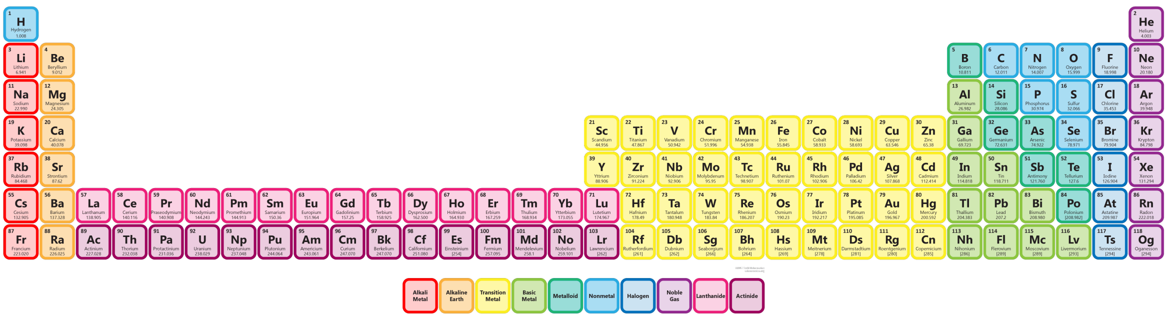
The periodic table of elements

Periodic table from 1876, preserved at the University of Saint-Petersburg

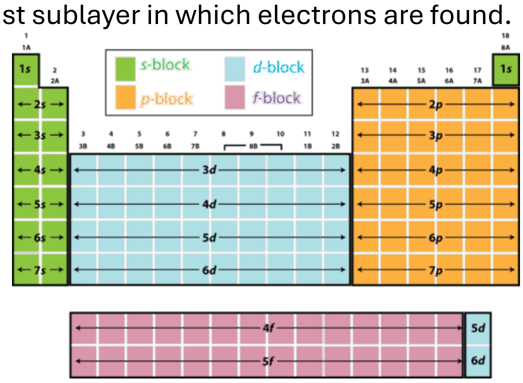
Structure of the periodic table of elements

A chemical element is characterized by its atomic number Z. It groups together all entities (atoms, monoatomic ions and their isotopes) with the same atomic number.
Chemical elements are classified in order of increasing atomic number in the periodic table of elements.



- **7 lines (or periods): they correspond to the valence shell of the element**
  - First line: valence shell n = 1
  - Second line: valence shell n = 2
  - Third line: valence shell n = 3
  - ...

  A change of line corresponds to a change of valence shell to be filled.
- **32 columns (18 from I to XVIII + 14):**
  All chemical elements in the same column form a chemical family. They have similar chemical properties, and the same number of electrons in their valence shell
- **4 blocks: s, p, d, f**
  It corresponds to the last sublayer in which electrons are found.

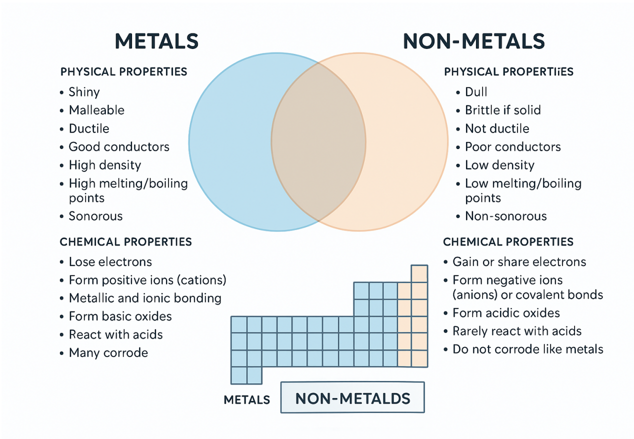


Ex : For an element of d-block, the last sublayer on which electrons are found is sublayer d.

