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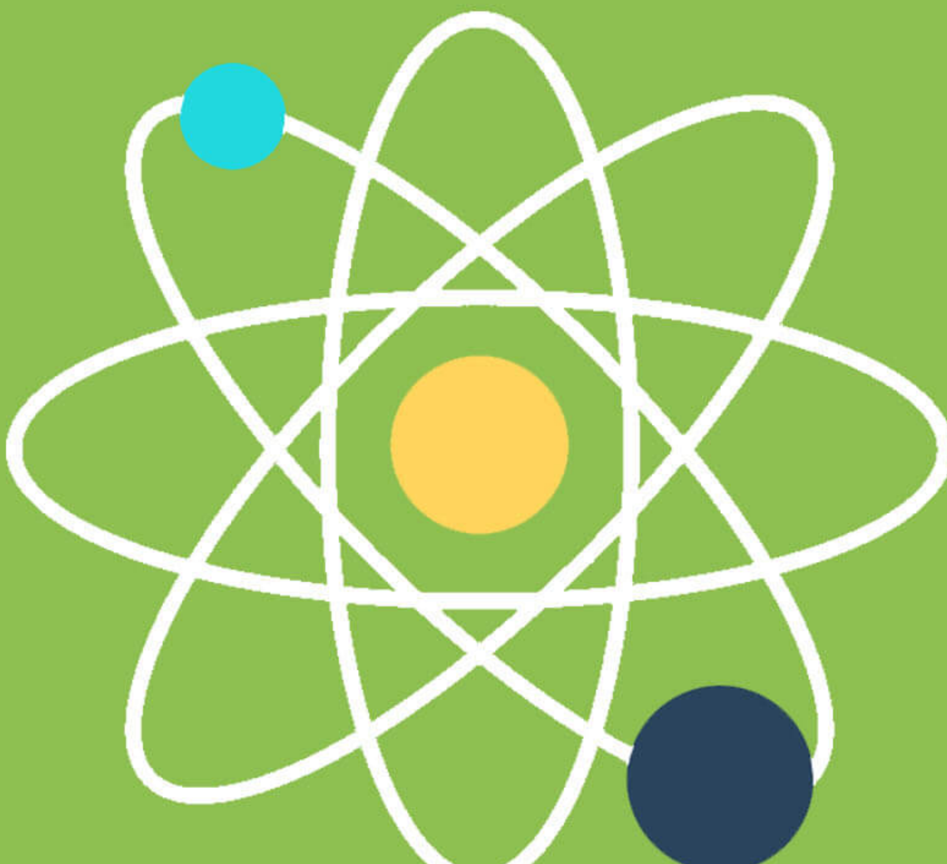
3.2 Oxides, Group 1 & Group 17



IB Chemistry - Revision Notes

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3.2.1 Periodic Trends: Oxides Across a Period

Oxides

Oxides across a period

- The **acid-base** character of the oxides provides evidence of chemical trends in the periodic table
- The broad trend is that oxides change from **basic** through **amphoteric** to **acidic** across a period
- Aluminium oxide is **amphoteric** which means that it can act both as a base (and react with an acid such as HCl) and an acid (and react with a base such as NaOH)

Acidic & Basic Nature of the Period 3 Oxides

Period 3 oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2, SO_3
Acid/base nature	Basic	Basic	Amphoteric	Acidic	Acidic	Acidic

- The acidic and basic nature of the Period 3 elements can be explained by looking at their **structure**, **bonding** and the Period 3 elements' **electronegativity**

Structure, Bonding & Electronegativity of the Period 3 Elements Table

Period 3 oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2, SO_3		
Relative melting point	High	High	Very high	Very high	Low	Low		
Chemical bonding	Ionic	Ionic	Ionic (with some degree of covalent	Covalent	Covalent	Covalent		
Structure	Giant ionic	Giant ionic	Giant ionic	Giant covalent	Simple molecular	Simple molecular		
Element	Na	Mg	Al	Si	P	S	Cl	O
Electronegativity	0.9	1.2	1.5	1.8	2.1	2.5	3.0	3.5

- The difference in electronegativity between oxygen and Na, Mg and Al is the largest
- Electrons will therefore be **transferred** to oxygen when forming oxides giving the oxide an **ionic bond**
- The oxides of Si, P and S will **share** the electrons with the oxygen to form **covalently bonded** oxides
- The oxides of **Na** and **Mg** which show purely **ionic bonding** produce **alkaline** solutions with water as their **oxide** ions (O^{2-}) become **hydroxide** ions (OH^-):

$$O^{2-}(aq) + H_2O(l) \rightarrow 2OH^-(aq)$$

- The oxides of **P** and **S** which show purely **covalent bonding** produce **acidic** solutions with water because when these oxides react with water, they form an acid which donates H^+ ions to water
  - Eg. SO_3 reacts with water as follows:

$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$$

  - The H_2SO_4 is an acid which will donate an H^+ to water:

$$H_2SO_4(aq) + H_2O(l) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$$

Exam Tip

Only examples of general trends across periods and groups are required, but you should be able to link trends in ionization energy, electron affinity and electronegativity with trends in chemical character such as the nature of the oxides and metallic / non-metallic behaviour.

