CAIE Chemistry A-level

9: The Periodic Table

Notes

Periodicity of Physical Properties of the Elements in Period 3

Atomic Radius

When comparing the atomic radius of period 3 atoms, the **metallic radii** is used for Na, Mg and Al and the **covalent radii** is used for Si, P, S and Cl.

Across period three, **atomic radius decreases from sodium to chlorine.** The radius of argon can't be compared as it does not form compounds. Across the period, atomic number increases so the **nucleus has a higher positive charge**. This draws electrons slightly closer to the nucleus meaning the atomic radius decreases.

Ionic Radius

Across period 3, the ionic radius **decreases from sodium to aluminium** (positive ions) then **increases from silicon to chlorine** (negative ions).

The **positive** ions have a decreasing ionic radius because, although the ions have the same electron configuration, the number of protons in the nucleus increases so **nuclear attraction increases.**

The **negative** ions have an increasing ionic radius because the ions have gained electrons meaning there are now **more electrons than protons**. As a result, the nuclear attraction to the electrons is weaker so they are not pulled in as strongly.

Melting Point

The melting points of elements in period 3 depend on **structure and bonding**:

- **Sodium, magnesium** and **aluminium** are **giant metallic structures** with metallic bonding. Their melting points **increase** across the period as the metal-metal bond strength increases. The bond strength increases because the charge of the metal ion increases and the atomic radius decreases.
- **Silicon** is a **macromolecule** with strong covalent bonds linking all its atoms together. This means it has the highest melting point of all the elements in period 3.
- **Phosphorus** (P_4), **sulfur** (S_8) and **chlorine** (Cl_2) are all simple covalent molecules. Their melting points are dependent on the strength of their **van der Waals**/ intermolecular forces. The more atoms/electrons in a molecule mean stronger van der Waals forces so sulfur has the greatest melting point of these three molecules. Chlorine will have the lowest melting point since it is only made up of two atoms.
- **Argon** will have the **lowest melting point** of period 3 because it exists as single atoms so there are very weak van der Waals intermolecular forces which are easy to overcome.

Electrical Conductivity

Conductivity of a compound relies on the presence of **charged particles** (such as ions or electrons) which are free to move.

Metallic compounds can conduct electricity due to the sea of **delocalised electrons.**

Conductivity **increases from sodium to aluminium** because the number of delocalised electrons increases so more electrons are **free to carry charge**.

The molecules silicon to chlorine are **covalent compounds with no charged particles** so they are non-conductors. Similarly argon is monatomic so is unable to conduct electricity.

First Ionisation Energy

The first ionisation energy is the energy required to **remove one mole of electrons** from one mole of gaseous atoms to **form one mole of gaseous ions.**

First ionisation energy **generally increases** across period 3. This is because the number of protons increases across the period while electron shielding remains the same. As a result, across the period, the **electrons are attracted more strongly** to the nucleus so they are harder to remove, leading to a higher first ionisation energy.

Exceptions to the trend:

- The first ionisation energy of **aluminium** is **lower** than that of magnesium. This is because the electron is being removed from a **3p orbital** rather than a 3s orbital. This means there is more **electron shielding** from the 3s orbital so the electron can be removed more easily.
- The first ionisation energy of **sulfur** is **lower** than that of phosphorus. Sulfur is the first element to have an electron pair in a 3p orbital so an electron is being removed from a pair. The electrons in the pair repel each other slightly making it easier to remove an electron.

Periodicity of Chemical Properties of the Elements in Period 3

Reactions with Oxygen

- **Sodium** burns in oxygen with an **orange flame** to produce a **white solid.**

$$4Na + O_2 \rightarrow 2Na_2O$$

- **Magnesium** burns in oxygen with a **bright white flame** to produce a **white solid.**

$$2Mg + O_2 \rightarrow 2MgO$$

- **Aluminium** burns in oxygen if the **aluminium oxide layer** on the outside of the metal is removed. This can be done by **powdering** the aluminium. **Sparks** can be seen when the powder is burned and a **white solid** is produced.

$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

- **Silicon** will only burn in oxygen if it is heated strongly enough.

$$Si + O_2 \rightarrow SiO_2$$

- **White phosphorus** reacts **spontaneously** in the air to produce a **white solid.**

$$P_4 + 5O_2 \rightarrow P_4O_{10}$$

- **Sulfur** burns with a **blue flame** in oxygen when heated gently. It produces a colourless gas of **sulfur dioxide** which reacts further with oxygen to form **sulfur trioxide.**

$$S + O_2 \rightarrow SO_2$$
$$2SO_2 + O_2 \rightarrow 2SO_3$$

- **Chlorine** does not react with oxygen (directly).
- **Argon** does not react with oxygen.

