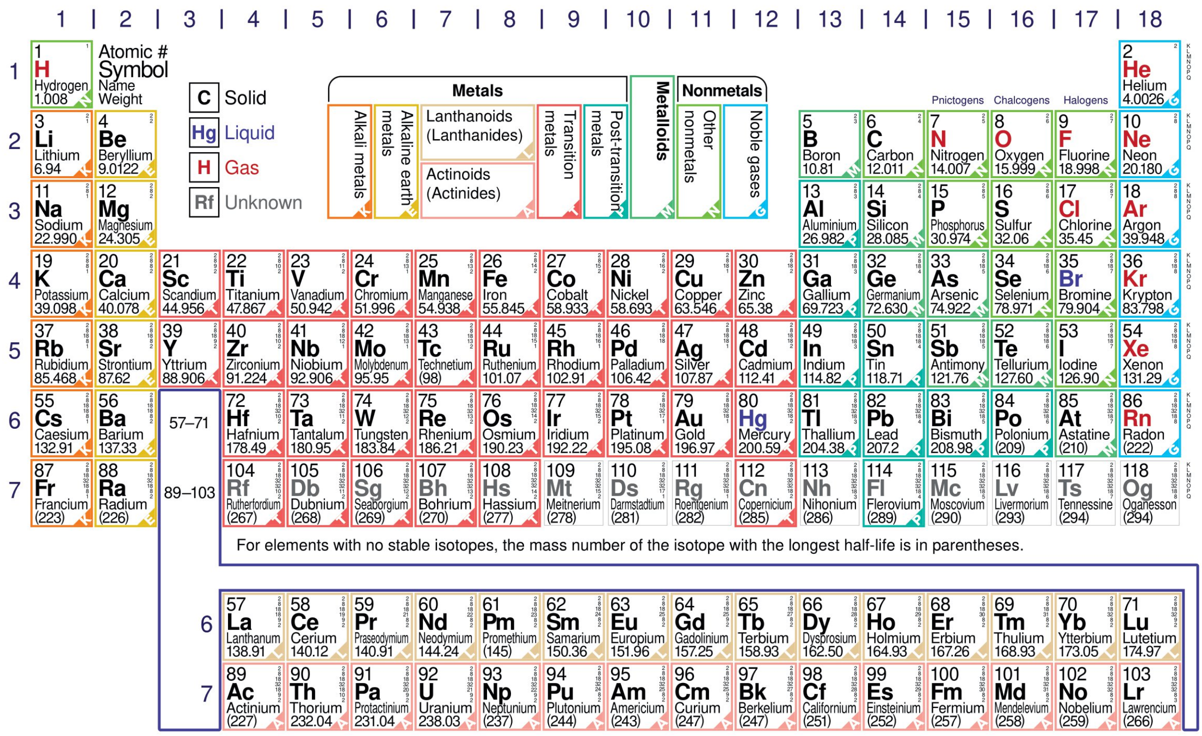
Chapter 6 - The Periodic Table and Bonding

PERIODIC TABLE OF ELEMENTS



Group

Group	Name
Group 1	Alkali Metals
Group 2	Alkaline Earth Metals
Group 17	Halogens
Group 18	Noble Gases

- The vertical columns of Periodic Table
- There're **18 groups** (Group 1 - 18) arranged according to the number of valence electrons.
- All members of the same group have the **same number of valence electrons**.
- Members of a group have **similar chemical properties**. Their physical properties may show gradual change when descending group.

Period

- The horizontal rows are called periods.
- There're **7 periods**.
- Period number is indicated by **number of filled electron shells**.
- All elements in the same period have the **same number of filled electron shells**.

