan, Oxidation agents for fireworks, **waste water regeneration**
- Mn^{+III}/$^{+IV}$...Photosystem II – water decomposition
- $2\ H_2O = O_2 + 4\ H^- + 4e^-$
- Tc – artificialy radioactive, **radioimaging**





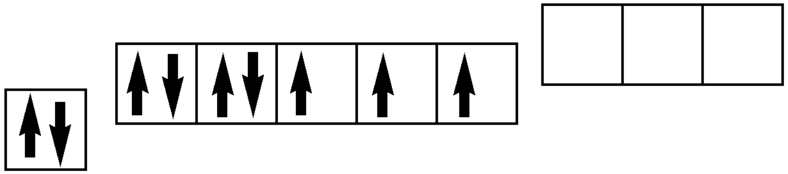
Iron metals (2+6 val. e$^-$)



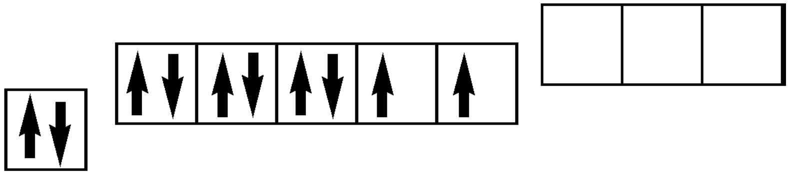
- **Fe**, Ru, Os, Hs
- The common stable oxidation states: +II, +IV, +VI
- Extraordinary oxidation states: Fe^{+VI}, Ru^{+VII}, Os^{+VIII}
- Iron – mostly Fe^{2+}/Fe^{3+} Fe_2O_3, Fe_3O_4 ($FeO + Fe_2O_3$) magnetit, hemoglobin – O_2/CO_2 transfer
- **Corrosion:** $4\,Fe + 2H_2O + 3\,O_2 = 2\,Fe_2O_3.H_2O$
- Complexes: $K_3[Fe(CN)_6]$, $[Ru(bpy)_3]^{2+}$, OsO_4
- Catalysis

Cobalt metals (2+7 val. e^-)

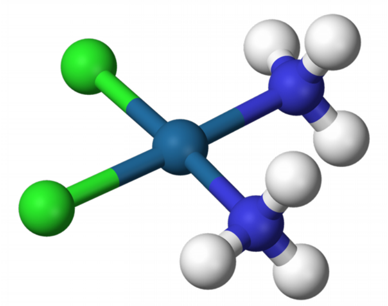
- **Co, Rh, Ir, Mt**
- Co (-I … +IV) $CoCl_2$, Co_3O_4 (CoO + Co_2O_3), cobalamin B_{12}
- Rh = +I, +III
- Ir = +I, +III, +IV
- heterogenous catalysts
- anticorosive coatings
- iron steel alloys, stainless steel



Nickel metals (2+8 val. e^-)



- **Ni, Pd,Pt, Ds**
- $NiO + H_2 + CO = Ni + Co$ –(330 K)- $[Ni(CO)_4]$
- $[Ni(CO)_4]$ --(440 K)- Ni + 4 CO Mondo‘s process
- **Pd, Pt - +II, +IV**
- catalysts, intersticial black hydrides PdH_x, PtH_x
- Resistent to O_2, H^+; Soluble in Aqua Regia
- Cancer chemotheraphy – „cis-Platin“ - disqualify DNA of rapid proliferating cells



https://en.wikipedia.org/wiki/Platinum

Cobalt metals (2+7 val. e^-)

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- Rh = +I, +III
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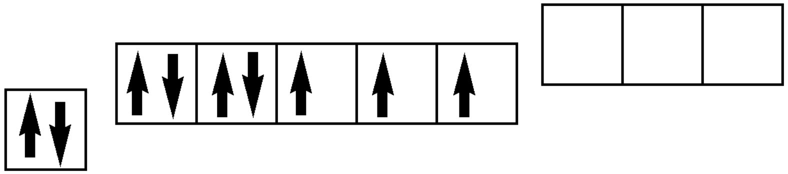

Question – periodicity

Please, look on the vertical form of the Periodic table of elements (PTE) – 7th column – Cl, Mn.

Please, mark oxidation states of stable compounds of Cl, Mn.

Cl: -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

Cl-compound:

Mn: -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

Mn-compound:

Have they some compounds with the same oxidation number and similar chemical properties? Please, describe facts on the example.

Are there some other pairs of elements shown in the vertical PTE with similar consequences? Please, describe facts on the example.

Questions – stable oxidation states

Please, try to mark the predominant oxidation states of some stable compounds of these elements:

Li: -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

Li-compound:

Ca: -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

Ca-compound:

Zn: -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

Zn-compound:

F: -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

F-compound:

Questions – Acids and Bases

Please, add the correct explanation (BA, BB, LA, LB, S, C) of mentioned compounds in order to evaluate their acidity or basicity.

i.e.: H_2O BA and also BB, LB, S

CO …

HCl …

NH_3…

SO_2 ...

SO_3 ...

Question – Chemical bond

please, describe respective chemical bonds of these compounds

Compound	Differencial Electronegativity	The type of chemical bond
K_2O		
Cl_2		
KCl		
O_2		
HBr		
N_2		
NaF		
H_2O_2		

Qestions – „Octet rule“

Please, decide if both elements in compounds shown in the Table could mimic the electronic configuration of the nearest Noble gas or not.

compound	number of shared valence e^-	number of shared valence orbitals	Could both elements mimic the Noble gas e^- configuration?
H_2O			
B_2			
O_2			
SF_6			

Recomended Bibliography

Housecroft C. E., Sharpe A. G., Inorganic Chemistry, 2nd Ed., Pearson Education Ltd., 2005, 987 p. ISBN 0130-39913-2.

Saito, T., Inorganic Chemistry, Kanagawa University, 2004, 194 p. PDF downloaded from: http://www.t.soka.ac.jp/chem/iwanami/inorg/