PERIODICITY

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Periodic Table

The Periodic Table – *the chemist's dictionary*

Tabular display of the chemical elements, which are arranged by atomic number, electron configuration, and recurring chemical properties.

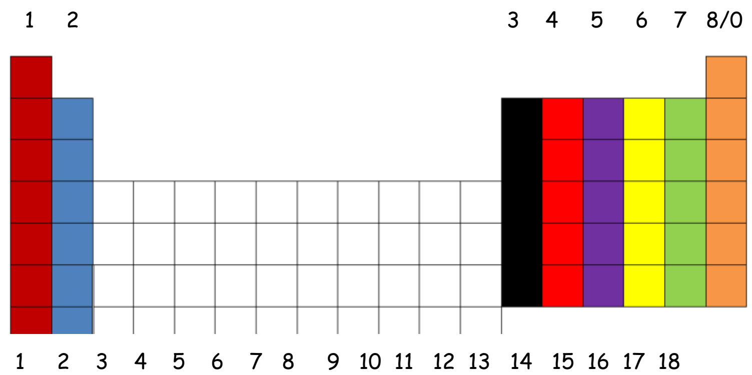
Elements are defined by the location and contents of their 'elemental box'.

hydrogen 1 **H** 1.00794																	helium 2 **He** 4.002602
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.012182											boron 5 **B** 10.811	carbon 6 **C** 12.0107	nitrogen 7 **N** 14.00674	oxygen 8 **O** 15.9994	fluorine 9 **F** 18.9984	neon 10 **Ne** 20.1797
sodium 11 **Na** 22.98977	magnesium 12 **Mg** 24.3050											aluminium 13 **Al** 26.981538	silicon 14 **Si** 28.0855	phosphorus 15 **P** 30.97376	sulphur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.984
potassium 19 **K** 39.0983	calcium 20 **Ca** 40.078	scandium 21 **Sc** 44.95591	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.9415	chromium 24 **Cr** 51.9961	manganese 25 **Mn** 54.93805	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.9332	nickel 28 **Ni** 58.6934	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.409	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.64	arsenic 33 **As** 74.9216	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.798
rubidium 37 **Rb** 85.4678	strontium 38 **Sr** 87.62	yttrium 39 **Y** 88.90585	zirconium 40 **Zr** 91.225	niobium 41 **Nb** 92.90638	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.9055	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.8682	cadmium 48 **Cd** 112.411	indium 49 **In** 114.818	tin 50 **Sn** 118.710	antimony 51 **Sb** 121.760	tellurium 52 **Te** 127.60	iodine 53 **I** 126.9045	xenon 54 **Xe** 131.293
caesium 55 **Cs** 132.90545	barium 56 **Ba** 137.327	lutetium 71 **Lu** 174.967	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.9479	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.207	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.217	platinum 78 **Pt** 195.078	gold 79 **Au** 196.96655	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.3833	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.980	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	darmstadtium 110 **Ds** [271]	roentgenium 111 **Rg** [272]	ununbium 112 **Uub** [285]						

lanthanum 57 **La** 138.9055	cerium 58 **Ce** 140.116	praseodymium 59 **Pr** 140.90765	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.964	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.9253	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.930	erbium 68 **Er** 167.259	thulium 69 **Tm** 168.934	ytterbium 70 **Yb** 173.04
actinium 89 **Ac** [227]	thorium 90 **Th** 232.038	protactinium 91 **Pa** 231.0359	uranium 92 **U** 238.0289	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]

Groups & Periods

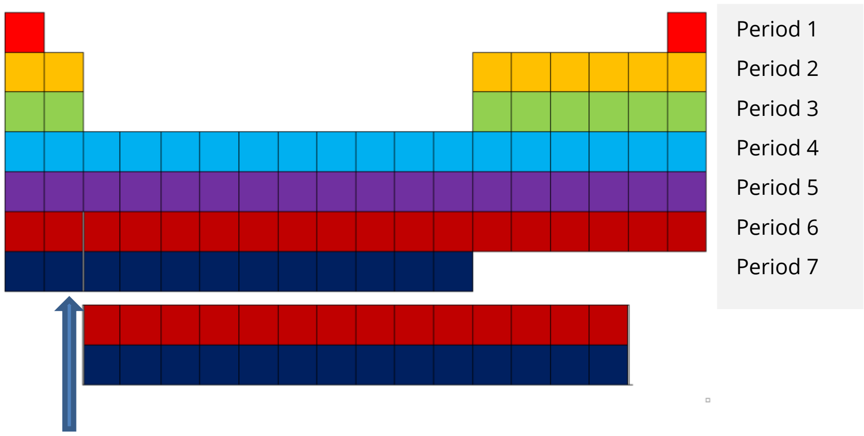
Groups



Two periodic group numbering systems are used. For convenience this text adopts the older system which numbers the main group from 1 to 8. In this system the number of outer electrons is the same as the group number.

Elements with similar properties are arranged in the same column (group), and elements with the same number of electron shells are arranged in the same row (period).