Oxides reacting with Water

- The pH changes for the reactions of the oxides with water can be explained by reference to the following equations

Reaction of Oxides with Water

Oxide	Chemical equation	pH
Na_2O	$Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$	14 (strongly alkaline)
MgO	$MgO(s) + H_2O(l) \rightarrow Mg(OH)_2(aq)$	10 (weakly alkaline)
P_4O_{10}	$P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$	2 (strongly acidic)
NO_2	$2NO_2(aq) + H_2O(l) \rightarrow HNO_3(aq) + HNO_2(aq)$	1 (strongly acidic)
SO_2, SO_3	$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$ $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$	1 (strongly acidic)

- The pattern here is that:
  - The metallic oxides form hydroxides when they react with water
  - The non-metallic oxides form oxoacids when they react with water

Exam Tip

You should learn how to construct these equations exactly as they are specifically mentioned in the syllabus

Making Predictions

- The position of an element in the periodic table can be used to predict and explain its **metallic** and **non-metallic** behaviour
- This is illustrated by the bonding of the oxides
- Metal and non-metal elements generally form **ionic** compounds so the elements **Na** to **Al** have **giant ionic structures**
- The oxides become more **ionic** as you go **down the group** as the **electronegativity decreases**
- The oxides become less **ionic** as you go **across a period** as the **electronegativity increases**
- The oxides of non-metals such as **S**, **N** and **P** form **molecular covalent compounds**

- Sometimes you may be asked to make predictions about oxides that are not specifically mentioned in the syllabus but you should be able deduce their properties if you understand the patterns outlined above, as the following example shows:

Worked example

Which of these oxides produces the solution with the highest pH when added to water?

A. CO_2

B. SO_3

C. CaO

D. Na_2O

Answer:

The correct option is **D**.

- CO_2 and SO_3 will produce a pH below 7 as they are non-metal oxides. CaO and Na_2O will produce a pH above 7 as they are metal oxides; however the pH is decreasing as you go across a period, so Na_2O will have a higher pH than CaO

3.2.2 Periodic Trends: Group 1 - The Alkali Metals

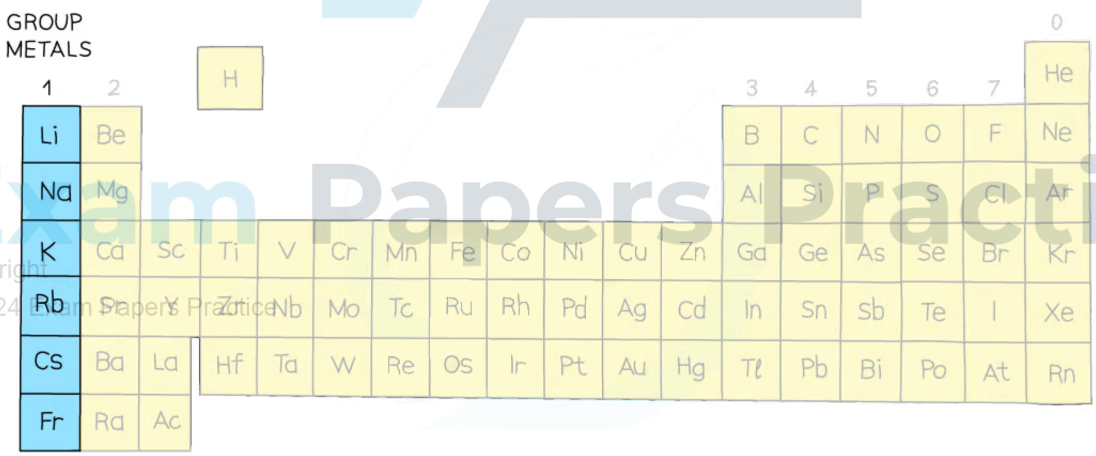
Alkali Metals

The group 1 metals

- The group 1 metals are called the **alkali metals** because they form **alkaline solutions** with high pH values when reacted with water
- Group 1 metals are lithium, sodium, potassium, rubidium, caesium and francium
- They all end in the electron configuration **ns^1**

