

# Cambridge (CIE) A Level Chemistry



Your notes

## Periodicity of Chemical Properties of the Elements in Period 3

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- \* Reactions of the Period 3 Elements
- \* Acid/Base Behaviour of the Period 3 Oxides & Hydroxides
- \* Period 3 Chlorides
- \* Electronegativity & Bonding of the Period 3 Elements
- \* Period 3 Chlorides & Oxides



# Reactions of the Period 3 Elements

## Reactions with oxygen & chlorine

### Reaction of Period 3 elements with oxygen table

	Chemical equation	Reaction conditions	Reaction	Flame	Product
<b>Na</b>	$4\text{Na (s)} + \text{O}_2 \text{ (g)} \rightarrow 2\text{Na}_2\text{O (s)}$	Heat	Vigorous	Bright yellow	White solid
<b>Mg</b>	$2\text{Mg (s)} + \text{O}_2 \text{ (g)} \rightarrow 2\text{MgO (s)}$	Heat	Vigorous	Bright white	White solid
<b>Al</b>	$4\text{Al (s)} + 3\text{O}_2 \text{ (g)} \rightarrow 2\text{Al}_2\text{O}_3 \text{ (s)}$	Powdered Al	Fast	Bright white	White powder
<b>Si</b>	$\text{Si (s)} + \text{O}_2 \text{ (g)} \rightarrow \text{SiO}_2 \text{ (s)}$	Powdered Si, heat strongly	Slow	Bright white sparkles	White powder
<b>P</b>	$\text{P}_4 \text{ (s)} + 5\text{O}_2 \text{ (g)} \rightarrow \text{P}_4\text{O}_{10} \text{ (s)}$	Heat, excess oxygen	Vigorous	Yellow or white	White clouds
<b>S</b>	$\text{S (s)} + \text{O}_2 \text{ (g)} \rightarrow \text{SO}_2 \text{ (g)}$	Powdered S, heat	Gentle	Blue	Toxic fumes



### Examiner Tips and Tricks

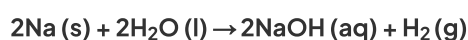
- Textbooks sometimes show the combustion of phosphorus as
  - $4\text{P} + 5\text{O}_2 \rightarrow \text{P}_4\text{O}_{10}$
  - But this shorthand isn't safe for exams
- Phosphorus exists as  $\text{P}_4$  molecules, as stated in the syllabus and mark schemes
- So, you should write reactions with  $\text{P}_4$
- Also, be careful with phosphorus(V) oxide:
  - Examiners expect the molecular formula  $\text{P}_4\text{O}_{10}$ , not the empirical formula  $\text{P}_2\text{O}_5$

### Reaction of Period 3 elements with chlorine table

	Chemical equation	Reaction conditions	Reaction
Na	$2\text{Na (s)} + \text{Cl}_2 \text{ (g)} \rightarrow 2\text{NaCl (s)}$	Heat	Vigorous
Mg	$\text{Mg (s)} + \text{Cl}_2 \text{ (g)} \rightarrow \text{MgCl}_2 \text{ (s)}$	Heat	Vigorous
Al	$2\text{Al (s)} + 3\text{Cl}_2 \text{ (g)} \rightarrow \text{Al}_2\text{Cl}_6 \text{ (s)}$	Heat	Vigorous
Si	$\text{Si (s)} + 2\text{Cl}_2 \text{ (g)} \rightarrow \text{SiCl}_4 \text{ (l)}$	Heat	Slow
P	$\text{P}_4 \text{ (s)} + 10\text{Cl}_2 \text{ (g)} \rightarrow 4\text{PCl}_5 \text{ (l)}$	Heat, excess chlorine	Slow

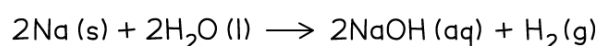
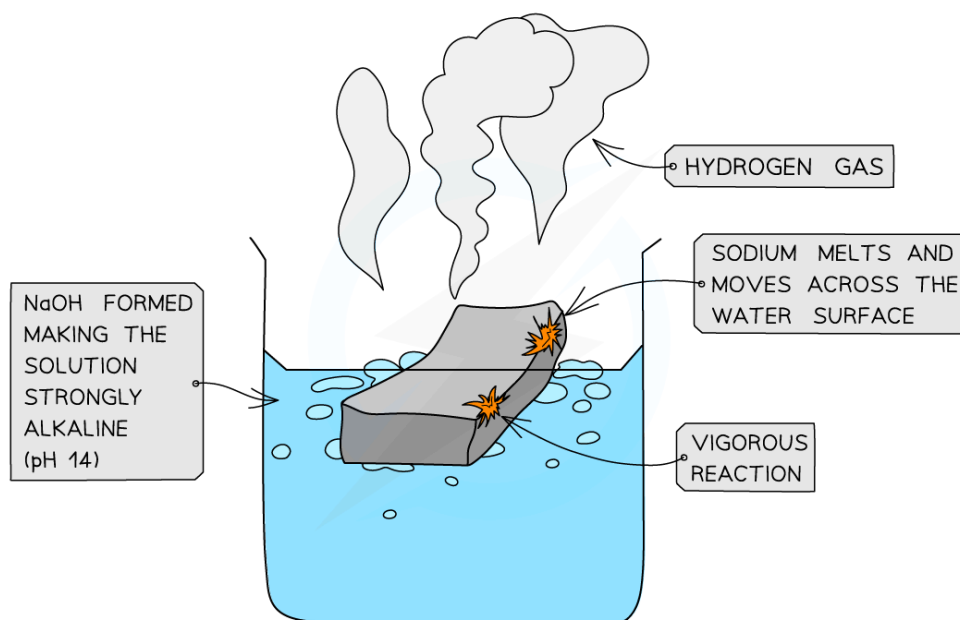
## Reaction of sodium with water