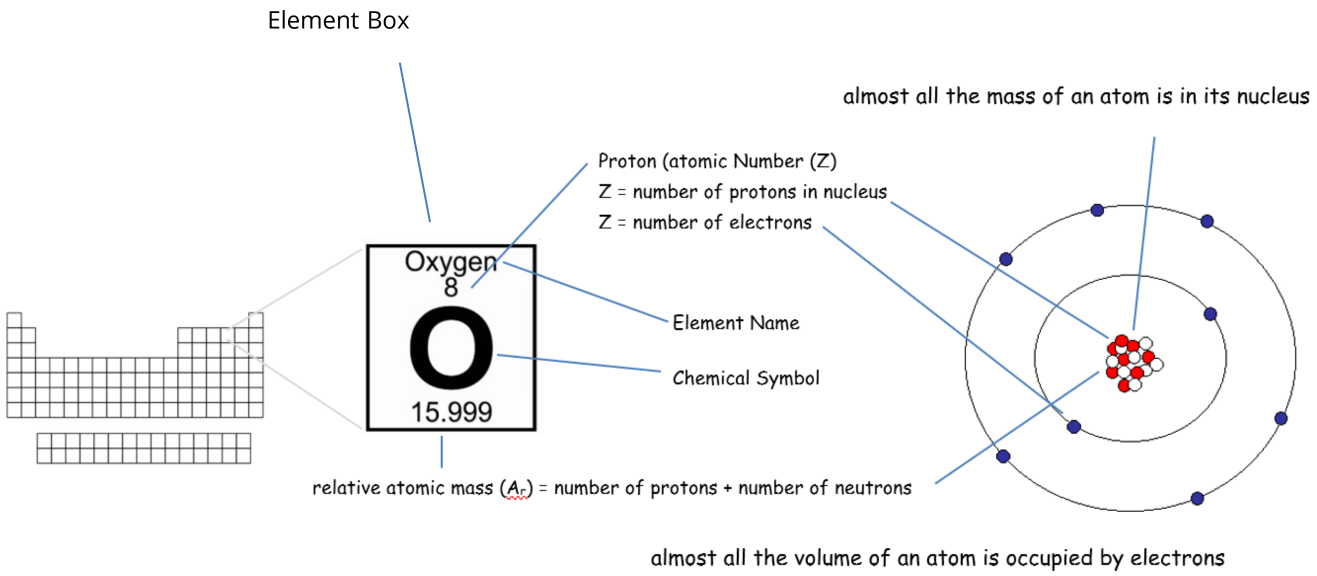
Periods



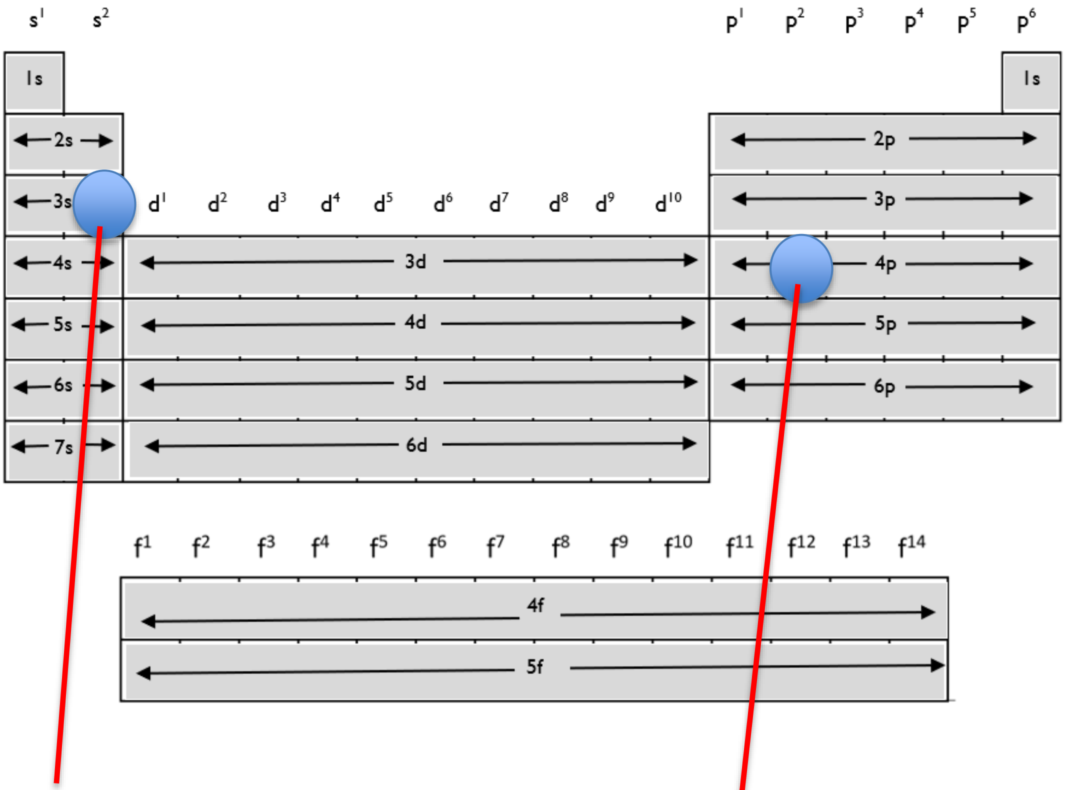
The two rows of elements located along the bottom are part of the whole Periodic Table. They occupy the space highlighted.

Elemental Boxes

Every element has its own box of chemical information. Let's take a closer look at one of the elemental boxes.



Electron Configuration by Group

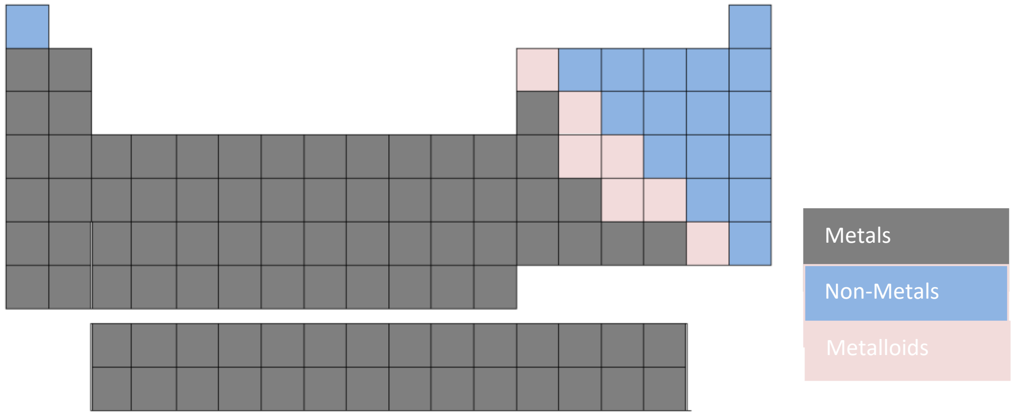


Electron configuration (Z =12, Group 2): $1s^2 2s^2 2p^6 3s^2$

Electron configuration (Z =32, Group 4): $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^2$

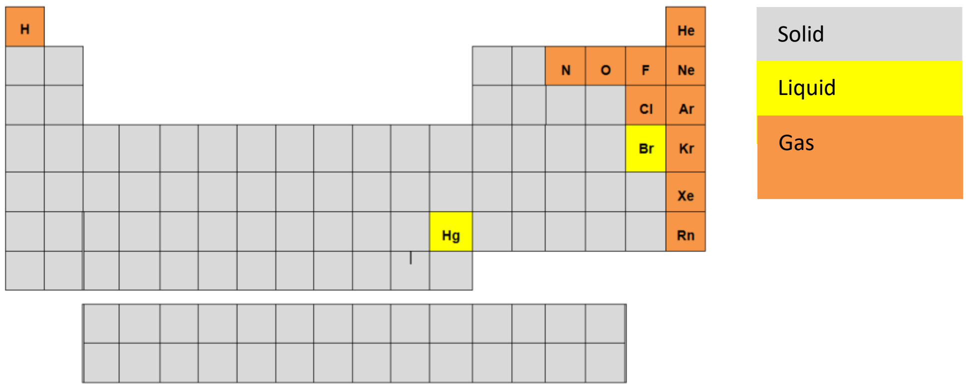
Classifying Elements

Metals, Non-Metals & Metalloids



Elements to the right of stair-stepped line (shaded in pink) and hydrogen (top left-hand corner) are classified as **non-metals**.

Solid, Liquid and Gaseous Chemical Elements



Electron Arrangement of the first 18 Elements

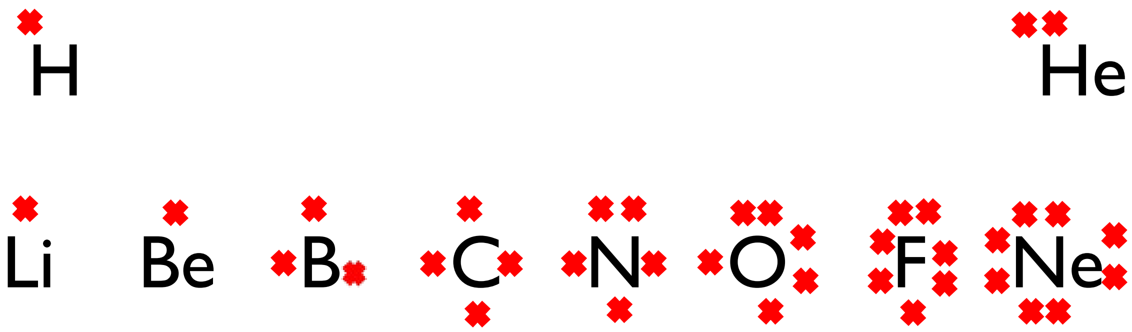
Element	Symbol	Proton Number	Period	Group Number	No. of Electrons in Shell 1(K)	No. of Electrons in Shell 2 (L)	No. of Electrons in Shell 3 (M)	Electron Configuration
Hydrogen	H	1	1		1	-	-	1
Helium	He	2	1		2	-	-	2
Lithium	Li	3	2	1	2	1	-	2:1
Beryllium	Be	4	2	2	2	2	-	2:2
Boron	B	5	2	3	2	3	-	2:3
Carbon	C	6	2	4	2	4	-	2:4
Nitrogen	N	7	2	5	2	5	-	2:5
Oxygen	O	8	2	6	2	6	-	2:6
Fluorine	F	9	2	7	2	7	-	2:7
Neon	Ne	10	2	8 (0)	2	8	-	2:8
Sodium	Na	11	3	1	2	8	1	2:8:1
Magnesium	Mg	12	3	2	2	8	2	2:8:2
Aluminum	Al	13	3	3	2	8	3	2:8:3
Silicon	Si	14	3	4	2	8	4	2:8:4
Phosphorus	P	15	3	5	2	8	5	2:8:5
Sulfur	S	16	3	6	2	8	6	2:8:6
Chlorine	Cl	17	3	7	2	8	7	2:8:7
Argon	Ar	18	3	8 (0)	2	8	8	2:8:8