Reactions with Chlorine

- **Sodium** burns in chlorine with a **bright orange flame** to form sodium chloride (white solid).

$$2Na + Cl_2 \rightarrow 2NaCl$$

- **Magnesium** burns in chlorine with a **bright white flame** to form magnesium chloride (white solid).

$$Mg + Cl_2 \rightarrow MgCl_2$$

- **Aluminium** burns in a stream of chlorine to produce **pale yellow aluminium chloride.**

$$2Al + 3Cl_2 \rightarrow 2AlCl_3$$

At high temperatures, $AlCl_3$ is converted into its molecular form Al_2Cl_6.

- If **chlorine** is passed over silicon powder, a **colourless liquid** forms (silicon tetrachloride).

$$Si + 2Cl_2 \rightarrow SiCl_4$$

- **White phosphorus** burns **spontaneously** in chlorine to produce phosphorus(V) chloride (off-white solid).

$$P_4 + 10Cl_2 \rightarrow 4PCl_5$$

Reactions with Water

- **Sodium** undergoes a very **exothermic** reaction with cold water, producing hydrogen (seen as bubbles) and a colourless solution of sodium hydroxide.

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

- **Magnesium** reacts **slowly** with **cold water.** Bubbles of hydrogen are produced and a thin layer of magnesium hydroxide forms on the magnesium which inhibits further reaction.

$$Mg + H_2O \rightarrow Mg(OH)_2 + H_2$$

Magnesium burns in **steam** with a **bright white flame** to produce white magnesium oxide and hydrogen:

$$Mg + H_2O \rightarrow MgO + H_2$$

Variation in Oxidation Numbers

Oxidation states can be worked out using the following rules:

- The oxidation state of an uncombined element is 0.
- The sum of oxidation states in a compound is 0 and the sum of oxidation states in an ion is equal to the overall charge.
- Common oxidation states:
  - +1 for group one atoms
  - +2 for group two atoms
  - -2 for oxygen (except when in a peroxide or F_2O)
  - +1 for hydrogen (except in metal hydrides where it is -1)
  - -1 for fluorine
  - -1 for chlorine (except when bonded with fluorine or oxygen)

The oxidation states of Group 3 oxides are shown in the table below:

Compound	**Oxidation state of non-oxygen element**
Na_2O	+1
MgO	+2
Al_2O_3	+3
SiO_2	+2
P_4O_{10}	+5
SO_2	+6
SO_3	+4

The oxidation states of Group 3 chlorides are shown in the table below:

Compound	**Oxidation state of non-chlorine element**
NaCl	+1
$MgCl_2$	+2
$AlCl_3$	+3
$SiCl_4$	+4
PCl_4	+5

In each of the cases above, the oxidation state has the same value as the number of **valence shell electrons** (the number of electrons in the outer energy level of the atom).

Period 3 Oxides and Water

- **Sodium oxide** is a strongly basic oxide which reacts **exothermically** with water to form a solution of sodium hydroxide (**around pH 14**).

$$Na_2O + H_2O \rightarrow 2NaOH$$

- **Magnesium oxide** undergoes a slight reaction with water, forming some **magnesium hydroxide** ions. As these are only **partially soluble**, the pH of the resulting solution is about 9 since not many hydroxide ions are released into the solution.

$$MgO + H_2O \rightarrow Mg(OH)_2$$

- **Aluminium oxide** does not react with water.

- **Silicon dioxide** does not react with water because it is difficult to break up the macromolecule.
- **Phosphorus(V) oxide** reacts **violently** with water to form **phosphoric acid.**

$$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$$

- **Sulfur dioxide** reacts with water to form an acidic solution of **sulfurous acid.**

$$SO_2 + H_2O \rightarrow H_2SO_3$$

- **Sulfur trioxide** reacts **violently** with water to produce **sulfuric acid.**

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Acid/Base Behaviour of Period 3 Oxides and Hydroxides

Oxides:

- **Sodium oxide** is a **strong base** which reacts with acid to form a salt and water.

$$Na_2O + 2HCl \rightarrow 2NaCl + H_2O$$

- **Magnesium oxide** reacts with warm dilute hydrochloric acid to form a salt and water.