Pattern in the Periodic Table - Group

Group 1 (Group IA, alkali metals)

Physical Properties

1. **Soft metals** which can be easily cut with knife
    - Number of delocalized electron is lesser compared to other metals, the metallic bond is weaker
2. **Silvery** solids with **shiny** surface
3. **Lower melting / boiling point** compared to other metals.
4. **Lower density** compared to other metals
5. Good **conductivity** of heat and electricity

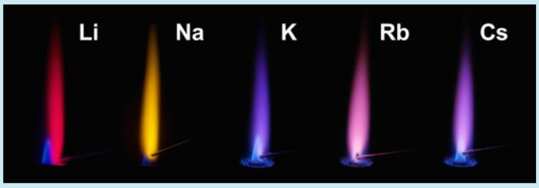
Trend in physical properties when going down the group

Characteristic	Trend	Reason
1. Atomic size	Increases	The number of electron shells increases when descending the group.
2. Density	Increases	Mass increases faster than the increase in radius.
3. Melting point / Boling point	Decreases	- Atomic size increases. - The distance between delocalized electron and positive atom is increased. - Metallic bond between atoms become weaker. - Less heat energy is needed to overcome the attraction force between delocalized electron and positive metal atoms.
4. Electropositivity	Increases	- Electropositivity: a measurement of the ability of an atom to lose an electron and form a cation. - Atomic size increases. - The attractive force between the positive nucleus and the single valence electron becomes weaker. - The atom loses electron more easily.

Chemical Properties

- Each group 1 elements have **similar chemical properties** because of all having 1 valence electron.
- All group 1 elements are **very reactive metals**, they will **release a valence electron** to form 1+ ion to **achieve octet electron arrangement**.
    - $M \longrightarrow M^+ + e^-$ (M = Li, Na, K, Rb, Cs, Fr)
- Their **chemical reactivity** is different. It depends on how easily it can **donate its valence electron**.
- The ***reactivity*** *of group 1 elements* ***increases when going down the group***, because:
    - *The number of shells increases, so the* ***atomic size increases***
    - *The valence electron in the outermost shell gets further away from nucleus, causing* ***attractive force*** *of proton to valence electron becoming* ***weaker****.*
    - *Thus, the valence electron can be released* ***easily****.*

Chemical Reactions

Chemical Reactions of Group 1 Elements			
	Alkali Metals	**Observation**	**Equation**
Group 1 metals react with water to produce alkali and hydrogen gas	Lithium	Reacts readily with water	$2\,Li_{(s)} + 2\,H_2O_{(l)} \longrightarrow 2\,LiOH_{(aq)} + H_{2\,(g)}$
	Sodium	Reacts vigorously; Catches fire	$2\,Na_{(s)} + 2\,H_2O_{(l)} \longrightarrow 2\,NaOH_{(aq)} + H_{2\,(g)}$
	Potassium	Reacts violently; Catches fire; then explodes	$2\,K_{(s)} + 2\,H_2O_{(l)} \longrightarrow 2\,KOH_{(aq)} + H_{2\,(g)}$
Group 1 metals can be oxidized in air to form white metal oxides	Lithium	Tarnish in air due to the formation of dull oxide on the surface	$4\,Li_{(s)} + O_{2\,(g)} \longrightarrow 2\,Li_2O_{(s)}$
	Sodium	Tarnish in air due to the formation of dull oxide on the surface	$4\,Na_{(s)} + O_{2\,(g)} \longrightarrow 2\,Na_2O_{(s)}$
	Potassium	Tarnish in air due to the formation of dull oxide on the surface	$4\,K_{(s)} + O_{2\,(g)} \longrightarrow 2\,K_2O_{(s)}$
Group 1 metals burn in sufficient oxygen with characteristic flame colors	 Flame tests are used to preliminary identify the presence of metal ions in a compound. Not all metal ions give flame colors.		
	Lithium	Bright red flame	
	Sodium	Yellow flame	
	Potassium	Violet flame	
	Rubidium	Red violet flame	
	Caesium	Blue flame	
Group 1 metals burn in sufficient oxygen form various oxides	Sodium	Sodium starts burning immediately in air when heated or put under a flame. Sodium burns with yellow flame and forms a mixture of sodium oxide and sodium peroxide.	$4\,Na_{(s)} + O_{2\,(g)} \longrightarrow \underset{\text{sodium oxide}}{2\,Na_2O_{(s)}}$ $2\,Na_{(s)} + O_{2\,(g)} \longrightarrow \underset{\text{sodium peroxide}}{Na_2O_{2\,(s)}}$
	Potassium	Sodium burns vigorously with lilac / violet flame and forms a mixture of potassium superoxide and potassium peroxide.	$K_{(s)} + O_{2\,(g)} \longrightarrow \underset{\text{potassium superoxide}}{KO_{2\,(s)}}$ $2\,K_{(s)} + O_{2\,(g)} \longrightarrow \underset{\text{potassium peroxide}}{K_2O_{2\,(s)}}$
Group 1 metals react with halogen to form white metal halides	Lithium	1. All of the alkali metals react vigorously with chlorine gas.	$2\,Li_{(s)} + Cl_{2\,(g)} \longrightarrow 2\,LiCl_{(s)}$
	Sodium	2. Each reaction produces a white crystalline salt.	$2\,Na_{(s)} + Cl_{2\,(g)} \longrightarrow 2\,NaCl_{(s)}$
	Potassium	3. The reaction gets more violent as you move down Group 1.	$2\,K_{(s)} + Cl_{2\,(g)} \longrightarrow 2\,KCl_{(s)}$