Electron Arrangements

	1	2	3	4	5	6	7	8 (0)	Number of occupied shells
Period 1								2 He 2	1
Period 2	2:1 Li 3	2:2 Be 4	2:3 B 5	2:4 C 6	2:5 N 7	2:6 O 8	2:7 F 9	2:8 Ne 10	2
Period 3	2:8:1 Na 11	2:8:2 Mg 12	2:8:3 Al 13	2:8:4 Si 14	2:8:5 P 15	2:8:6 S 16	2:8:7 Cl 17	2:8:8 Ar 18	3
Period 4	2:8:8:2 K 19	2:8:8:2 Ca 20							
Number of Valence electrons	1	2	3	4	5	6	7	8 Except He	

Electron arrangements of the first 20 element. Note that the group number equals the number of electrons in the outer (valence) shell, ie oxygen in Group 6, has 6 electrons in its valence shell, ie 2:6.

Lewis Structures

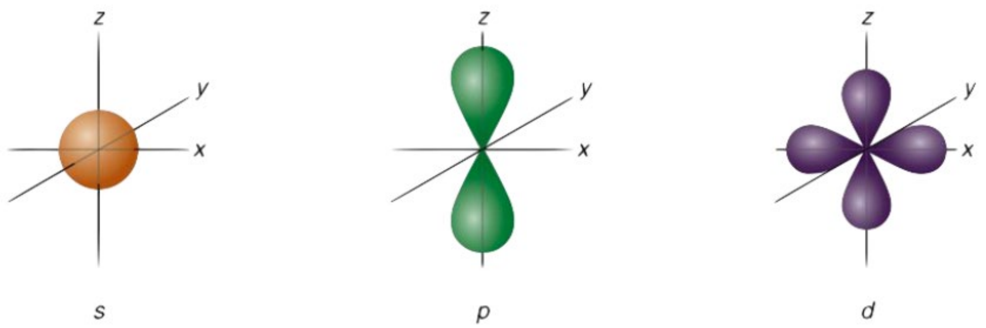


Lewis structures of the elements of the first two periods, showing the number of valence electrons (✖). These structures help visualize the valence electrons of atoms and molecules, and their role in bonding.

Electron Shells & Orbitals

Shell Number	Shell Name	Maximum No. of Electrons	Sub Shells
1	K	2	1s
2	L	8	2s 2p
3	M	18	3s 3p 3d
4	N	32	4s 4p 4d 4f
5	O	50	5s 5p 5d 5f 5g

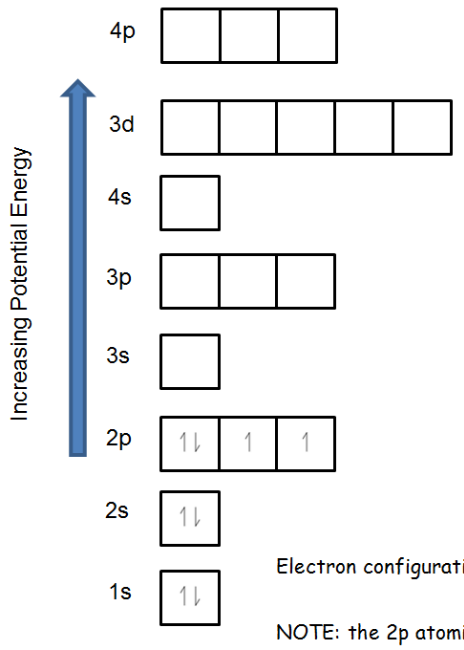
Sub Shell	Number of Atomic Orbitals	Maximum No. of Electrons
s	1	2
p	3	6
d	5	10
f	7	14



Atomic orbitals

Atomic orbital shapes are based on the probability of finding the electron at a certain point in space around the nucleus.

Electron Arrangements



Electrons occupy areas of space known as atomic Orbitals

Four types of atomic orbitals – s, p, d, f

Each atomic orbital can hold 2 electrons with opposite spin ↿⇂

Lowest energy atomic orbitals are occupied first

Electrons remain unpaired if possible to reduce

Electron configuration of Carbon: $1s^2 2s^2 2p^4$

NOTE: the 2p atomic orbitals are first filled singly and then paired up

Atomic orbitals are filled in the following order:

1s

2s 2p

3s 3p 3d

4s 4p 4d 4f

5s 5p 5d ……

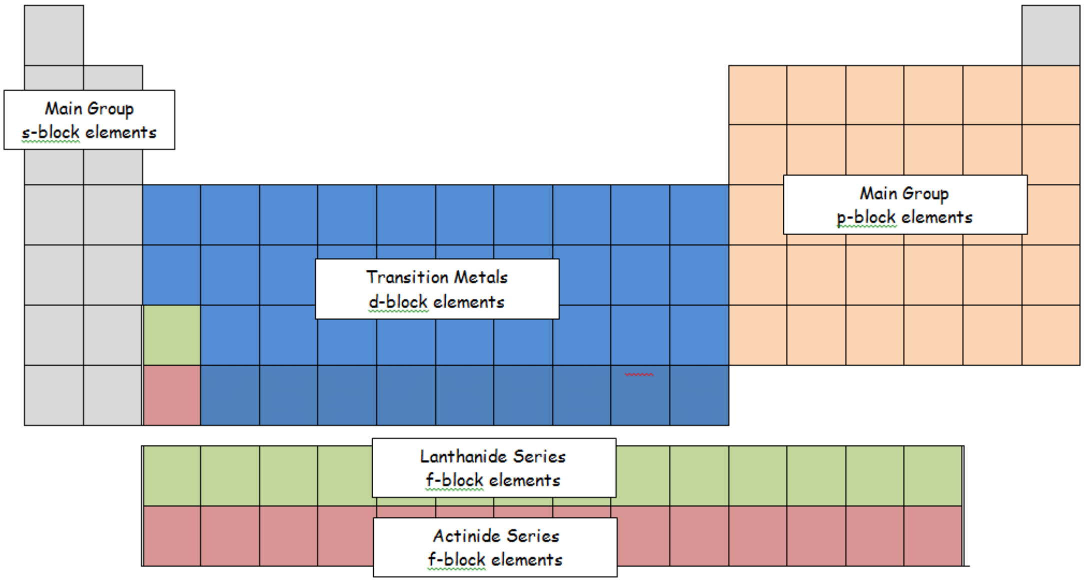
6s 6p …..