- Sodium reacts **vigorously** with **cold water**:



- The sodium **melts** into a ball and moves across the water surface until it disappears
- Hydrogen gas** is given off
- The solution formed is **strongly alkaline** (pH 14) due to the **sodium hydroxide** which is formed

## The reaction of sodium with cold water



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**Sodium fizzes while vigorously reacting with water to form sodium hydroxide**



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## Table of formulae of the Period 3 oxides & the elements oxidation numbers



Your notes

Period 3 element	Na	Mg	Al	Si	P	S
Formula of 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>
Oxidation number of the Period 3 element	+1	+2	+3	+4	+5	+4 +6



### Examiner Tips and Tricks

- SiO<sub>2</sub> is not written in the specification as expected knowledge but you should be able to apply the oxidation number rules to this and other chemicals



### Worked Example

#### Deducing oxidation numbers of Period 3 elements in their oxides

State the oxidation number of the bold atoms in these compounds or ions.

1. **Na**<sub>2</sub>O
2. **Al**<sub>2</sub>O<sub>3</sub>
3. **P**<sub>4</sub>O<sub>10</sub>

#### Answer

1. **Na**<sub>2</sub>O
  - 1 O atom = -2
  - The overall charge of the compound = 0
  - 2 Na atoms = +2
  - Oxidation number of 1 Na atom = (+2) / 2 = +1
2. **Al**<sub>2</sub>O<sub>3</sub>
  - 3 O atoms = 3 x (-2) = -6
  - The overall charge of the compound = 0
  - 2 Al atoms = +6
  - Oxidation number of 1 Al atom = (+6) / 2 = +3
3. **P**<sub>4</sub>O<sub>10</sub>
  - 10 O atoms = 10 x (-2) = -20
  - The overall charge of the compound = 0
  - 4 P atoms = +20
  - Oxidation number of 1 P atom = (+20) / 4 = +5

## Oxidation numbers of Period 3 elements in their chlorides



Your notes

- The normal [Oxidation Number Rules](#) apply to the Period 3 chlorides

### Table of formulae of the Period 3 chlorides & the elements oxidation numbers

Period 3 element	Na	Mg	Al	Si	P
Formula of chloride	NaCl	MgCl <sub>2</sub>	AlCl <sub>3</sub>	SiCl <sub>4</sub>	PCl <sub>5</sub>
Oxidation number of the Period 3 element	+1	+2	+3	+4	+5



### Worked Example

#### Deducing oxidation numbers of Period 3 elements in their chlorides

State the oxidation number of the bold atoms in these compounds or ions.

1. **Mg**Cl<sub>2</sub>
2. **Al**Cl<sub>3</sub>
3. **P**Cl<sub>5</sub>

#### Answer

1. **Mg**Cl<sub>2</sub>
  - 2 Cl atoms =  $2 \times (-1) = -2$
  - The overall charge of the compound = 0
  - Oxidation number of 1 Mg atom = +2
  - Or, the oxidation number of a Group 2 metal is +2
2. **Al**Cl<sub>3</sub>
  - 3 Cl atoms =  $3 \times (-1) = -3$
  - The overall charge of the compound = 0
  - Oxidation number of 1 Al atom = +3
3. **P**Cl<sub>5</sub>
  - 5 Cl atoms =  $5 \times (-1) = -5$
  - The overall charge of the compound = 0
  - Oxidation number of 1 P atom = +5