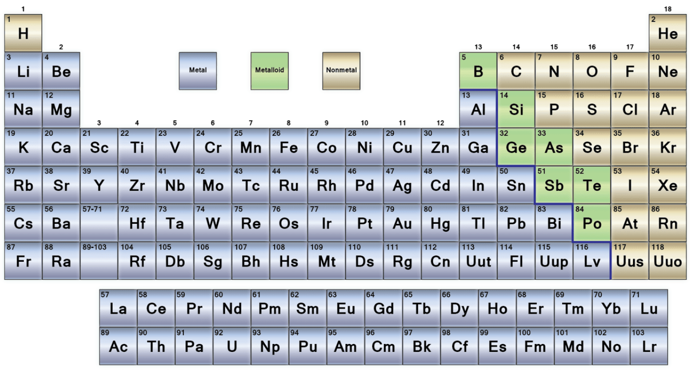
Chemical properties in the periodic table

1. A first division: Metals and non-metals…

Metals are shiny, malleable and conductors (for both electricity and heat). These elements form cations.
Non-metals are dull, brittle and insulators (for both electricity and heat). These elements either form anions or covalent bonds.



Note: A few elements (Boron (B), Silicon(Si), Germanium (Ge), Arsenic (As), Antimony (Sb) and Tellurium (Te)) have mixed properties between metals and non-metals. Called metalloids, they form a "staircase" dividing the periodic table.



2. … Leading to more subtle distinctions: families

Family (Group name)	Group number	Valence electrons	Key Elements	Main Properties
Alkali Metals	I	1	Li, Na, K, Rb, Cs, Fr	Soft, highly reactive metals; react violently with water; form +1 ions.
Alkaline Earth Metals	II	2	Be, Mg, Ca, Sr, Ba, Ra	Reactive (less than alkali metals); form +2 ions; important in minerals.
Transition Metals	III–XII	Varies	Fe, Cu, Zn, Ag, Au	Good conductors; form colorful compounds; multiple oxidation states.
Lanthanides	Period 6 f-block	Varies	Ce, Nd, Eu	Shiny, reactive metals; often used in magnets, electronics.
Actinides	Period 7 f-block	Varies	U, Pu, Th	Radioactive metals; some synthetic; used in nuclear energy.
Boron Family	XIII	3	B, Al, Ga, In, Tl	Form +3 ions; include metals and a metalloid (boron).
Carbon Family	XIV	4	C, Si, Ge, Sn, Pb	Varied bonding; includes nonmetals, metalloids, and metals.
Nitrogen Family (Pnictogens)	XV	5	N, P, As, Sb, Bi	Form –3 ions; diverse chemistry (nonmetals to metals).
Oxygen Family (Chalcogens)	XVI	6	O, S, Se, Te, Po	Form –2 ions; essential to life (oxygen, sulfur).
Halogens	XVII	7	F, Cl, Br, I, At	Very reactive nonmetals; form salts with metals; form –1 ions.
Noble Gases	XVIII	8	He, Ne, Ar, Kr, Xe, Rn	Unreactive monoatomic gases

Note: Hydrogen (H) sits above group 1 because it has only one valence electron. However, it is NOT a metal and behaves uniquely (sometimes like group I, and sometimes like group XVII)