7s ……

> 4s atomic orbital is of lower energy than 3p atomic orbital and hence is occupied first.

i.e. 1s 2s 2p 3s 3p 4s 3d 4p 5s 4d 5p 6s 4f 5d 6p 7s

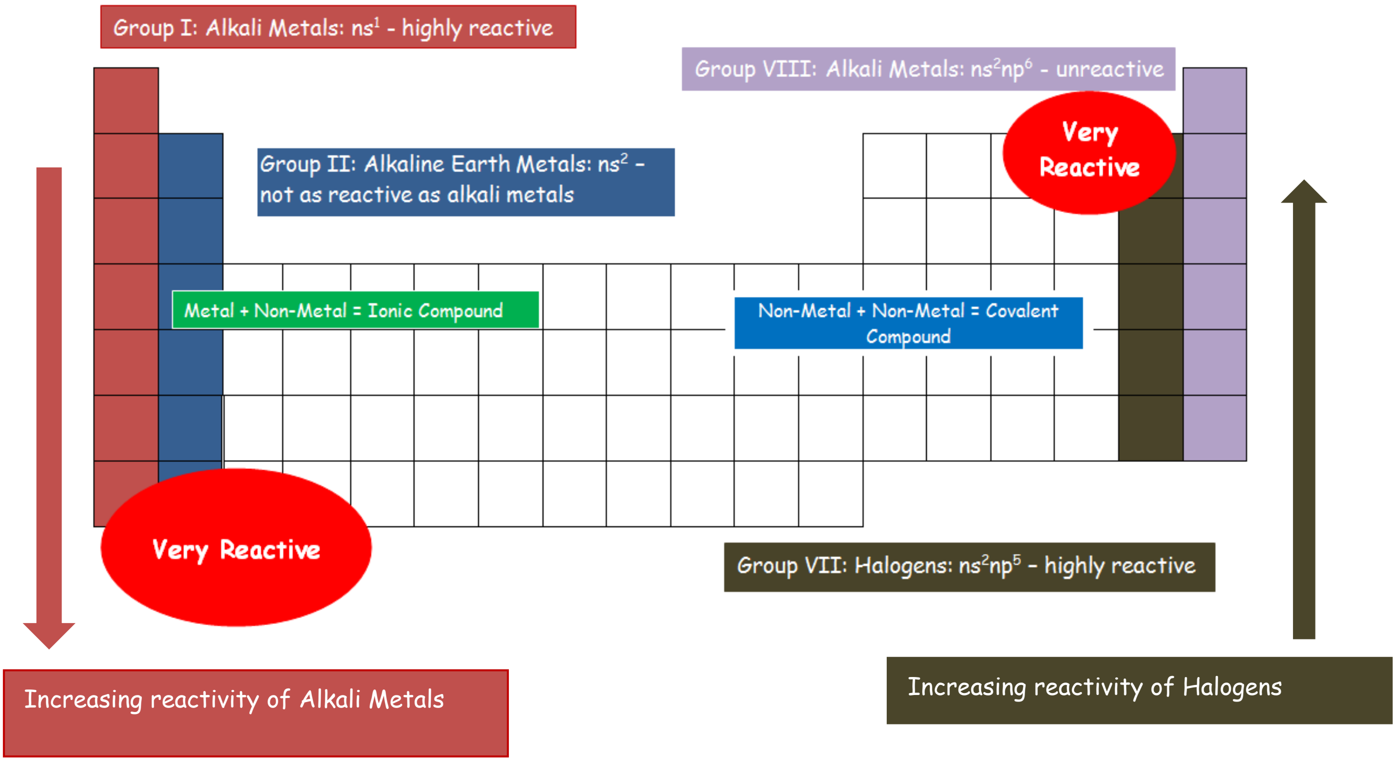
Blocks of Elements



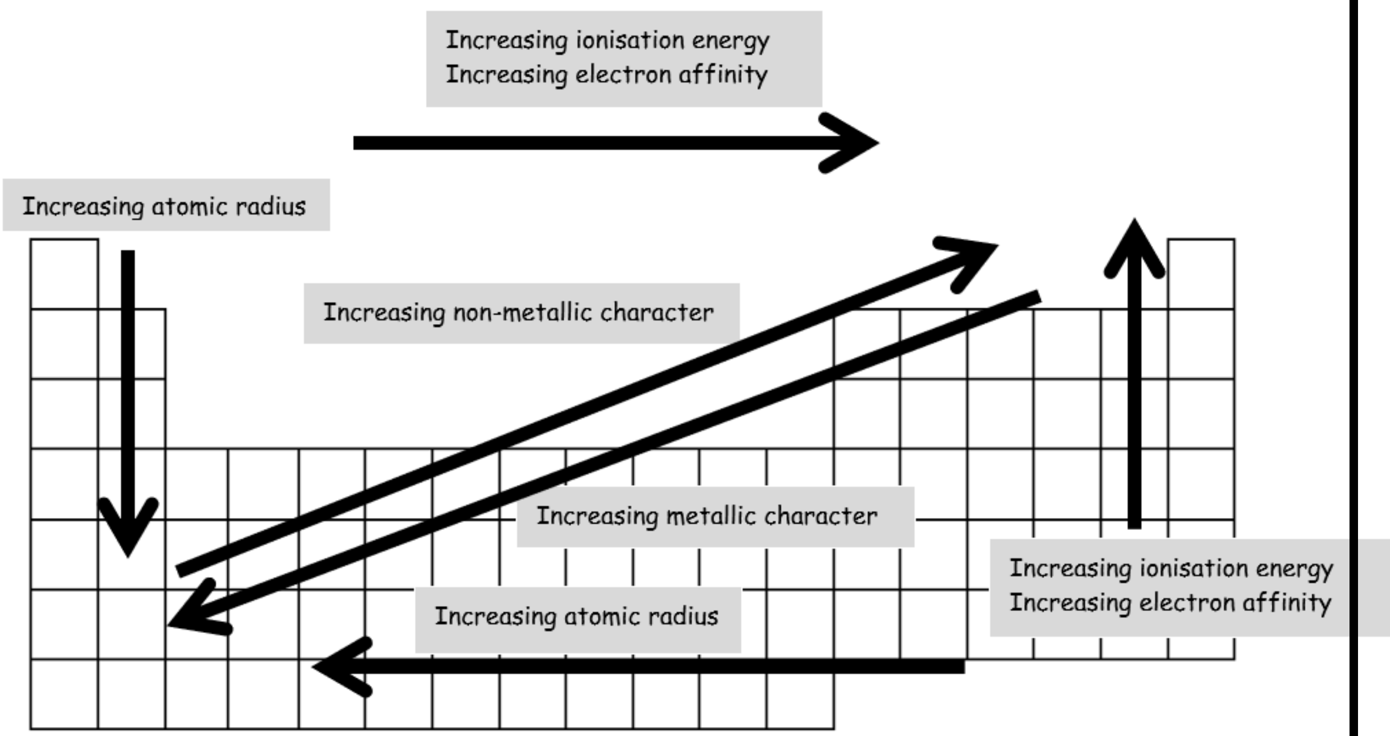
A block of the periodic table is a set of chemical elements having their differentiating electrons predominately in the same atomic orbital type.

Each block is named after its characteristic orbital: s-block; p-block; d-block; and f-block.