## Reaction of Period 3 Oxides & Water

- Not all Period 3 oxides **react** with or are **soluble** in water

### Reaction of Period 3 oxides with water table



Your notes

Oxide	Chemical equation	pH	Comments
<b>Na<sub>2</sub>O</b>	$\text{Na}_2\text{O (s)} + \text{H}_2\text{O (l)} \rightarrow 2\text{NaOH (aq)}$	12 - 14 (Strongly alkaline)	-
<b>MgO</b>	$\text{MgO (s)} + \text{H}_2\text{O (l)} \rightarrow \text{Mg(OH)}_2 \text{ (aq)}$	8 - 10 (Weakly alkaline)	-
<b>Al<sub>2</sub>O<sub>3</sub></b>	No reaction	-	Al <sub>2</sub> O <sub>3</sub> is insoluble in water
<b>SiO<sub>2</sub></b>	No reaction	-	SiO <sub>2</sub> is insoluble in water
<b>P<sub>4</sub>O<sub>10</sub></b>	$\text{P}_4\text{O}_{10} \text{ (s)} + 6\text{H}_2\text{O (l)} \rightarrow 4\text{H}_3\text{PO}_4 \text{ (aq)}$	3 - 4 (Weakly acidic)	Vigorous reaction
<b>SO<sub>2</sub></b>	$\text{SO}_2 \text{ (g)} + \text{H}_2\text{O (l)} \rightleftharpoons \text{H}_2\text{SO}_3 \text{ (aq)}$	1 - 2 (Strongly acidic)	-
<b>SO<sub>3</sub></b>	$\text{SO}_3 \text{ (g)} + \text{H}_2\text{O (l)} \rightarrow \text{H}_2\text{SO}_4 \text{ (aq)}$	1 - 2 (Strongly acidic)	-



### Examiner Tips and Tricks

- Since aluminium oxide does not react or dissolve in water, the oxide layer protects the aluminium metal from corrosion
- The reaction of silicon(IV) oxide is not required knowledge

## Acid / Base Behaviour of Period 3 Oxides & Hydroxides

### Period 3 oxides

- 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 and basic nature of Period 3 oxides table

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

### Reaction of Period 3 oxides with acid / base table

Oxide	Chemical equation	Comment
Na <sub>2</sub> O	$\text{Na}_2\text{O (s)} + 2\text{HCl (aq)} \rightarrow 2\text{NaCl (aq)} + \text{H}_2\text{O (l)}$	
MgO	$\text{MgO (s)} + 2\text{HCl (aq)} \rightarrow \text{MgCl}_2\text{ (aq)} + \text{H}_2\text{O (l)}$	Used in indigestion remedies by neutralising excess acid in the stomach
Al <sub>2</sub> O <sub>3</sub>	$\text{Al}_2\text{O}_3\text{ (s)} + 3\text{H}_2\text{SO}_4\text{ (aq)} \rightarrow \text{Al}_2(\text{SO}_4)_3\text{ (aq)} + 3\text{H}_2\text{O (l)}$ $\text{Al}_2\text{O}_3\text{ (s)} + 2\text{NaOH (aq)} + 3\text{H}_2\text{O (l)} \rightarrow 2\text{NaAl(OH)}_4\text{ (aq)}$	Reacts with acid to form salt and water Reacts with hot, concentrated alkali to form salt
SiO <sub>2</sub>	$\text{SiO}_2\text{ (s)} + 2\text{NaOH (aq)} \rightarrow \text{Na}_2\text{SiO}_3\text{ (aq)} + \text{H}_2\text{O (l)}$	
P <sub>4</sub> O <sub>10</sub>	$\text{P}_4\text{O}_{10}\text{ (s)} + 12\text{NaOH (aq)} \rightarrow 4\text{Na}_3\text{PO}_4\text{ (aq)} + 6\text{H}_2\text{O (l)}$	
SO <sub>2</sub> SO <sub>3</sub>	$\text{SO}_2\text{ (g)} + 2\text{NaOH (aq)} \rightarrow \text{Na}_2\text{SO}_3\text{ (aq)} + \text{H}_2\text{O (l)}$ $\text{SO}_3\text{ (g)} + 2\text{NaOH (aq)} \rightarrow \text{Na}_2\text{SO}_4\text{ (aq)} + \text{H}_2\text{O (l)}$	

- 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 of the Period 3 oxides table

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 covalent character)	Covalent	Covalent	Covalent
Structure	Giant ionic	Giant ionic	Giant ionic	Giant covalent	Simple molecular	Simple molecular



Your notes

## Electronegativity of Period 3 elements table

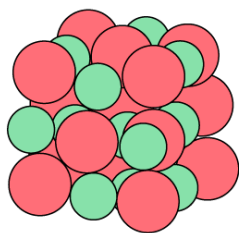
Period 3 element	Na	Mg	Al	Si	P	S	Cl
Electronegativity	0.9	1.2	1.5	1.8	2.1	2.5	3.0

- Oxygen has an electronegativity value of 3.5
- Therefore, the difference in electronegativity between oxygen and Na, Mg and Al is the largest
- So, electrons will be **transferred** to oxygen when forming oxides giving the oxide an **ionic binding**
- The oxides of Si, P and S will **share** the electrons with the oxygen to form **covalently bonded** oxides
- The **giant ionic** and **giant covalent** structured oxides will have **high melting points** as it is difficult to break the structures apart

