Chem Factsheet

September 2001 Number 19

The Periodic Table - Period 3

To succeed in this topic you need to:-
- **understand the work in Factsheet 12 on Periodicity - Trends in Period 3**
- **understand work on bonding (Factsheet 05) and structure (Factsheet 06)**

After working through this Factsheet you will:-
- **know the reactions of Period 3 elements with oxygen, chlorine and water**
- **know the formulae and some characteristics of the oxides, hydroxides and chlorides of Period 3 elements.**

The trends in the physical properties of the Period 3 elements are summarised in Table 1.

Table 1. Trends in physical properties across Period 3

Group	1	2	3	4	5	6	7	8
Element	sodium	magnesium	aluminium	silicon	phosphorus	sulphur	chlorine	argon
Symbol	Na	Mg	Al	Si	P	S	Cl	Ar
Structure	← Giant Metallic →			Giant Covalent	← Molecular →			Atomic
Character	← Metallic →			Metalloid/ Non-metal	← Non - Metallic →			
Melting Point	General increase →				General decrease →			
Conductance	General increase →			General decrease →				
First Ionization Energy	General increase →							
Atomic Radius	General decrease →							

Reactions of the Period 3 elements with oxygen

The oxide products are generally very stable, as oxygen is a very electronegative element – this means that the enthalpy of formation of the oxides are usually negative.

As we move across the period the electronegativity differences become smaller and the oxides become less stable.

Element	**Equation for reaction**
Sodium	$4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$ (simple oxide) and $2Na(s) + O_2(g) \rightarrow Na_2O_2(s)$ (peroxide)
Magnesium	$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
Aluminium	$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$
Silicon	$Si(s) + O_2(g) \rightarrow SiO_2(s)$
Phosphorus	$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s)$
Sulphur	$S(s) + O_2(g) \rightarrow SO_2(g)$
Chlorine	Does not react directly with oxygen
Argon	No reaction with oxygen

Exam Hint: *Candidates must be able to recall the equations for oxide and chloride formation.*

Reactions of the Period 3 elements with chlorine

All of the Period 3 elements (except argon and chlorine itself) react directly on heating with chlorine. Moving across the period from left to right, the reactions become less vigorous with less heat released on formation, and the bonds formed become increasingly covalent in character.

The change in behaviour is due to the increasing electronegativity across the period. The s-block metals are very electropositive so form strong ionic bonds with the electronegative chlorine.

Element	**Equation for reaction**
Sodium	$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$ sodium chloride (white ionic solid)
Magnesium	$Mg(s) + Cl_2(g) \rightarrow MgCl_2(s)$ magnesium chloride (white ionic solid)
Aluminium	$2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$ Aluminium chloride (yellow covalent solid). Dimerises to form Al_2Cl_6
Silicon	$Si(s) + 2Cl_2(g) \rightarrow SiCl_4(l)$ silicon chloride (colourless covalent liquid)
Phosphorus	$2P(s) + 3Cl_2(g) \rightarrow 2PCl_3(l)$ phosphorus (III) chloride (colourless covalent liquid)
Sulphur	$2S(s) + Cl_2(g) \rightarrow S_2Cl_2(l)$ sulphur chloride (pale yellow covalent liquid)

Reactions of the Period 3 elements with water

Element	Reaction	Equation
Sodium	Vigorous reaction, sodium melts into sphere and darts about on surface of water; hydrogen gas given off and resulting solution is alkaline.	$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$
Magnesium	Extremely slow reaction with cold water; bubbles of hydrogen formed on surface of metal. Reacts quickly with steam, metal glows red and white flame is seen as solid white magnesium oxide is formed, and hydrogen evolved.	$Mg(s) + 2H_2O(l) \rightarrow Mg(OH)_2(s) + H_2(g)$ $Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)$
Aluminium	No reaction with cold water, but will react with steam to give oxide if powdered and heated strongly	$2Al(s) + 3H_2O(l) \rightarrow Al_2O_3(s) + 3H_2(g)$
Silicon	No reaction with H_2O	
Phosphorus	No reaction with H_2O	
Sulphur	No reaction with H_2O	
Chlorine	Forms an acidic solution; hydrochloric acid and hypochlorous acid (a bleach) formed as chlorine undergoes disproportionation.	$Cl_2(g) + H_2O(l) \quad HCl(aq) + HOCl(aq)$

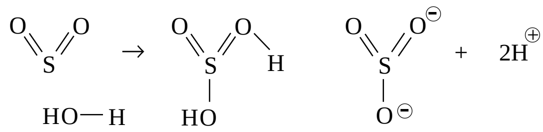
The Oxides of Period 3

The acidic/basic nature of the oxide depends upon the properties of the Period 3 element. The more electropositive the element, the more basic the oxide, as the compound will be more ionic in character and the O^{2-} ions can accept hydrogen ions to form water. This lowers the concentration of $H^+(aq)$, so solution is alkaline.