Group 17 (Group VIIA, halogens)

- Group 17 elements: Fluorine (F), Chlorine (Cl), Bromine (Br), Iodine (I), Astatine (At)
- The halogens molecules exist as **diatomic molecules**: F_2, Cl_2, Br_2, I_2, At_2

Physical Properties

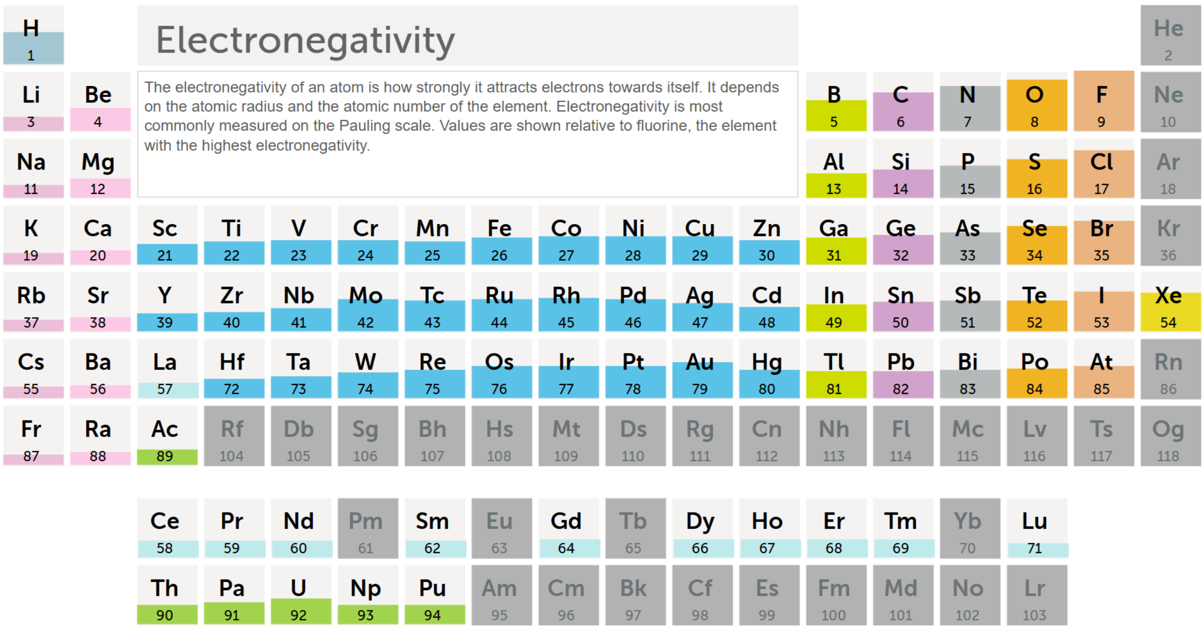
1. All Group 17 elements are non-metals. They exist as diatomic molecules.
2. They're **non-conductors** of heat and electricity.
3. Low density.
4. **Low melting and boiling point**, because the halogen molecules are attracted by **weak van der Waals force**.

