

Chapter 6 - The Periodic Table and Bonding

PERIODIC TABLE OF ELEMENTS

| 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 | | | | | | | | | | | | | | | | | | | | | |
|--|--|---------------------------------------|--|--|---|--|--|---|---|--|--|---------------------------------------|--|--|--|---|--|--|--|------------------|--|
| 1 H Hydrogen 1.008 | Atomic # Symbol Name Weight | | | | | | | | | | | | | | | | 2 He Helium 4.0026 | | | | |
| | 3 Li Lithium 6.94 | 4 Be Beryllium 9.0122 | C Solid | Hg Liquid | H Gas | Rf Unknown | Metals | | | | | | | | | | Metalloids | | | Nonmetals | |
| | | | | | | | Alkali metals | Alkaline earth metals | Lanthanoids (Lanthanides) | | Transition metals | Post-transition metals | Other nonmetals | Noble gases | | | | | | | |
| | | | | | | | | | Actinoids (Actinides) | | | | | | | | | | | | |
| 5 B Boron 10.81 | 6 C Carbon 12.011 | 7 N Nitrogen 14.007 | 8 O Oxygen 15.999 | 9 F Fluorine 18.998 | 10 Ne Neon 20.180 | | | | | | | | | | | | | | | | |
| 11 Na Sodium 22.990 | 12 Mg Magnesium 24.305 | | | | | | | | | | | | | | | | | | | | |
| 19 K Potassium 39.098 | 20 Ca Calcium 40.078 | 21 Sc Scandium 44.956 | 22 Ti Titanium 47.867 | 23 V Vanadium 50.942 | 24 Cr Chromium 51.996 | 25 Mn Manganese 54.938 | 26 Fe Iron 55.845 | 27 Co Cobalt 58.933 | 28 Ni Nickel 58.693 | 29 Cu Copper 63.546 | 30 Zn Zinc 65.38 | 31 Ga Gallium 69.723 | 32 Ge Germanium 72.630 | 33 As Arsenic 74.922 | 34 Se Selenium 78.971 | 35 Br Bromine 79.904 | 36 Kr Krypton 83.798 | | | | |
| 37 Rb Rubidium 85.468 | 38 Sr Strontium 87.62 | 39 Y Yttrium 88.906 | 40 Zr Zirconium 91.224 | 41 Nb Niobium 92.906 | 42 Mo Molybdenum 95.95 | 43 Tc Technetium (98) | 44 Ru Ruthenium 101.07 | 45 Rh Rhodium 102.91 | 46 Pd Palladium 106.42 | 47 Ag Silver 107.87 | 48 Cd Cadmium 112.41 | 49 In Indium 114.82 | 50 Sn Tin 118.71 | 51 Sb Antimony 121.76 | 52 Te Tellurium 127.60 | 53 I Iodine 126.90 | 54 Xe Xenon 131.29 | | | | |
| 55 Cs Caesium 132.91 | 56 Ba Barium 137.33 | 57–71 | 72 Hf Hafnium 178.49 | 73 Ta Tantalum 180.95 | 74 W Tungsten 183.84 | 75 Re Rhenium 186.21 | 76 Os Osmium 190.23 | 77 Ir Iridium 192.22 | 78 Pt Platinum 195.08 | 79 Au Gold 196.97 | 80 Hg Mercury 200.59 | 81 Tl Thallium 204.38 | 82 Pb Lead 207.2 | 83 Bi Bismuth 208.98 | 84 Po Polonium (209) | 85 At Astatine (210) | 86 Rn Radon (222) | | | | |
| 87 Fr Francium (223) | 88 Ra Radium (226) | 89–103 | 104 Rf Rutherfordium (261) | 105 Db Dubnium (268) | 106 Sg Seaborgium (269) | 107 Bh Bohrium (270) | 108 Hs Hassium (277) | 109 Mt Meitnerium (278) | 110 Ds Darmstadtium (281) | 111 Rg Roentgenium (282) | 112 Cn Copernicium (285) | 113 Nh Nihonium (286) | 114 Fl Flerovium (289) | 115 Mc Moscovium (290) | 116 Lv Livermorium (293) | 117 Ts Tennessine (294) | 118 Og Oganesson (294) | | | | |
| For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses. | | | | | | | | | | | | | | | | | | | | | |
| 6 | 57 La Lanthanum 138.91 | 58 Ce Cerium 140.12 | 59 Pr Praseodymium 140.91 | 60 Nd Neodymium 144.24 | 61 Pm Promethium (145) | 62 Sm Samarium 150.36 | 63 Eu Europium 151.96 | 64 Gd Gadolinium 157.25 | 65 Tb Terbium 158.93 | 66 Dy Dysprosium 162.50 | 67 Ho Holmium 164.93 | 68 Er Erbium 167.26 | 69 Tm Thulium 168.93 | 70 Yb Ytterbium 173.05 | 71 Lu Lutetium 174.97 | | | | | | |
| | 89 Ac Actinium (227) | 90 Th Thorium 232.04 | 91 Pa Protactinium 231.04 | 92 U Uranium 238.03 | 93 Np Neptunium (237) | 94 Pu Plutonium (244) | 95 Am Americium (243) | 96 Cm Curium (247) | 97 Bk Berkelium (247) | 98 Cf Californium (251) | 99 Es Einsteinium (252) | 100 Fm Fermium (257) | 101 Md Mendelevium (258) | 102 No Nobelium (259) | 103 Lr Lawrencium (260) | | | | | | |