Physical properties of the group 1 metals

- The group 1 metals:
  - Are soft and easy to cut, getting **softer** and **denser** as you move down the group
  - Have **shiny** silvery surfaces when freshly cut
  - Conduct **heat** and **electricity**
  - They all have **low** melting points and **low** densities and the melting point **decreases** going down the group as the atomic radius increases and the metallic bonding gets weaker



The alkali metals are located on the left of the periodic table in the first column of the s block

Chemical properties of the Group 1 metals

- They react readily with oxygen and water vapour in air so they are usually kept under **oil** to stop them from reacting

- Group 1 metals will react similarly with water, reacting vigorously to produce an **alkaline** metal hydroxide solution and **hydrogen** gas

The Reactions of Group 1 Metals and Water

ELEMENT	REACTION
LITHIUM	$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$ – REACTION SLOWER THAN WITH SODIUM, BUBBLES OF H2 GAS – LITHIUM DOESN'T MELT DUE TO ITS HIGH M.P.
SODIUM	$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$ – BUBBLES OF H_2 GAS, MELTS INTO A SHINY BALL THAT DASHES AROUND THE SURFACE – NAOH FORMED WHICH PRODUCES A HIGHLY ALKALINE SOLUTION
POTASSIUM	$2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$ – REACTS MORE VIOLENTLY THAN SODIUM, BUBBLES OF H_2 GAS, MELTS INTO A SHINY BALL THAT DASHES AROUND THE SURFACE – HOT ENOUGH TO BURN H_2 WHICH FORMS LILAC FLAME

- Test yourself on this example question:

Worked example

What would you see when sodium is added to water?

I. a gas is given off

II. the temperature of the water increases

III. a clear, colourless solution is formed

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

Answer:

The correct option is **D**.

- Bubbles of hydrogen gas are given off. The sodium melts, so that tells you it is an exothermic reaction and the product, sodium hydroxide, is very soluble so a clear, colourless solution would be formed.

Alkali metals with halogens

- All the **alkali metals** react vigorously with the **halogens** in group 17
- The reaction results in an **alkali metal halide salt**

$$2Na\,(s) + Cl_2\,(g) \rightarrow 2NaCl\,(s)$$

- The reaction becomes increasingly vigorous going down group 1 because
  - The atoms of each element get **larger** going down the group
  - This means that the **ns^1** electron gets **further away** from the nucleus and is **shielded** by more electron shells.
  - The further an electron is from the positive nucleus, the easier it can be lost in reactions

Can you apply what you have just learned? Check out the following example question:

Worked example

Which pair of elements has the most vigorous reaction?

A. Cs and I

B. Li and Cl

C. Cs and F

D. Li and F

Answer:

The correct option is **C.**

- You need to choose the lowest element in group 1 and the highest element in group 17 to predict the most vigorous reaction as reactivity increases going down group 1, but decreases going down group 17

3.2.3 Periodic Trends: Group 17 – The Halogens

Halogens

The halogens

- These are the group 17 non-metals that are **poisonous** and include fluorine, chlorine, bromine, iodine and astatine
- Halogens are **diatomic**, meaning they form molecules of **two** atoms
- All halogens have seven electrons in their outer shell
- They form **halide** ions by gaining one more electron to complete their outer shells

