

# DP IB Chemistry: HL



## 3.2 Oxides, Group 1 & Group 17

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Your notes

## 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 <sub>2</sub> O	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	P <sub>4</sub> O <sub>10</sub>	SO <sub>2</sub> , SO <sub>3</sub>
Acid/base nature	Basic	Basic	Amphoteric	Acidic	Acidic	Acidic

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- 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



Your notes

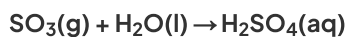
Period 3 oxide	Na <sub>2</sub> O	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	P <sub>4</sub> O <sub>10</sub>	SO <sub>2</sub> , SO <sub>3</sub>		
Relative melting point	High	High	Very high	Very high	Low	Low		
Chemical bonding	ionic	ionic	ionic (with some degree of covalent)	Covalent	Covalent	Covalent		
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

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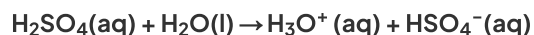
- The difference in electronegativity between oxygen and Na, Mg and Al is the largest
- Electrons will therefore be **transferred** to oxygen when forming oxides giving the oxide an **ionic bond**
- The oxides of Si, P and S will **share** the electrons with the oxygen to form **covalently bonded** oxides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



- 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<sup>+</sup>** ions to water
  - Eg. SO<sub>3</sub> reacts with water as follows:



- The H<sub>2</sub>SO<sub>4</sub> is an acid which will donate an H<sup>+</sup> to water:



### Examiner 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 <sub>2</sub> O	$\text{Na}_2\text{O}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{NaOH}(\text{aq})$	14 (strongly alkaline)
MgO	$\text{MgO}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{Mg}(\text{OH})_2(\text{aq})$	10 (weakly alkaline)
P <sub>4</sub> O <sub>10</sub>	$\text{P}_4\text{O}_{10}(\text{s}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}_3\text{PO}_4(\text{aq})$	2 (strongly acidic)
NO <sub>2</sub>	$2\text{NO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HNO}_3(\text{aq}) + \text{HNO}_2(\text{aq})$	1 (strongly acidic)
SO <sub>2</sub> , SO <sub>3</sub>	$\text{SO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{SO}_3(\text{aq})$ $\text{SO}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{SO}_4(\text{aq})$	1 (strongly acidic)

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- 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

### Examiner Tip

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



Your notes



Your notes

## 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.  $\text{CO}_2$
- B.  $\text{SO}_3$
- C.  $\text{CaO}$
- D.  $\text{Na}_2\text{O}$

#### Answer:

The correct option is **D**.

- $\text{CO}_2$  and  $\text{SO}_3$  will produce a pH below 7 as they are non-metal oxides.  $\text{CaO}$  and  $\text{Na}_2\text{O}$  will produce a pH above 7 as they are metal oxides; however the pH is decreasing as you go across a period, so  $\text{Na}_2\text{O}$  will have a higher pH than  $\text{CaO}$



Your notes

## 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

GROUP METALS

1	2											3	4	5	6	7	0
Li	Be		H									B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

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*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



Your notes

### The Reactions of Group 1 Metals and Water

ELEMENT	REACTION
LITHIUM	$2\text{Li (s)} + 2\text{H}_2\text{O (l)} \rightarrow 2\text{LiOH (aq)} + \text{H}_2\text{(g)}$ <ul style="list-style-type: none"> <li>REACTION SLOWER THAN WITH SODIUM, BUBBLES OF H<sub>2</sub> GAS</li> <li>LITHIUM DOESN'T MELT DUE TO ITS HIGH M.P.</li> </ul>
SODIUM	$2\text{Na (s)} + 2\text{H}_2\text{O (l)} \rightarrow 2\text{NaOH (aq)} + \text{H}_2\text{(g)}$ <ul style="list-style-type: none"> <li>BUBBLES OF H<sub>2</sub> GAS, MELTS INTO A SHINY BALL THAT DASHES AROUND THE SURFACE</li> <li>NAOH FORMED WHICH PRODUCES A HIGHLY ALKALINE SOLUTION</li> </ul>
POTASSIUM	$2\text{K (s)} + 2\text{H}_2\text{O (l)} \rightarrow 2\text{KOH (aq)} + \text{H}_2\text{(g)}$ <ul style="list-style-type: none"> <li>REACTS MORE VIOLENTLY THAN SODIUM, BUBBLES OF H<sub>2</sub> GAS, MELTS INTO A SHINY BALL THAT DASHES AROUND THE SURFACE</li> <li>HOT ENOUGH TO BURN H<sub>2</sub> WHICH FORMS LILAC FLAME</li> </ul>

- Test yourself on this example question:

#### Worked example

What would you see when sodium is added to water?