Group

| Group | Name |
|----------|----------------------|
| Group 1 | Alkali Metal |
| Group 2 | Alkaline Earth Metal |
| 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
 - On going down, number of delocalized electron remains unchanged, but the distance between delocalized electron and positive atoms is increased, the attraction force is decrease, the b.p. and m.p. is therefore lower when going down the group
4. Lower density
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 / Boiling point | Decreases | - Atomic size increases. - Metallic bond between atoms become weaker. |
| 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**.
 - $M \rightarrow M^+ + e^-$ (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

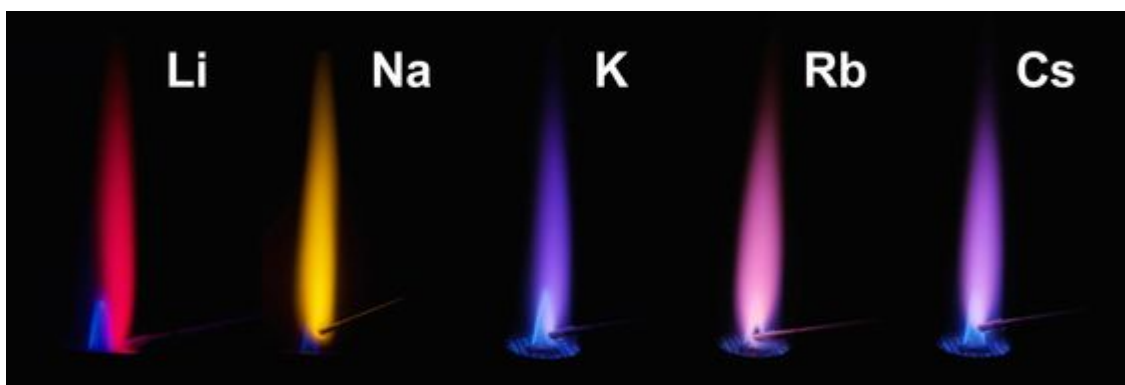
(i) Group 1 metals react with water to produce alkali and hydrogen gas

| Alkali Metal | Observation | Equation |
|--------------|---|--|
| Lithium | Reacts readily with water | $2\text{Li}_{(s)} + 2\text{H}_2\text{O}_{(l)} \longrightarrow 2\text{LiOH}_{(aq)} + \text{H}_{2(g)}$ |
| Sodium | Reacts vigorously; Catches fire | $2\text{Na}_{(s)} + 2\text{H}_2\text{O}_{(l)} \longrightarrow 2\text{NaOH}_{(aq)} + \text{H}_{2(g)}$ |
| Potassium | Reacts violently; Catches fire; then explodes | $2\text{K}_{(s)} + 2\text{H}_2\text{O}_{(l)} \longrightarrow 2\text{KOH}_{(aq)} + \text{H}_{2(g)}$ |

(ii) Group 1 metals can be oxidized in air to form white metal oxides

- Due to the formation of dull oxide on the surface, alkali metals **tarnish in air**.
- Equation
 - $4\text{Li}_{(s)} + \text{O}_{2(g)} \longrightarrow 2\text{Li}_2\text{O}_{(s)}$
 - $4\text{Na}_{(s)} + \text{O}_{2(g)} \longrightarrow 2\text{Na}_2\text{O}_{(s)}$
 - $4\text{K}_{(s)} + \text{O}_{2(g)} \longrightarrow 2\text{K}_2\text{O}_{(s)}$

Alkali metals burn in sufficient oxygen with characteristic flame colors



| Metal | Li | Na | K | Rb | Cs |
|-------|------------|--------|--------|------------|------|
| Color | Bright red | Yellow | Violet | Red violet | Blue |

- **Flame test:** Flame tests are used to preliminary identify the presence of metal ions in a compound. Not all metal ions give flame colors.