$$MgO + 2HCl \rightarrow MgCl_2 + H_2O$$

- **Aluminium oxide** is **amphoteric** so reacts with **acids and bases**. It reacts with warm dilute hydrochloric in the same way as magnesium and sodium:

$$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$$

  Aluminium oxide also reacts with bases:

$$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$$

- **Silicon dioxide** reacts with hot concentrated sodium hydroxide solution. A **colourless solution** is formed.

$$SiO_2 + NaOH \rightarrow Na_2SiO_3 + H_2O$$

- **Phosphorus(V) oxide** can form a **range of salts** when reacted with a base. Here is one example:

$$P_4O_{10} + 12NaOH \rightarrow 4Na_3PO_4 + 6H_2O$$

- **Sulfur dioxide** will react with a base when bubbled through it:

$$SO_2 + NaOH \rightarrow Na_2SO_3 + H_2O$$

- **Sulfur trioxide** reacts with a base to form sulfuric acid and water.

$$SO_3 + 2NaOH \rightarrow Na_2SO_4 + H_2O$$

Hydroxides:

- **Sodium and magnesium hydroxides** are both simple **basic hydroxides.**

$$NaOH + HCl \rightarrow NaCl + H_2O$$

$$Mg(OH)_2 + 2HCl \rightarrow MgCl_2 + 2H_2O$$

- **Aluminium hydroxide** is **amphoteric** so will react with acids and bases:

$$Al(OH)_3 + 3HCl \rightarrow AlCl_3 + 3H_2O$$

$$Al(OH)_3 + NaOH \rightarrow NaAl(OH)_4$$

- The **other period three hydroxides** each act as **acids** since the **OH group is covalently bonded** to the element.

Period 3 Chlorides and Water

- **Sodium chloride** and **magnesium chloride** are ionic compounds so they **dissolve in water** to form their ions.

- **Aluminium chloride** reacts **violently** with water. Lots of **misty fumes** of hydrogen chloride are produced:

$$AlCl_3 + 6H_2O \rightarrow [Al(H_2O)_6]^{3+} + 3Cl^-$$

An **equilibrium** is set up with the product so H^+ ions, and hence HCl, are formed:

$$[Al(H_2O)_6]^{3+} \rightleftharpoons [Al(H_2O)_5(OH)]^{2+} + H^+$$

- **Silicon tetrachloride** reacts with water in the air to produce hydrogen chloride.

$$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$$

- **Phosphorus(V) chloride** also reacts violently with water to produce hydrogen chloride.

$$PCl_5 + H_2O \rightarrow POCl_3 + 2HCl$$

- **Disulfur dichloride** reacts slowly with water to produce a range of products. There are lots of examples of equations that could take place so it is unlikely this will be asked in an exam. Potential products include **HCl, S and H_2S**.

Chemical Bonding in Chlorides and Oxides

In chlorides and oxides, the chemical bonding is **ionic** from sodium to aluminium and **covalent** from silicon to sulfur. This can be deduced from observing the physical and chemical properties of the chloride or oxide being analysed.

Sodium and magnesium form ionic bonds with oxygen and chlorine. Aluminium forms covalent bonds with oxygen and either covalent or ionic bonds with chlorine. Other period 3 elements form simple molecular compounds (covalent). This is because the difference in **electronegativity** between chlorine/ oxygen and the period 3 element decreases across the period. There is sufficient difference in the electronegativity of chlorine/ oxygen and sodium or magnesium to form ions. After aluminium, the difference in electronegativity is **too small** for ions to form.

Bonding and Properties of Chlorides and Oxides

The type of bonding can be deduced using the **physical properties** of group 3 compounds. For example, a high **melting point** means that it is a giant molecular structure, either ionic like NaCl and MgO or covalent like SiO_2.

Chemical properties can also be used to identify the type of bonding:

- Chlorides that dissolve in water to form a solution with a pH close to 7 are ionic whereas chlorides that react with water to form an acidic solution and hydrogen chloride gas are covalent.
- If a Period 3 oxide forms an acidic solution when it dissolves in water, it is covalent. If it is ionic, it may react with water to form an alkaline solution or it may not react with water.
- Generally, ionic oxides are basic and can react with acids. Covalent oxides tend to be acidic and can react with bases.Amphoteric oxides such as aluminium oxide are usually ionic with some covalent character.
- If a molten oxide or chloride can undergo electrolysis, it must be ionic.

Chemical Periodicity of Other Elements

The chemical properties of an element can be predicted by using knowledge of chemical **periodicity**. Similarly, an unknown element can be identified from information given about its **chemical and physical properties**.