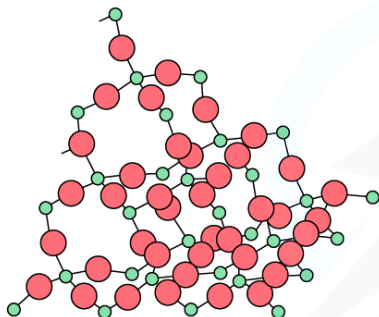
## The structure of some Period 3 oxides



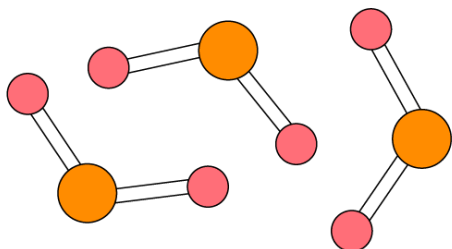
Your notes



THE GIANT IONIC STRUCTURE  
OF MAGNESIUM OXIDE (MgO)



THE GIANT COVALENT STRUCTURE  
OF SILICON DIOXIDE (SiO<sub>2</sub>)

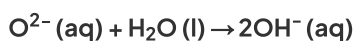


THE SIMPLE MOLECULAR STRUCTURE  
OF SULFUR DIOXIDE (SO<sub>2</sub>)

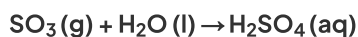
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**Magnesium oxide is giant ionic, silicon dioxide is giant covalent and sulfur dioxide is simple molecular**

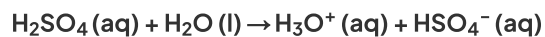
- The oxides of **Na and Mg** which show purely **ionic bonding** produce **alkaline** solutions with water as their **oxide** ions (O<sup>2-</sup>) become **hydroxide** ions (OH<sup>-</sup>):



- 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 a H<sup>+</sup> to water:

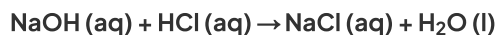


- **Al** and **Si** are insoluble and when they react with **hot, concentrated alkaline solution** they act as an acid and form a salt
  - This behaviour is very typical of a **covalently bonded oxide**
- **Al** can also react with **acidic solutions** to form a salt and water

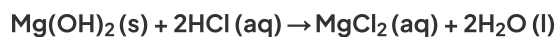
- This behaviour is very typical of an **ionic bonded metal oxide**
- This behaviour of **Al** proves that the chemical bonding in aluminium oxide is not purely ionic nor covalent: it is **amphoteric**

## Period 3 hydroxides

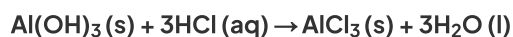
- NaOH is a strong base and will react with acids to form a salt and water:



- Mg(OH)<sub>2</sub> is also a basic compound which is often used in indigestion remedies by neutralising the excess acid in the stomach to relieve pain:



- Al(OH)<sub>3</sub> is **amphoteric** and can act both as an acid and base:



### Examiner Tips and Tricks

- Electronegativity is the power of an element to draw the electrons towards itself in a covalent bond.
- For example, in Na<sub>2</sub>O the oxygen will draw the electrons more strongly towards itself than sodium does.



Your notes



## Reaction of Period 3 Chlorides & Water

- Chlorides of Period 3 elements show characteristic behaviour when added to water which can be explained by looking at their **chemical bonding** and **structure**

### Chemical bonding & structure of Period 3 chlorides table

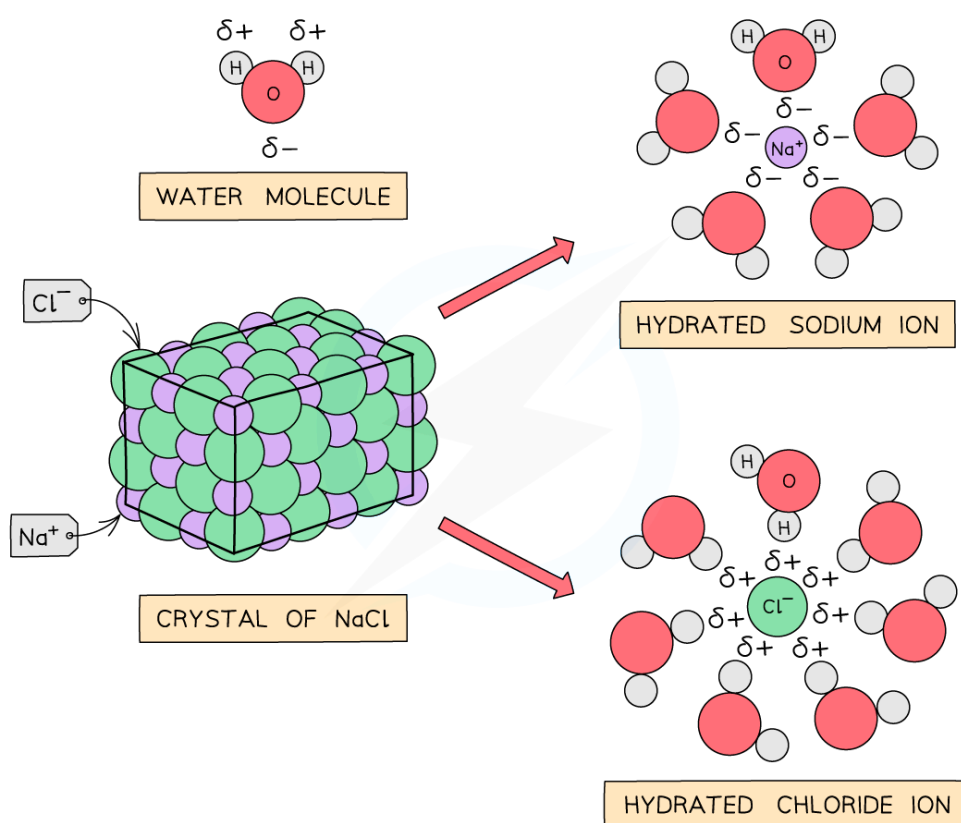
Period 3 chloride	NaCl	MgCl <sub>2</sub>	Al <sub>2</sub> Cl <sub>6</sub>	SiCl <sub>4</sub>	PCl <sub>5</sub>	SCl <sub>2</sub>
Chemical bonding	Ionic	Ionic	Covalent	Covalent	Covalent	Covalent
Structure	Giant ionic	Giant ionic	Simple molecular	Simple molecular	Simple molecular	Simple molecular
Observations	White solids dissolve to form colourless solutions		Chlorides react with water giving off white fumes of hydrogen chloride gas			
pH of solution formed	7.0	6.5	3.0	2.0	2.0	2.0