Alkali Metals burning in sufficient oxygen form various oxides

1. Potassium

- Observations
 - Sodium burns vigorously with lilac / violet flame and forms a mixture of **potassium superoxide** and **sodium peroxide**.
- Equation
 - $\text{K}_{(s)} + \text{O}_{2(g)} \longrightarrow \text{KO}_{2(s)}$ (potassium superoxide)
 - $2\text{K}_{(s)} + \text{O}_{2(g)} \longrightarrow \text{K}_2\text{O}_{2(s)}$ (potassium peroxide)

2. Sodium

- Observations

- 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**.
- Equation
 - $4\text{Na}_{(s)} + \text{O}_{2(g)} \longrightarrow 2\text{Na}_2\text{O}_{(s)}$
 - $2\text{Na}_{(s)} + \text{O}_{2(g)} \longrightarrow \text{Na}_2\text{O}_{2(s)}$

(ii) Group 1 metals react with halogen to form white metal halides

- All of the alkali metals react vigorously with chlorine gas.
- Each reaction produces a white crystalline salt.
- The reaction gets more violent as you move down Group 1A.
- Equation
 - $2\text{Li}_{(s)} + \text{Cl}_{2(g)} \longrightarrow 2\text{LiCl}_{(s)}$
 - $2\text{Na}_{(s)} + \text{Cl}_{2(g)} \longrightarrow 2\text{NaCl}_{(s)}$
 - $2\text{K}_{(s)} + \text{Cl}_{2(g)} \longrightarrow 2\text{KCl}_{(s)}$

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 \propto molecule size
 - $\text{I}_{2(s)} > \text{Br}_{2(l)} > \text{Cl}_{2(g)} > \text{F}_{2(g)}$ [25°C]

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. |

| Characteristic | Trend | Reason |
|-------------------|-----------|--|
| Electronegativity | Decreases | <ul style="list-style-type: none"> - 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

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----------|----------|-------------------|-----------|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|--|--|
| H 1 | | Electronegativity | | | | | | | | | | | | | | | | He 2 | | | | | | | | | | | | | | | |
| Li 3 | | Be 4 | | The electronegativity of an atom is how strongly it attracts electrons towards itself. It depends on the atomic radius and the atomic number of the element. Electronegativity is most commonly measured on the Pauling scale. Values are shown relative to fluorine, the element with the highest electronegativity. | | | | | | | | | | | | | | B 5 | C 6 | N 7 | O 8 | F 9 | Ne 10 | | | | | | | | | | |
| Na 11 | | Mg 12 | | | | | | | | | | | | | | | | Al 13 | Si 14 | P 15 | S 16 | Cl 17 | Ar 18 | | | | | | | | | | |
| K 19 | Ca 20 | Sc 21 | Ti 22 | V 23 | Cr 24 | Mn 25 | Fe 26 | Co 27 | Ni 28 | Cu 29 | Zn 30 | Ga 31 | Ge 32 | As 33 | Se 34 | Br 35 | Kr 36 | | | | | | | | | | | | | | | | |
| Rb 37 | Sr 38 | Y 39 | Zr 40 | Nb 41 | Mo 42 | Tc 43 | Ru 44 | Rh 45 | Pd 46 | Ag 47 | Cd 48 | In 49 | Sn 50 | Sb 51 | Te 52 | I 53 | Xe 54 | | | | | | | | | | | | | | | | |
| Cs 55 | Ba 56 | La 57 | Hf 72 | Ta 73 | W 74 | Re 75 | Os 76 | Ir 77 | Pt 78 | Au 79 | Hg 80 | Tl 81 | Pb 82 | Bi 83 | Po 84 | At 85 | Rn 86 | | | | | | | | | | | | | | | | |
| Fr 87 | Ra 88 | Ac 89 | Rf 104 | Db 105 | Sg 106 | Bh 107 | Hs 108 | Mt 109 | Ds 110 | Rg 111 | Cn 112 | Nh 113 | Fl 114 | Mc 115 | Lv 116 | Ts 117 | Og 118 | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | Ce 58 | Pr 59 | Nd 60 | Pm 61 | Sm 62 | Eu 63 | Gd 64 | Tb 65 | Dy 66 | Ho 67 | Er 68 | Tm 69 | Yb 70 | Lu 71 | | |
| | | | | | | | | | | | | | | | | | | Th 90 | Pa 91 | U 92 | Np 93 | Pu 94 | Am 95 | Cm 96 | Bk 97 | Cf 98 | Es 99 | Fm 100 | Md 101 | No 102 | Lr 103 | | |