- a gas is given off
- the temperature of the water increases
- a clear, colourless solution is formed

- I and II only
- I and III only
- II and III only
- I, II and III

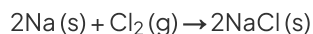
**Answer:**

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**



- 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<sup>1</sup>** 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





Your notes

### 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

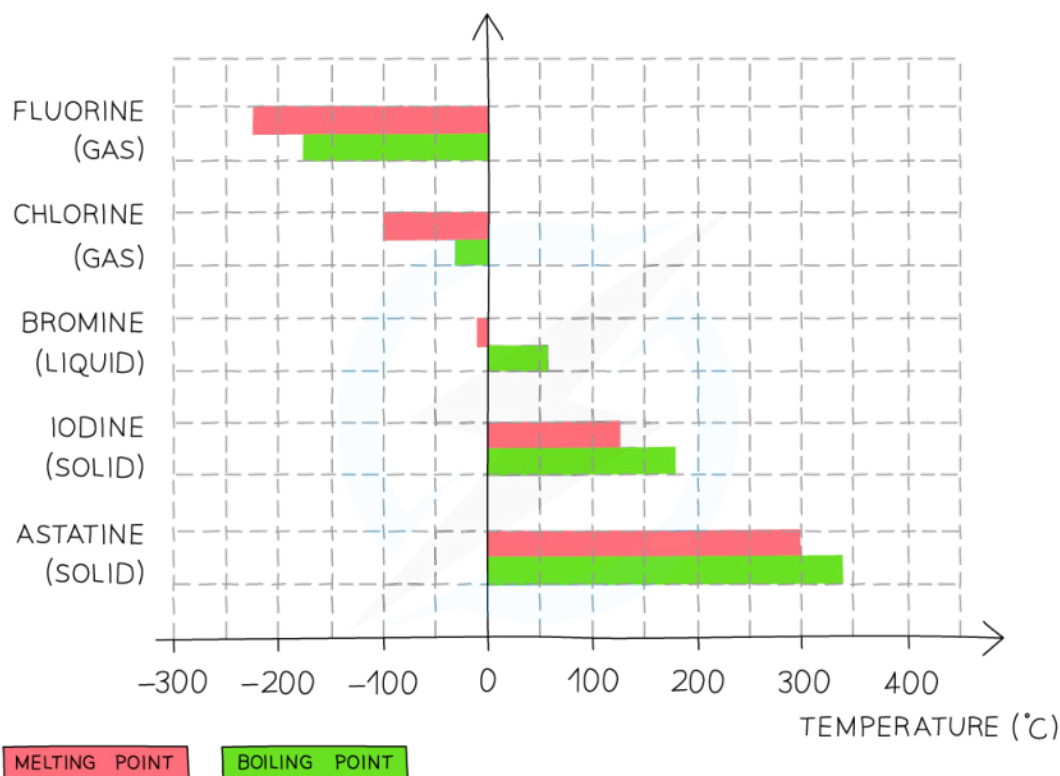
#### Colours and States at Room Temperature

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



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### 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



Your notes

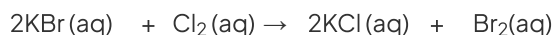
### Aqueous Solution Colour of Halogens

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

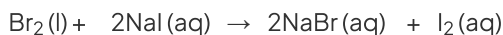
- If you add chlorine solution to colourless potassium bromide solution, the solution becomes orange as bromine is formed
- Chlorine is **above** bromine in group 17 so it is more reactive
- Chlorine will therefore **displace** bromine from an aqueous solution of a metal bromide



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



bromine + sodium iodide → sodium bromide + iodine

Test yourself on halogen displacements:



Your notes

### 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