### Sodium & magnesium chloride

- NaCl and MgCl<sub>2</sub> do not react with water as the **polar** water molecules are attracted to the ions **dissolving** the chlorides and breaking down the **giant ionic structures**; the metal and chloride ions become hydrated ions



Your notes



The diagram shows water molecules breaking down the giant ionic structure of NaCl to form hydrated ions

## Aluminium chloride

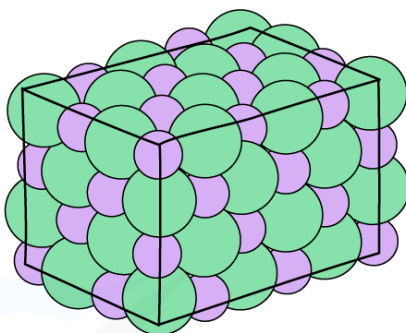
- Aluminium chloride exists in two different forms depending on conditions:
  - Anhydrous  $\text{AlCl}_3$**  is covalent and exists as a dimer,  $\text{Al}_2\text{Cl}_6$
  - In aqueous solution**,  $\text{AlCl}_3$  dissociates into  $\text{Al}^{3+}$  and  $\text{Cl}^-$  ions and behaves ionically

### The two forms of aluminium chloride

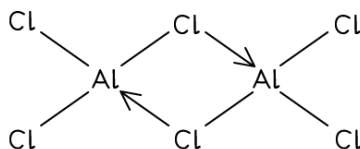
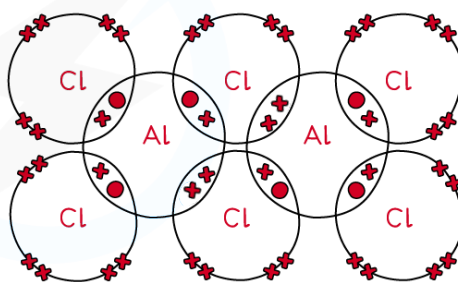


Your notes

ALUMINIUM CHLORIDE  
AS A GIANT IONIC  
LATTICE ( $\text{AlCl}_3$ )



ALUMINIUM CHLORIDE  
AS A DIMER ( $\text{Al}_2\text{Cl}_6$ )

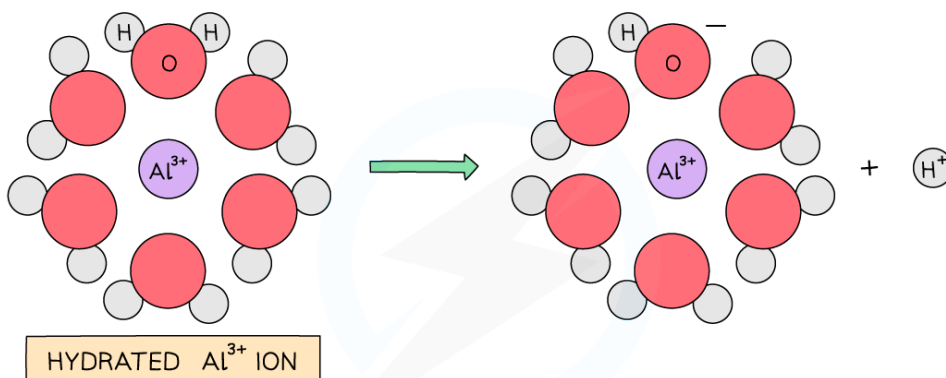


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**Aluminium chloride exists as a giant ionic lattice or a covalent dimer**