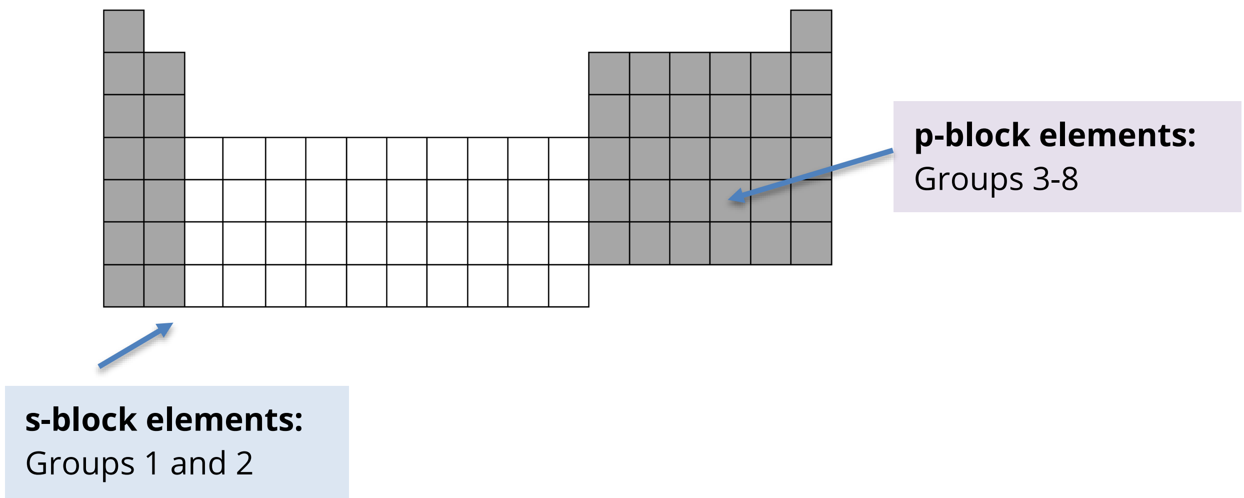
Reactivity of Elements



Periodic Trends



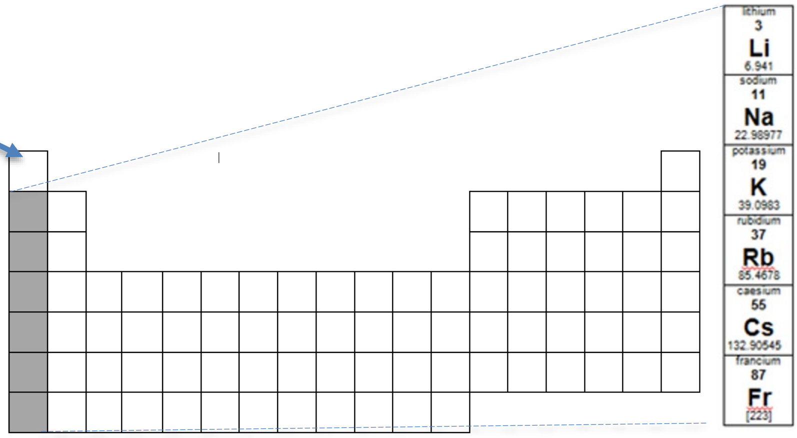
Main Group Elements (shaded)



Group 1: Alkali Metals

(valence shell configuration ns, where n = 2-7)

Hydrogen (H) $1s^1$: despite its location in the periodic table and electron configuration it is a non-metal and does not belong to any group.



As you do down group 1 from lithium (Li) to francium (Fr):

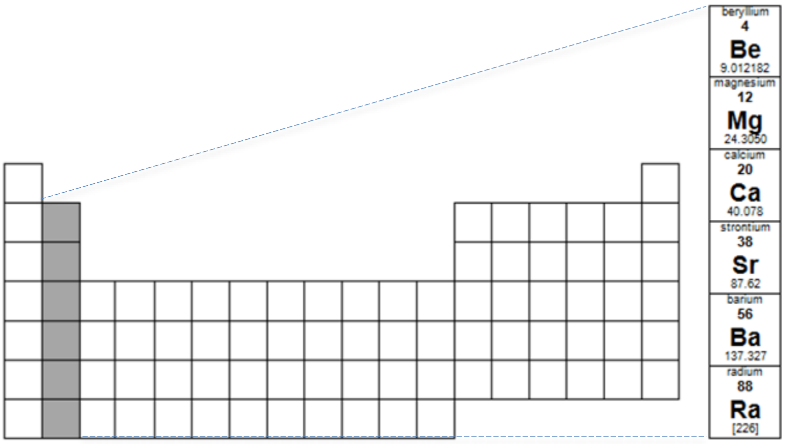
- atomic radii increase,
- metallic character increases,
- electronegativity decreases,
- melting and boiling temperatures decrease,
- metals become softer,
- first ionisation energy decreases,
- reactivity increases.

Alkali metals have the following properties in common:

- low melting and boiling, temperatures (compared with 'everyday' metals),
- very soft and can be cut with a knife,
- low densities (lithium, sodium, and potassium float on water),
- form singly charged cations, M^+,
- low electronegativity,
- low ionisation energies, resulting in the formation of ionic compounds with non-metals,
- react vigorously with water, producing hydroxides (MOH) and hydrogen gas: $M_{(s)} + H_2O_{(l)} \longrightarrow 2MOH_{(aq)} + H_{2\,(g)}$,
- form basic hydroxides (MOH) and oxides (M_2O).

Group 2: Alkaline Earth Metals

(valence shell configuration ns^2, where n = 2-7)



As you go down group 2 from beryllium (Be) to barium (Ba):

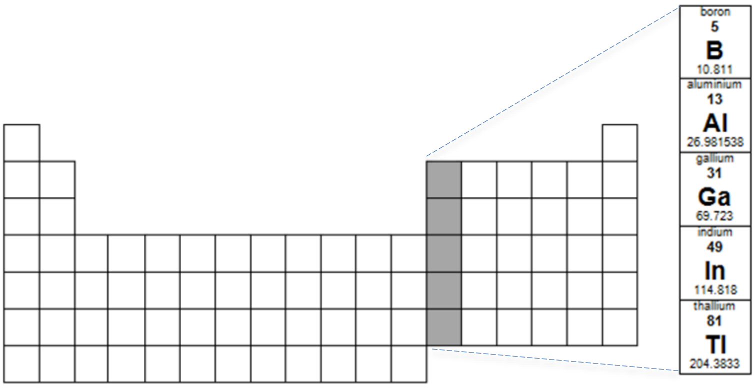
- atomic and ionic radii increase,
- electronegativity decreases,
- metallic character increases,
- ionisation energy decreases,
- melting temperature generally decreases,
- reactivity increases.

Alkaline earth metals have the following properties in common:

- low melting and boiling temperatures.
- low density, soft and silvery metals (less metallic in character than the group 1 elements).
- form doubly positively charged ions, M^{2+},
- predominantly form ionic compounds,
- low electronegativity
- low first and second ionisation energies
- act as powerful reducing agents,
- readily react with water and halogens.

Group 3: Triels

(valence shell configuration ns^2np^1, where n = 2-6)



Group 3 elements:

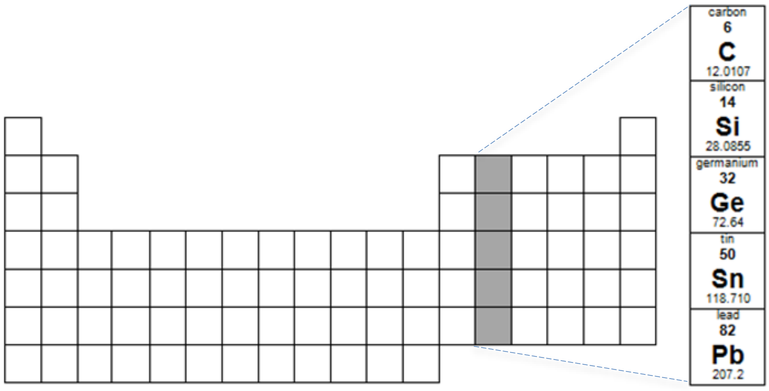
- Al, Ga, In and Tl all form a range of compounds in the +3-oxidation state, e.g. M_2O_3 and MX_3,
- Al and Ga oxides are amphoteric, whilst the remaining oxides are more basic,
- Group 3 trihalides, MX_3, are Lewis acids and Lewis acid strengths decrease in the order: Al > Ga > I.

As you go down group 3 from boron (B) to thallium (Tl):

- atomic radii and density increase,
- first Ionization energy decreases (except thallium),
- boiling temperature decreases,
- chemical reactivity increases,
- electronegativity decreases from boron to aluminium, but then marginally increases,
- relative stability of the +1 oxidation state increases,
- oxides become increasingly basic in nature (B - acidic, Al, Ga - amphoteric, In, Tl - basic).