Trends in the periodic table

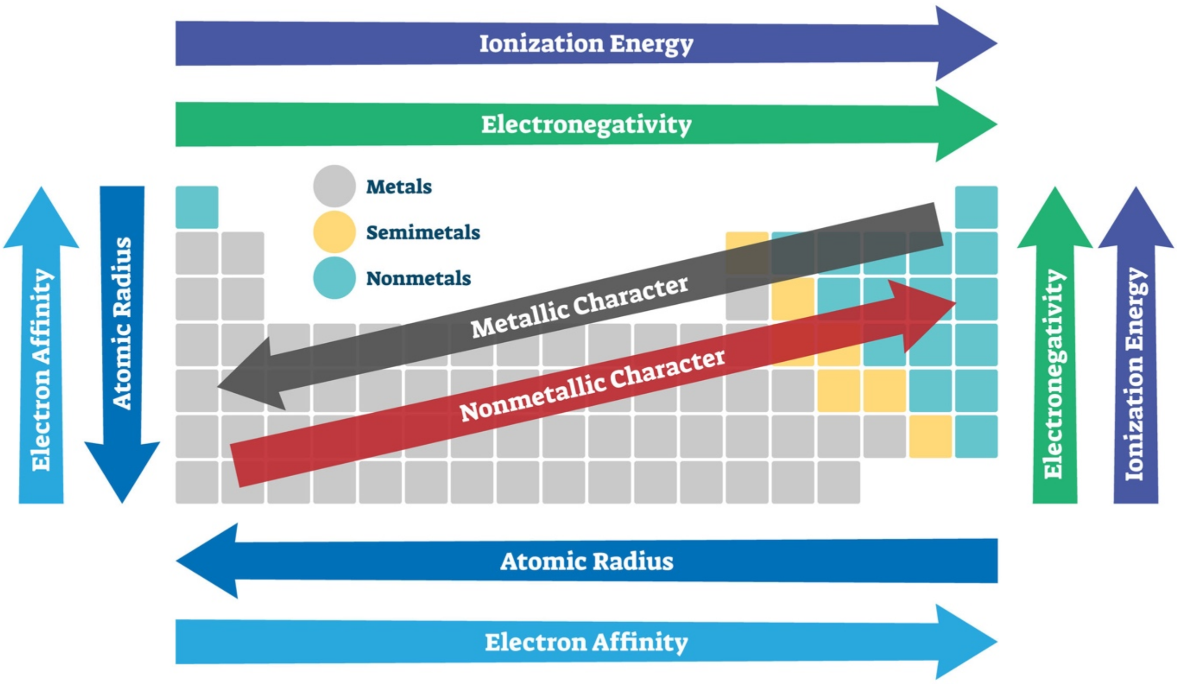
Chemical properties of elements are linked to the configuration of their valence shell. However, the number of protons, and therefore the nuclear charge and the shielding effect from inner electrons have an influence on the intensity of these properties, leading to trends in the different families, which appear in the periodic table.

- The **Atomic Radius** of an element, usually measured in m, corresponds to the radius of the individual atom.
- The **Ionization Energy** of an element, usually measured in kJ.mol-1, corresponds to the energy needed to remove one electron.

  Note: First ionization energy is the energy needed to remove the first electron: $X \longrightarrow X^+$
  Second ionization energy is the energy needed to remove the second electron: $X^+ \longrightarrow X^{2+}$
  ...
- The **Electron Affinity** of an element, usually measured in kJ.mol-1, corresponds to the energy change when an atom gains an electron

  Note: The electron affinity has a negative frame reference: a high affinity means a high negative value.
  Ex: EA(Cl) = - 349 kJ.mol^{-1}
  EA(O) = - 141 kJ.mol^{-1}
  Chlorine has a higher electron affinity than Oxygen
- The **Electronegativity** of an element corresponds to its tendency to attract the electrons in a covalent bond.

  Notes: Electronegativity uses the Pauling scale, introduced in 1932. It is based on bond energy differences and is unitless. Fluorine is attributed the highest value of 4.0, and the electronegativity of all other elements is derived from this choice.
  The least electronegative element is Cesium, with a value of 0.7.
  Noble gases being considered as forming no bonds, their electronegativity is undefined.



HL note: There are always a few exceptions

- ***Atomic Radius:***
  - *The atomic radius of transition metals changes very little across a period: added electrons go into an inner d-subshell, which poorly shields the outer electrons.*
  - *Gallium is smaller than Aluminum, due to their extra protons pulling electrons closer despite extra shielding from the d-subshell.*
- ***Ionization Energy and Electron Affinity:***
  - *Small dips in IE trend occur when a new subshell starts or a subshell is more than half-full.*

    Ex: *Compared to Beryllium, Boron's last electron is in a higher p-orbital, thus easier to remove.*

    Compared to Nitrogen, Oxygen's last electron leads to a non-bonding pair, causing electron repulsion, thus easier to remove.

    Magnesium has a full s-subshell, thus resists adding an extra electron

    Phosphorus has a stable half-full p-subshell, thus a positive EA.
- ***Electronegativity:***
  - *Due to d-orbital effects and variable oxidation states, the electronegativity of transition metals doesn't follow any trend; it changes irregularly.*