- When water is added to aluminium chloride the dimers are broken down and  $\text{Al}^{3+}$  and  $\text{Cl}^-$  ions enter the solution
- The highly charged  $\text{Al}^{3+}$  ion becomes hydrated and causes a water molecule that is bonded to the  $\text{Al}^{3+}$  to lose an  $\text{H}^+$  ion which turns the solution **acidic**
- The  $\text{H}^+$  and the  $\text{Cl}^-$  form **hydrogen chloride gas** which is given off as **white fumes**

## How the $\text{Al}^{3+}$ makes an acidic solution



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The hydrated aluminium causes a water molecule to lose a hydrogen ion turning the solution acidic



Your notes

## Silicon chloride

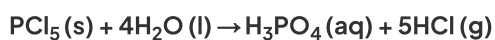
- SiCl<sub>4</sub> is **hydrolysed** in water, releasing **white fumes of hydrogen chloride gas** in a **rapid** reaction



- The SiO<sub>2</sub> is seen as a **white precipitate** and some of the **hydrogen chloride gas** produced dissolves in water to form an **acidic** solution

## Phosphorus(V) chloride

- PCl<sub>5</sub> also gets **hydrolysed** in water



- Both H<sub>3</sub>PO<sub>4</sub> and dissolved HCl are highly **acidic**



# Trends in Period 3 Electronegativity & Bonding

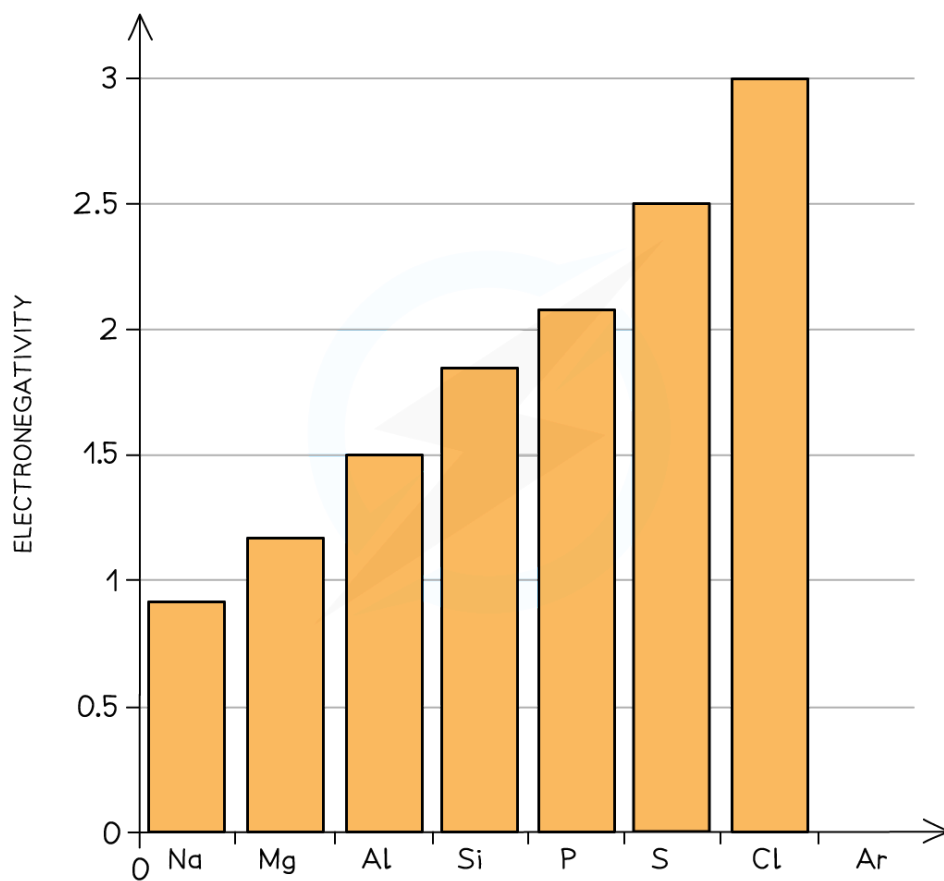
## Electronegativity

- **Electronegativity** is the power of an element to draw the electrons towards itself in a covalent bond
- Going **across** the period, the **electronegativity** of the elements increases

## Electronegativity across Period 3 table

Period 3 element	Na	Mg	Al	Si	P	S	Cl	Ar
Electronegativity	0.9	1.2	1.5	1.8	2.1	2.5	3.0	-

## Graph of the electronegativity of the Period 3 elements



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*Electronegativity of the Period 3 elements increases from Na to Cl*





- As the **atomic number** increases going across the period, there is an **increase in nuclear charge**
- Across the period, there is an increase in the number of **valence electrons** however the **shielding** is still the same as each extra electron enters the same shell
- As a result of this, electrons will be more strongly attracted to the nucleus causing an increase in electronegativity across the period