Group 4: Triels

(valence shell configuration ns^2np^2, where n = 2-6)



Group 4 elements:

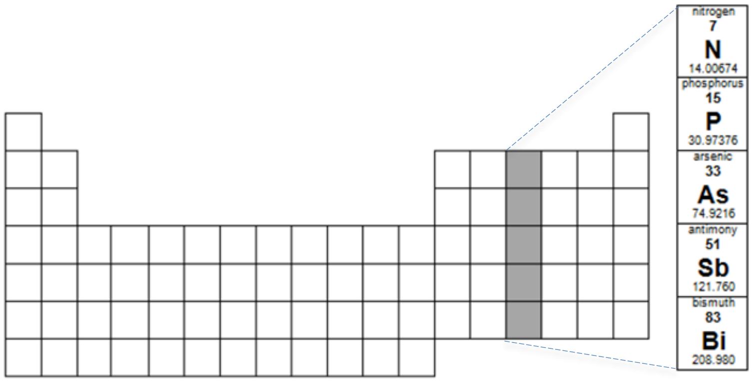
- C is non-metal, Si and Ge are metalloids; Sn and Pb are metals,
- +4 oxidation state is dominant for C, Si, and Ge whereas Sn and Pb form compounds in both +2 and +4 oxidation states,
- C is unique in that it can form strong single, double and triple bonds with itself,
- Si and the remaining group 4 elements only form single bonds.

As you go down group 4 from C to Pb:

- atomic radii increase,
- metallic character increases
- non-metallic character decreases,
- boiling temperature (higher than corresponding group 3 elements) decreases from silicon to lead,
- first ionisation energy generally decreases,
- little variation in electronegativity from silicon to lead, but higher than the corresponding group 3 members,
- stability of +4 oxidation state decreases,
- stability of +2 oxidation state increases from germanium to lead,
- elements react with oxygen to form both monoxides (MO) and dioxides (MO_2),
- acidity of dioxides decreases down the group.

Group 5: Pnictogens

(valence shell configuration ns^2np^3, where n = 2-6)



Group V consists of two non-metals, one gas- N; one solid – P; two metalloids - As and Sb and one metal - Bi.

Apart from N and Bi, group 5 elements have two or more allotropic forms.

Group V elements:

- form double and triple bonds resulting in high stability, low reactivity, and toxicity,
- less reactive than the corresponding group 6 elements,
- all form +3 (M_2O_3) and +5 (M_2O_5) oxidation state oxides,
- halides exist in two oxidation states: MX_3), and penta-halides (MX_5).

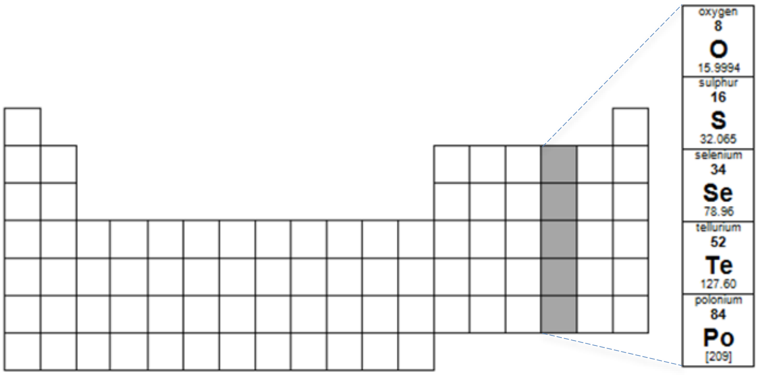
Trihalides are known for all group 5 elements and all apart from N form pentahalides.

As you go down group 5 from N to arsenic As:

- atomic radii increase,
- metallic character increases
- non-metallic character increases,
- ionisation energy decreases,
- electronegativity decreases,
- boiling temperature increases to arsenic (As) and then decreases up to bismuth (Bi),
- stability of -3 and +5 oxidation state decrease,
- oxides of higher oxidation state are more acidic and acidic character of these oxides decreases down the group.

Group 6: Chalcogenides

(valence shell configuration ns^2np^3, where n = 2-6)



O and S are non-metals; Se and Te are metalloids, whereas Po is a metal.

The first few members of group 6 are critical to life, whilst the heavier elements are toxic.

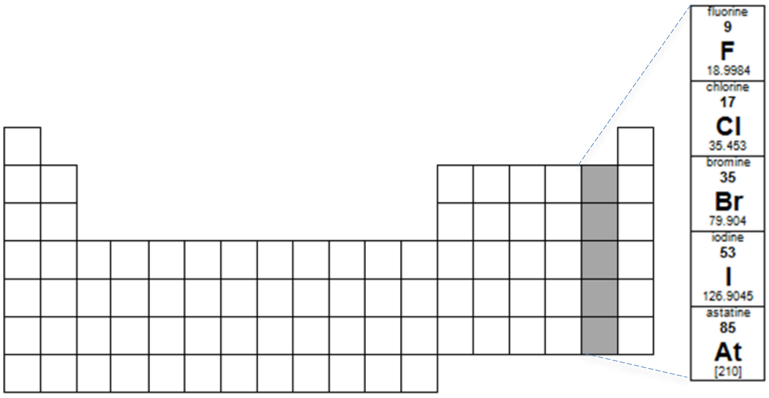
O has 9 allotropes, S has more than 20, Se has 5, Po has 2 and Te is thought to have just 1.

As you do down group 6:

- atomic radii, ionic radii, metallic character, melting and boiling points increase,
- ionization energy decreases,
- electronegativity decreases
- stability of -2 and +6 oxidation states decreases,
- stability of +4 oxidation state increases.

Group 7: Halogens

(valence shell configuration ns^2np^5, where n = 2-6)



The halogens ("salt formers") exist as solids (I_2), liquids (Br_2), and gases (F_2, Cl_2) at room temperature and pressure.

In general, the halogens are very reactive, especially with group1 and 2 elements with which they form ionic compounds, i.e. MX and MX_2, respectively.

High reactivity of the halogens is due to their high electronegativity and the stability of the X^- (F^-, Cl^-, Br^- etc) ions.

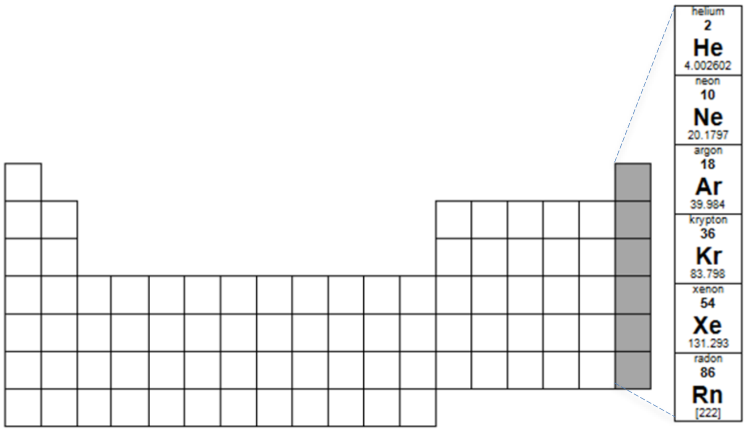
All elements apart from the noble gases form compounds with some or all the halogens. Metallic halide tend to be ionic, whilst non-metal halides are predominantly

The halogens have the following properties in common:

- non-metals,
- low melting and boiling points,
- brittle when solid,
- poor conductors of heat and electricity,
- coloured gases,
- exist as diatomic molecules (X_2),
- form highly stable singly charged anions, X^-,
- form ionic salts with metals (MX_n),
- form covalent compounds with non-metals.