- 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 | $\text{Cl}_{2(g)} + \text{H}_2\text{O}_{(l)} \rightleftharpoons \text{HCl}_{(aq)} + \text{HOCl}_{(aq)}$ |
| Bromine | Dissolves slowly; reddish brown solution | Blue turns red, then decolorized after a longer time | $\text{Br}_{2(g)} + \text{H}_2\text{O}_{(l)} \rightleftharpoons \text{HBr}_{(aq)} + \text{HOBr}_{(aq)}$ |
| Fluorine | Dissolves slightly; pale brown solution | Blue turns red, is not decolorized | $\text{I}_{2(g)} + \text{H}_2\text{O}_{(l)} \rightleftharpoons \text{HI}_{(aq)} + \text{HOI}_{(aq)}$ |

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

- $\text{Cl}_{2(g)} + 2\text{NaOH}_{(aq)} \rightarrow \text{NaCl}_{(aq)} + \text{NaClO}_{(aq)} + \text{H}_2\text{O}_{(l)}$
- $\text{Br}_{2(g)} + 2\text{NaOH}_{(aq)} \rightarrow \text{NaBr}_{(aq)} + \text{NaBrO}_{(aq)} + \text{H}_2\text{O}_{(l)}$
- $\text{I}_{2(g)} + 2\text{NaOH}_{(aq)} \rightarrow \text{NaI}_{(aq)} + \text{NaIO}_{(aq)} + \text{H}_2\text{O}_{(l)}$

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

- All noble gases are insoluble in water.
- They're non-conductors of heat and electricity.
- Very low density. Due to the atoms are very far apart.
- The density of noble gases increases when descending the group, due to the atomic mass increases faster than the increase in radius.
- 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.
- 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

- They exist as **monoatomic molecules** (single atoms) because the atom does **not lose, gain or share electrons**.
- 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)
- Elements in period 3 show a gradual change of physical and chemical properties across the period from left to right.

Physical and Chemical Properties across Period 3

| Characteristic | Trend | Reason |
|----------------------------------|--|---|
| 1. Atomic radius | Decreases | <ul style="list-style-type: none"> - 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. - The size of atom decreases across the period. |
| 2. Electronegativity | Increases | <ul style="list-style-type: none"> - 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) | <ul style="list-style-type: none"> - 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) | <ul style="list-style-type: none"> - 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. |
| | c. Decreases (from the middle to right of period) | <ul style="list-style-type: none"> - P, S, Cl and Ar are non-metals with weak van der Waal's force between molecules. - They have low melting and boiling point. - m.p. S₈ > P₄ > Cl₂ > Ar |

| Characteristic | Trend |
|----------------------|---|
| 4. Metallic property | Metals [Na, Mg, Al] \longrightarrow Metalloid [Si] \longrightarrow Non-metal [P, S, Cl, Ar] |
| 5. Nature of oxides | Basic oxides [Na ₂ O, MgO] \longrightarrow Amphoteric oxide [Al ₂ O ₃] \longrightarrow Acidic oxides [SiO ₂ , P ₄ O ₁₀ , SO ₂ , Cl ₂ O ₇] |

Transition Elements

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

Special Characteristic

- 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 Zn²⁺

- Form colored compounds

| Transition Ions | Color |
|------------------|-------|
| Fe ²⁺ | green |
| Fe ³⁺ | brown |
| Cu ²⁺ | blue |
| Co ²⁺ | pink |

- Exception: Zn²⁺ & Sc³⁺

- Form complex ions

- e.g. [Cu(NH₃)₄]²⁺

- Used as catalyst

| Transition metals / compounds | Process | Usage |
|-------------------------------|-----------------|-----------------------|
| V ₂ O ₅ | Contact process | produce sulfuric acid |
| Pt | Ostwald process | produce nitric acid |

| Transition metals / compounds | Process | Usage |
|-------------------------------|---------------|-----------------|
| Fe | Haber process | produce ammonia |

Bonding