## Bonding & structure of Period 3 elements table

Period 3 element	Na	Mg	Al	Si	P	S	Cl
Bonding	Metallic	Metallic	Metallic	Covalent	Covalent	Covalent	Covalent
Structure	Giant metallic	Giant metallic	Giant metallic	Giant molecular	Simple molecular	Simple molecular	Simple molecular

## Bonding and structure from Al to S

- As you move across the Periodic Table from aluminium (Al) to sulfur (S), both bonding and structure change:
  - Bonding changes from **metallic** (in Al) to **covalent** (in Si, P, S, etc.)
  - Structure changes from **giant lattices to simple molecular structures**
- Sodium (Na), magnesium (Mg), and aluminium (Al) are all metals
- They form a **giant metallic lattice**:
  - Positive metal ions are arranged in a regular lattice
  - They are surrounded by a 'sea' of delocalised electrons
  - These electrons come from the outer shell (valence shell) of each atom

## Delocalised electrons and bond strength

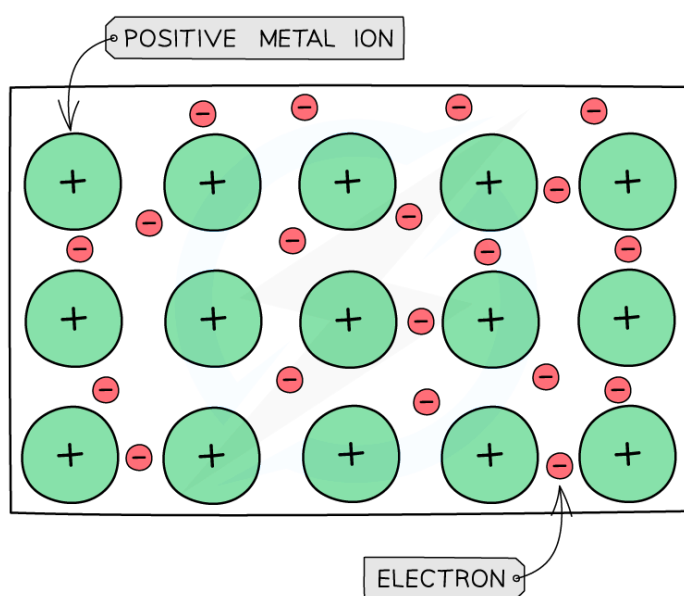
- Na donates **1** electron per atom
- Mg donates **2** electrons per atom
- Al donates **3** electrons per atom
- As a result:
  - More **delocalised electrons = stronger electrostatic forces** between the metal ions and the electron cloud
  - $\text{Al}^{3+}$  forms stronger metallic bonds than  $\text{Na}^+$ , due to:
    - Higher ionic charge
    - Greater number of delocalised electrons

## Electrical conductivity

- Because aluminium contributes more delocalised electrons, it has:
  - More **charge carriers**
  - Stronger **metallic bonding**
  - Therefore, aluminium is a **better conductor** of electricity than sodium or magnesium



## A giant metallic lattice



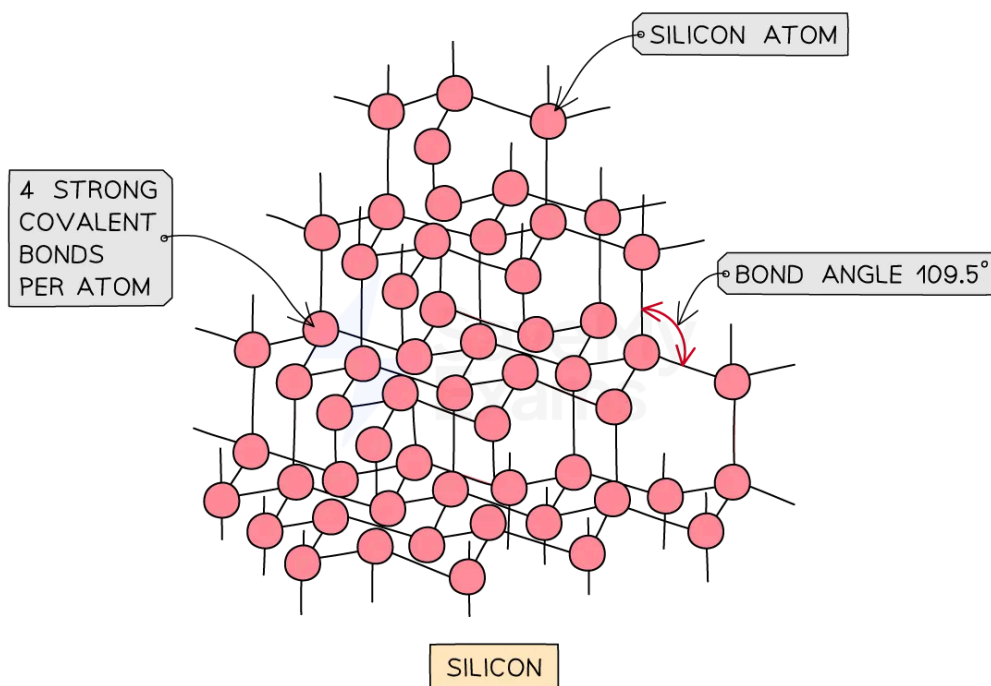
***Metal cations form a giant lattice held together by electrons that can freely move around***