Group 8 (0): Nobel Gases

(valence shell configuration ns^2np^6, where n = 2-6)



He, Ne, Ar, Xe, Kr, Rn have very low melting and boiling temperatures and consequently are all gases at room temperature.

They have complete valence shells and are hence are very stable and unreactive.

Although once thought to be totally inert, the heavier noble gases Kr, Xe and Rn form a small number of compounds with O, F and Cl e.g. KrF_2, $XeCl_2$) and RnO_3

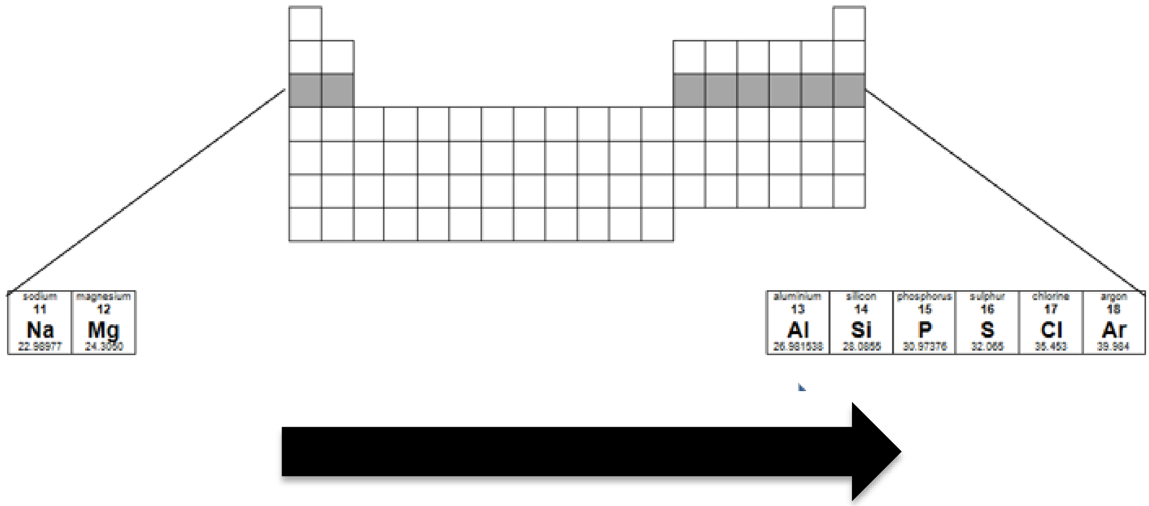
As you go down group 8(0) from helium (He) to radium (Ra):

- atomic radii increase,
- ionisation energy decreases,
- melting and boiling temperatures increase,
- density increases.

The noble gases have the following properties in common:

- non-metallic,
- low melting and boiling temperatures (eg He: melting temperature -272^{o}C, boiling temperature -268^{o}C),
- melting and boiling, temperatures are very close together, so they only exist as a liquid over a small temperature range (<10^{o}C),
- unreactive (inert) gases,
- do not usually form chemical bonds,
- colourless. odourless, tasteless and non-flammable
- exist as single atoms (they are monatomic).

Period 3 Trends

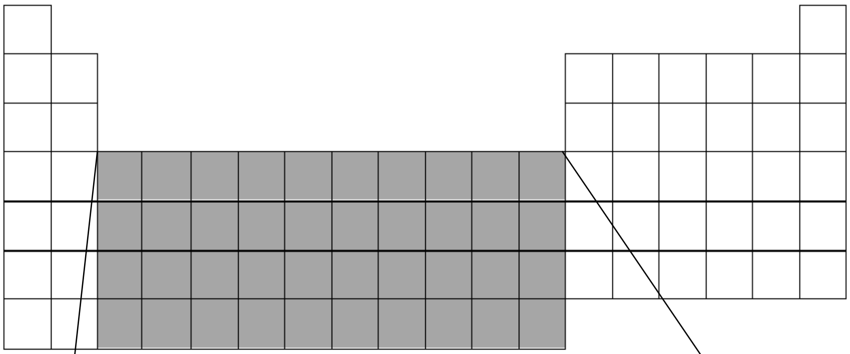


As you move from left to right across period 3, the elements exhibit the following general trends:

- proton number and nucleus charge increase,
- number of valence electrons increases,
- atomic radii decrease,
- melting and boiling temperatures decrease,
- metallic character decreases,
- non-metallic character increases,
- electrical conductivity decreases,
- valence electrons are held more tightly, resulting in an increase in first ionisation energy,
- ease of cation formation decreases (excluding argon),
- ease of anion formation increases (excluding argon),
- electronegativity increases (excluding argon).

These trends can all be explained by the electron configurations of the elements and the stability of full valence electron shells.

Transition Metals



scandium 21 **Sc** 44.95591	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.9415	chromium 24 **Cr** 51.9961	manganese 25 **Mn** 54.93805	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.9332	nickel 28 **Ni** 58.6934	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.409
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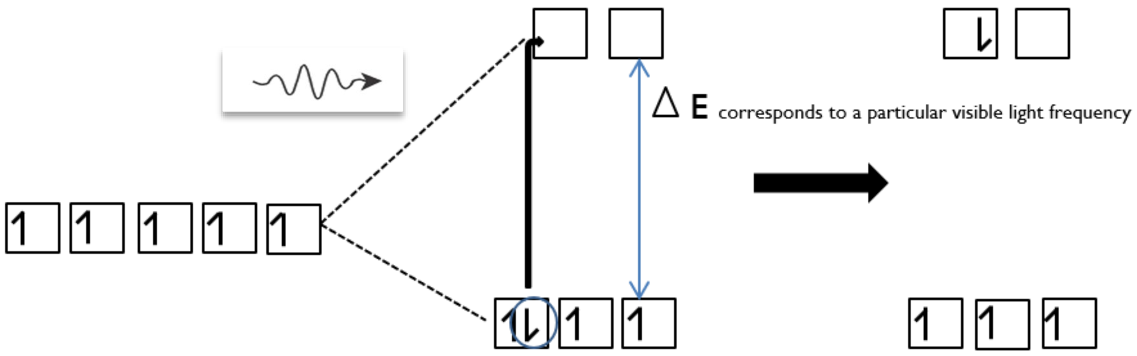
Physical & Chemical Properties

Transition element typically exhibit the following physical properties:

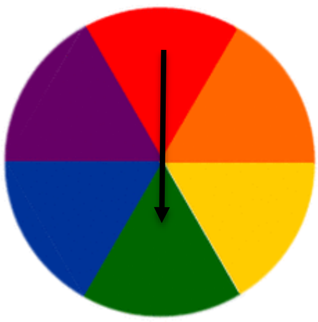
- hard and high-density solids,
- good conductors of heat and electricity,
- high melting and boiling temperatures,
- exhibit variable oxidation states,
- form coloured ions,
- form complex ions,
- form compounds with high catalytic activity.