- van der Waals force ∝ molecule size
- $I_{2(s)} > Br_{2(l)} > Cl_{2(g)} > F_{2(g)}$ [at 25℃]

Trend in physical properties when going down the group

Characteristic	Trend	Reason
Atomic radius	Increases	The number of electron shells increases when descending the group.
Density	Increases	Mass increases faster than the increase in radius.
Melting point / Boiling point	Increases	- Molecular size increases. - Causes van der Waals force between the molecules become stronger. - More heat is required to overcome the attractive force.
Electronegativity	Decreases	- Atomic radius increases. - Causes the attractive force between the nucleus and the valence electrons becomes weaker. - Hence, the ability of atoms to attract electrons decreases.

***Electronegativity**



- A measure of the **tendency of an atom to attract a bonding pair of electrons**.
- When two atoms with different electronegativity bond covalently, the electron pair will be pulled more to the atom with higher electronegativity.
- The Pauling scale is most commonly used. Fluorine (the most electronegative element) is assigned a value of 4.0, and values ranges down to francium which is the least electronegative at 0.7.
- **F > O > Cl > N > Br > I > S > C > H > metals**
- No electronegativity difference between two atoms leads to a pure **non-polar covalent bond**.
- A small electronegativity difference leads to a **polar covalent bond**.
- A large electronegativity difference leads to an **ionic bond**.

Chemical Properties

- Each of Group 17 elements have **similar chemical properties** because all atoms have 7 valence electrons.
- All group 17 elements are very reactive non-metals. An atom of group 17 elements will **accept an valence electron** to form 1- ion to **achieve octet electron arrangement**.
  - $X_2 + 2e^- \longrightarrow 2X^-$ (X = F, Cl, Br, I)
- The reactivity of Group 17 elements depends on its ability to gain an electron. ***The reactivity decreases when going down the group***, because:
  - *The number of shells increases so the atomic radius of group 17 elements increases down the group.*
  - *The valence electron in the outermost shell gets further away from the nucleus, thus causes attractive force of proton to valence electron becomes weaker.*
  - *The ability of a halogen atom to attract electron decreases from fluorine to astatine.*

Chemical Reactions

(i) Group 17 elements react with water to produce acid

Halogen	Observation: Solubility	Observation: Effect on Litmus Paper	Equation
Chlorine	Dissolves rapidly; light yellow solution	Blue turns red, then decolorized	$Cl_{2(g)} + H_2O_{(l)} \rightleftharpoons HCl_{(aq)} + HOCl_{(aq)}$
Bromine	Dissolves slowly; reddish brown solution	Blue turns red, then decolorized after a longer time	$Br_{2(g)} + H_2O_{(l)} \rightleftharpoons HBr_{(aq)} + HOBr_{(aq)}$
Iodine	Dissolves slightly; pale brown solution	Blue turns red, is not decolorized	$I_{2(g)} + H_2O_{(l)} \rightleftharpoons HI_{(aq)} + HOI_{(aq)}$

(ii) Group 17 elements react with sodium hydroxide to produce water and salt

- $Cl_{2(g)} + 2NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + NaClO_{(aq)} + H_2O_{(l)}$
- $Br_{2(g)} + 2NaOH_{(aq)} \longrightarrow NaBr_{(aq)} + NaBrO_{(aq)} + H_2O_{(l)}$
- $I_{2(g)} + 2NaOH_{(aq)} \longrightarrow NaI_{(aq)} + NaIO_{(aq)} + H_2O_{(l)}$

Group 18 (Group VIIIA, noble gases / inert gases)

- Group 18 elements: Helium (He), Neon (Ne), Argon (Ar), Krypton (Kr), Xenon (Xe), Radon (Rn)

Physical Properties

1. All noble gases are **insoluble** in water.
2. They're **non-conductors** of heat and electricity.
3. Very **low density**. Due to the atoms are very far apart.
4. The **density** of noble gases **increases** when descending the group, due to the atomic mass increases faster than the increase in radius.
5. Noble gases have **very low melting and boiling point**. This is because noble gases exist as **monoatomic molecules** which are attracted by **weak van der Waals forces**, less energy is required to overcome the forces.