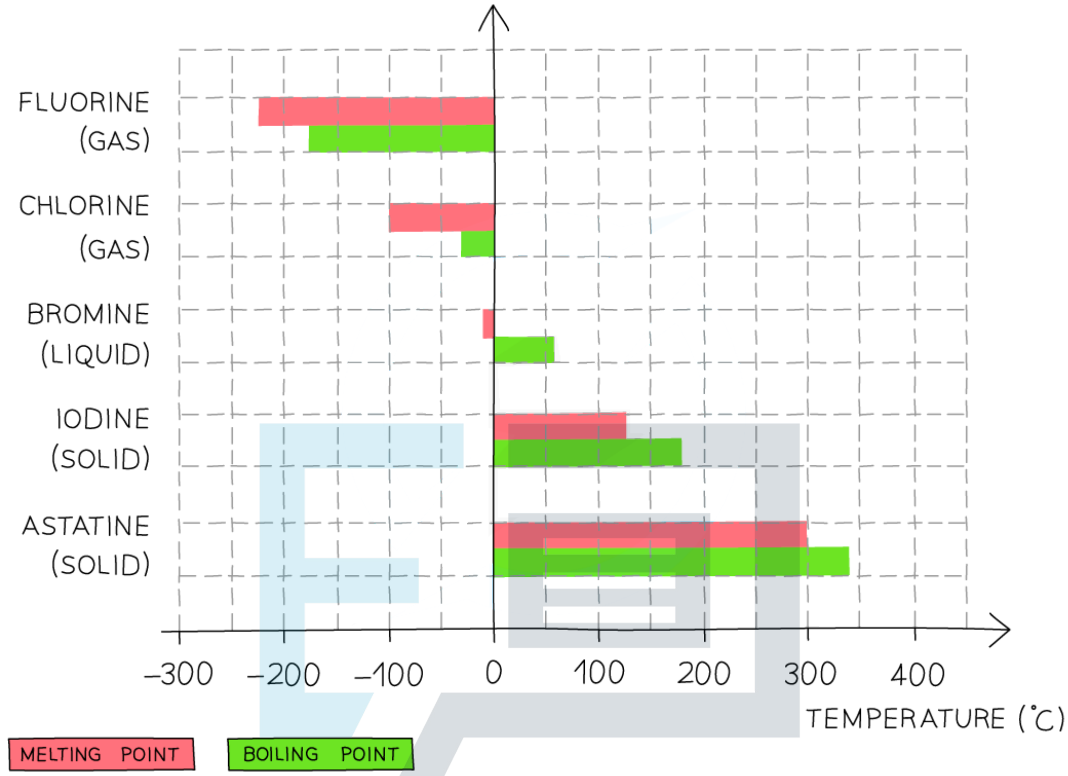
Colours and States at Room Temperature

HALOGEN	PHYSICAL STATE AT ROOM TEMPERATURE	COLOUR	COLOUR IN SOLUTION
FLUORINE	GAS	YELLOW	–
CHLORINE	GAS	PALE GREEN	GREEN–BLUE
BROMINE	LIQUID	RED–BROWN (READILY EVAPORATES TO FORM A BROWN GAS)	ORANGE
IODINE	SOLID	BLACK (SUBLIMES TO FORM A PURPLE GAS)	DARK BROWN

Trends in physical properties of the halogens

Melting point

- The density and melting and boiling points of the halogens **increase** as you go down the group



Explaining the trend in reactivity in Group VII

- Reactivity of group 17 non-metals **decreases** as you go down the group
- The halogens electron configurations all end in **ns^2np^5**
- Each outer shell contains seven electrons and when they react, they will need to gain one outer electron to get a full outer shell of electrons
- Going down the group, the **electron affinity** decreases and the **atomic radius** increases
- As you go down group 17, the number of shells of electrons **increases** so **shielding** also increases
- This means that the outer electrons are **further** from the nucleus so there are **weaker** electrostatic forces of attraction that attract the extra electron needed
- The electron is attracted less readily, so the **lower** down the element is in Group 17 the **less reactive** it is

Reaction of the halogens with halide ions in displacement reactions

- A halogen **displacement** occurs when a **more** reactive halogen displaces a **less** reactive halogen from an aqueous solution of its halide
- The reactivity of group 17 non-metals increases as you move up the group
- Out of the 3 halogens, chlorine, bromine and iodine, chlorine is the most reactive and iodine is the least reactive

Aqueous Solution Colour of Halogens

AQUEOUS SOLUTION	COLOUR
CHLORINE	VERY PALE GREEN, BUT USUALLY APPEARS COLOURLESS AS IT IS VERY DILUTE
BROMINE	ORANGE BUT WILL TURN YELLOW WHEN DILUTED
IODINE	BROWN

Halogen displacement reactions

Chlorine and bromine

- If you add chlorine solution to colourless potassium bromide solution, the solution becomes orange as bromine is formed
- Chlorine is **above** bromine in group 17 so it is more reactive
- Chlorine will therefore **displace** bromine from an aqueous solution of a metal bromide

$$2KBr(aq) + Cl_2(aq) \rightarrow 2KCl(aq) + Br_2(aq)$$

potassium bromide + chlorine → potassium chloride + bromine

Bromine and iodine

- Bromine is **above** iodine in group 17 so it is **more** reactive
- Bromine will therefore **displace** iodine from an aqueous solution of a metal iodide

$$Br_2(l) + 2NaI(aq) \rightarrow 2NaBr(aq) + I_2(aq)$$

bromine + sodium Iodide → sodium bromide + iodine

Test yourself on halogen displacements:

Worked example

Which of the statements below are correct?

I. potassium chloride solution will react with fluorine to form chlorine.

II. sodium chloride solution will react with iodine to form chlorine.

III. lithium iodide solution will react with bromine to form iodine.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

Answer:

The correct option is **B**.

- Fluorine will displace chlorine as it is higher up in the group and bromine will displace iodine for the same reason.
- Iodine is below chlorine so cannot displace chlorine from sodium chloride