Colour of Transition Metal Complexes

Electron promoted to a higher energy level by absorbing a photon of light of energy, ∆E



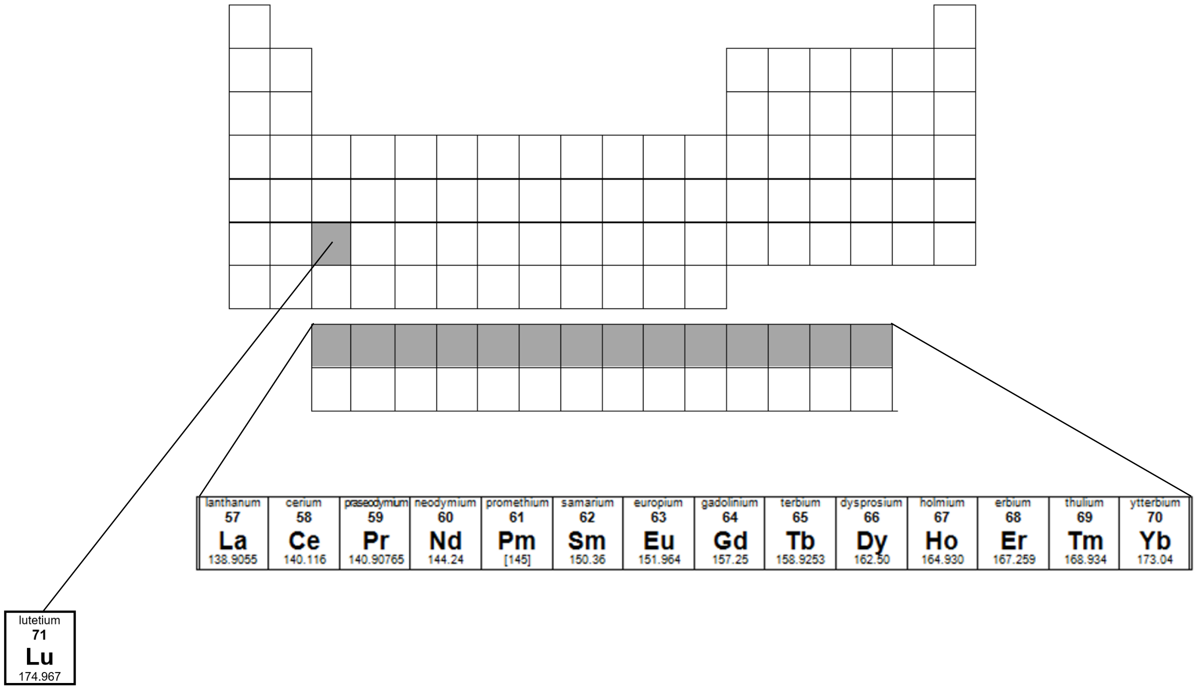
d- orbitals split when ligands are bonded to the transition metal



Colour wheel

The colour of the complex is simply the complementary colour of the light absorbed. If red light is absorbed, the colour detected by the human eye is green. Complementary colours are opposite each other on the 'colour wheel'.

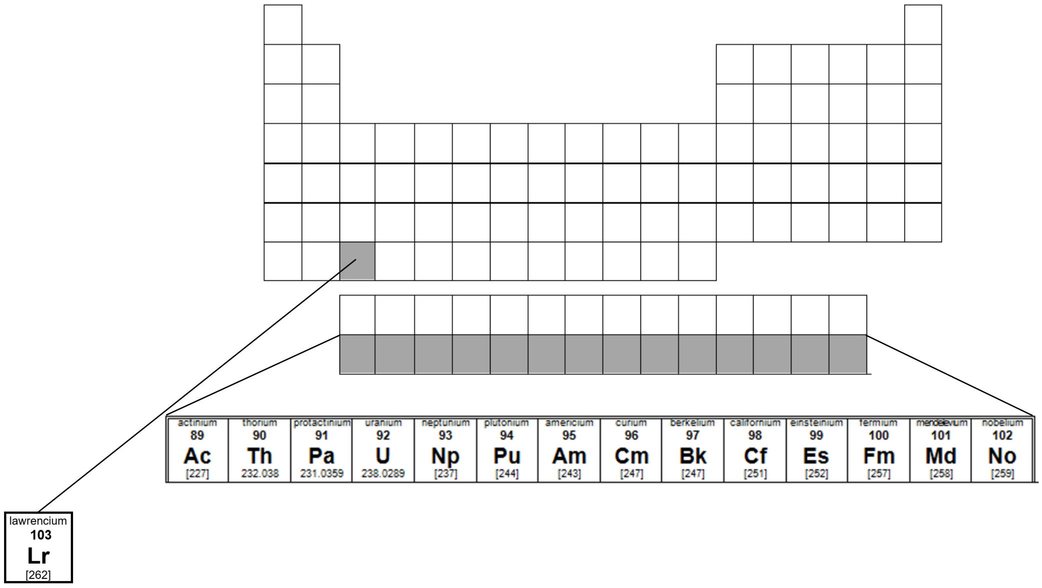
Lanthanide Elements



Lanthanides have the following common properties:

- occur naturally,
- relatively soft silvery-white metals that tarnish in air,
- high melting and boiling temperatures,
- hardness increases with proton number,
- exhibit variable oxidation states,
- strong reducing agents,
- highly reactive; generate hydrogen on contact with water, burn in air etc.,
- form predominantly ionic compounds,
- their compounds exhibit **fluorescence** under UV light.

Actinide Elements

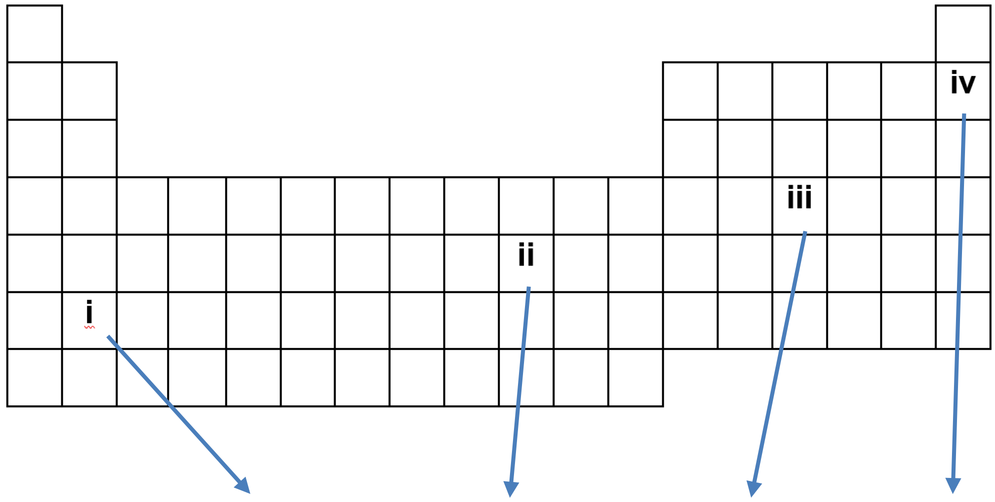


The actinide elements (proton numbers 89 to 103) are ‘typical’ metals and share the following common properties:

- toxic and radioactive,
- dense silver coloured metals at room temperature,
- exist in a range of allotropes,
- fairly soft and often cuttable with a knife,
- malleable and ductile,
- exhibit a range of oxidation states,
- tarnish rapidly in air,
- react directly with most non-metals,
- generate hydrogen on contact with boiling water and weak acids.

Reading the Periodic Table

Elements are defined by the position they occupy in the periodic table. From its location alone, many physical and chemical properties of an element can be reliably predicted.



	Element i	Element ii	Element iii	Element iv
Valence Shell Configuration	ns^2	ns^2nd^8	ns^2np^3	ns^2np^6
Group	Group 2 Alkaline Earth Metal s-block	2nd row Transition Metal d-block	Group 5 Pnictogen p-block	Group 8 Noble Gas p-block
Classification	Metal Conductor	Metal Conductor	Metalloid Semiconductor	Non-Metal Insulator
State at Room Temperature	Solid	Solid	Solid	Gas
Oxidation States Exhibited	+2	+2 and others	+3 and +5	0
Oxide	MO Ionic/basic	MO and others Ionic /amphoteric	X_2O_3 and X_2O_5 Molecular/acidic	None
Chloride	MCl White ionic Soluble in water	MCl_2 and others Coloured ionic Soluble in water	XCl_3 and XCl_5 Covalent molecular Likely to react with water to form acidic solutions	None
Reactivity	Very reactive	Less reactive than element i, more re4active than element iv.	Less reactive than element i, more reactive than element iv.	Inert