6. However, the **melting and boiling point increases** when going down the group, because atomic size increases, causing van der Waals forces stronger and more energy is required to overcome the forces.

Chemical Properties

1. They exist as **monoatomic molecules** (single atoms) because the atom does **not lose, gain or share electrons**.
2. Noble gases are **chemically inert** (unreactive) because the atoms have achieved **duplet electron arrangement** for helium and **octet electron arrangement** for others.

Pattern in the Periodic Table - Period

Period 3

- The elements in period 3: Sodium (Na), Magnesium (Mg), Aluminum (Al), Silicon (Si), Phosphorus (P), Sulphur (S), Chlorine (Cl), Argon (Ar).

Physical and Chemical Properties across Period 3

Characteristic	Trend	Reason
1. Atomic radius	Decreases	- All atoms of the elements have 3 shells occupied with electrons. - **Proton number increases** one by one from Na to Cl - It causes the number of positive charge in the nucleus increases. - The strength of **attraction** between proton in nucleus and electrons in the shells **increases**. -All electrons in the shells are pulled closer toward nucleus - The **size of atom decreases** across the period.
2. Electronegativity	Increases	- Electronegativity: a measurement of **tendency of an element to attract protons**. - The increase in number of protons and decrease in atomic radius cause **increase** in **attractive force between nucleus and outermost shell electron**. - The **electronegativity increases** when moving across period.
3. Melting point / Boiling Point	a. Increases (from left to the middle of period)	- ***Na, Mg and Al*** are metals with strong metallic bond between atoms. - The strength of **metallic bond increases** from Na to Al with **increase** in number of protons and **valence electrons**. - Hence, they have high melting and boiling point
	b. Very high melting and boiling point (at the middle of the period)	- ***Si*** has very high melting and boiling point. - It forms a **giant covalent network structure**, atoms are held by **strong covalent bond**. - A large amount of energy is required to break to strong covalent bond.

Characteristic	Trend	Reason
	c. Decreases (from the middle to right of period)	- ***P, S, Cl and Ar*** are non-metals with **weak van der Waals force** between molecules. - They have low melting and boiling point. - m.p. $\mathbf{S_8 > P_4 > Cl_2 > Ar}$

Characteristic	Trend
4. Metallic property	**Metals** [Na, Mg, Al] ——> **Metalloid** [Si] ——> **Non-metal** [P, S, Cl, Ar]
5. Nature of oxides	**Basic** oxides [Na_2O, MgO] ——> **Amphoteric** oxide [Al_2O_3] ——> **Acidic** oxides [SiO_2, P_4O_{10}, SO_2, Cl_2O_7]

Transition Elements

- located between group IIA and IIIA (group 2 and group 13)
- shows metal properties: shiny conduct heat / electricity, malleable, high tensile strength, high melting and boiling point and high density

Special Characteristic

1. Have **more than one oxidation state**

Transition Metals	Oxidation States
Fe	+2, +3
Cr	+3, +6
Cu	+1, +2
Ni	+2, +3

   - Exception: Zinc, only form Zn^{2+}

2. Form **colored compounds**

Transition Ions	Color
Fe^{2+}	green
Fe^{3+}	brown
Cu^{2+}	blue
Co^{2+}	pink

   - Exception: Zn^{2+} & Sc^{3+}

3. From **complex ions**
   - e.g. $[Cu(NH_3)_4]^{2+}$

4. Used as **catalyst**

Transition metals / compounds	**Process**	**Usage**
V_2O_5	Contact process	produce sulfuric acid
Pt	Ostwald process	produce nitric acid
Fe	Haber process	produce ammonia