- Si is a non-metallic element and has a **giant molecular** structure in which each Si atom is held to its neighbouring Si atoms by **strong covalent bonds**
- There are no delocalised electrons in the structure of Si which is why silicon cannot conduct electricity and is classified as a **metalloid**

## The giant molecular structure of silicon



Your notes



The diagram shows the giant molecular structure of silicon where silicon atoms are held together by strong covalent bonds

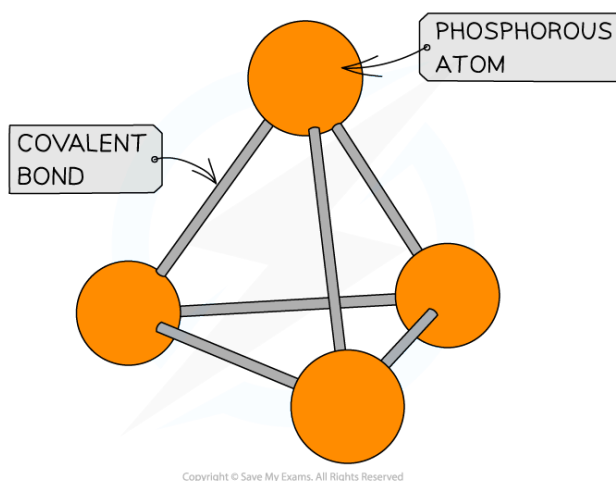
## Bonding from P to Ar

- Phosphorous, sulfur, chlorine and argon are non-metallic elements
  - Phosphorous, sulfur and chlorine exist as simple molecules ( $P_4$ ,  $S_8$ ,  $Cl_2$ )
  - Argon exists as **single** atoms
- The **covalent bonds within** the molecules are strong, however, **between** the molecules there are only weak **instantaneous dipole-induced dipole forces**
- It doesn't take much energy to break these **intermolecular** forces
- The lack of delocalised electrons means that these compounds cannot conduct electricity

## The simple molecular structure of phosphorous

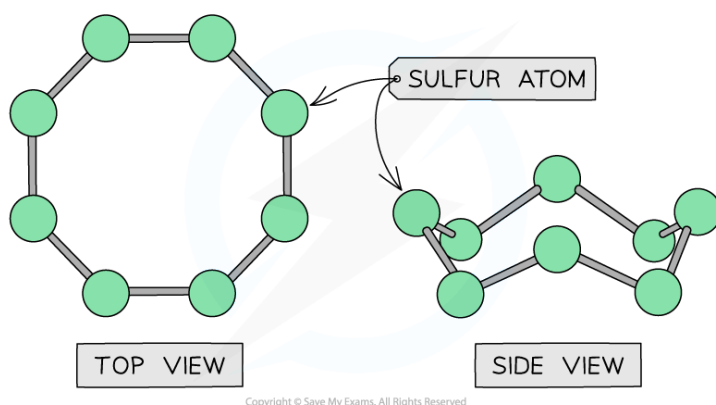


Your notes



*The diagram shows the simple molecular structure of phosphorus with covalent bonds between the atoms*

## The simple molecular structure of sulfur



*The diagram shows the simple molecular structure of sulfur with covalent bonds between the atoms*



## Bonding in Period 3 Chlorides & Oxides

### Period 3 chlorides

#### Chemical bonding & structure of Period 3 chlorides table

Period 3 chloride	NaCl	MgCl <sub>2</sub>	Al <sub>2</sub> Cl <sub>6</sub>	SiCl <sub>4</sub>	PCl <sub>5</sub>	SCl <sub>2</sub>
Chemical bonding	Ionic	Ionic	Covalent	Covalent	Covalent	Covalent
Structure	Giant ionic	Giant ionic	Simple molecular	Simple molecular	Simple molecular	Simple molecular

### Period 3 oxides

#### Chemical bonding & structure of Period 3 oxides table

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>
Chemical bonding	Ionic	Ionic	Ionic (with some covalent character)	Covalent	Covalent	Covalent
Structure	Giant ionic	Giant ionic	Giant ionic	Giant covalent	Simple molecular	Simple molecular

- Going across Period 3, their chlorides and oxides become more **covalent** and their structure shifts from a **giant ionic** to a **simple molecular** structure
- Their reactions with water become more **vigorous** as a result of this, as it becomes easier to **hydrolyse** the chlorides and oxides