As we move from left to right across Period 3, elements become more electronegative, so the covalent character of the oxides increases, so there is no oxide ion to receive protons. Instead covalent molecules with a tendency to dissociate and donate hydrogen ions (i.e. acids) are formed.

> ***Exam Hint: -*** *The trends in acidic and basic character of the oxides are frequently examined. However, an understanding of the trends must be backed up by a detailed knowledge of the equations for reactions which demonstrate this acidic, basic or amphoteric character - i.e. those with water or H^+ or OH^- ions.*

For example, sulphur dioxide combines with water to form the covalent molecule H_2SO_3; the polar bond between the oxygen and hydrogen means that this will dissociate readily to form hydrogen ions.



> ***Exam Hint: -*** *Ensure you can link the behaviour of the oxides and chlorides of the elements with the trend in electronegativity across the period.*

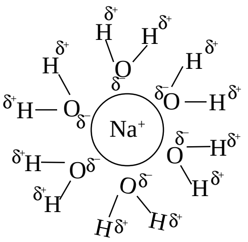
Oxide	Structure/Bonding	Acidic/Basic character	Reaction with water
sodium oxide Na_2O	giant ionic	basic	Reacts to form a strong alkali $Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$
magnesium oxide MgO	giant ionic, polarised	basic, but less so than Na_2O	Reacts to form a weak alkali $MgO(s) + H_2O(l) \rightarrow Mg(OH)_2(aq)$
aluminium oxide Al_2O_3	ionic, some covalent character	amphoteric - reacts with both H^+ and OH^- ions $Al_2O_3(s) + 6H^+(aq) \rightarrow 2Al^{3+}(aq) + 3H_2O(1)$ $Al_2O_3(s) + 2OH^-(aq) + 3H_2O(1) \rightarrow 2Al(OH)_4^-(aq)$	No reaction
silicon(IV) oxide SiO_2	giant covalent	acidic - reacts with OH^- ions $SiO_2(s) + 2OH^-(aq) \rightarrow SiO_3^{2-}(aq) + H_2O(l)$	No reaction
phosphorus(V) oxide P_4O_{10}	molecular covalent solid	acidic	Reacts to form phosphoric (V) acid $P_4O_{10}(s) + 6H_2O(l) \rightarrow H_3PO_4(aq)$
sulphur(IV) oxide (or dioxide) SO_2 sulphur(VI) oxide (or trioxide) SO_3	molecular covalent gas	acidic	React to form sulphuric (IV) and sulphuric (VI) acids: $SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$ $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$
chlorine oxide(Cl_2O)	molecular covalent gas	acidic	Reacts to form hypochlorous acid $Cl_2O(g) + H_2O(l) \rightarrow 2HOCl(aq)$

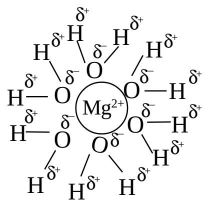
Chlorides of Period 3

Chloride	Structure/ Bonding	Reaction with water
sodium chloride NaCl	Giant ionic	Dissolves to give a neutral solution
magnesium chloride $MgCl_2$	Giant ionic	Dissolves to give a weakly acid solution
aluminium chloride $AlCl_3$	When anhydrous, covalent solid which exists as dimers Al_2Cl_6 The hydrated form is an ionic solid	Anhydrous form reacts to produce hydrochloric acid $AlCl_3(s) + 3H_2O(l) \rightarrow Al(OH)_3(s) + 3HCl(aq)$ Hydrated form is hydrolysed in water, forming acidic solution $[Al(H_2O)_6]^{3+}(aq) + H_2O(l) \rightarrow Al[(H_2O)_5(OH)]^{2+}(aq) + H_3O^+(aq)$
silicon chloride $SiCl_4$	molecular covalent liquid	Reacts to produce hydrochloric acid $SiCl_4(1) + 2H_2O(1) \rightarrow SiO_2(s) + 4HCl(aq)$
phosphorus chlorides PCl_3 and PCl_5	molecular covalent liquid	Reacts to form phosphoric and hydrochloric acids $PCl_3(1) + 3H_2O(1) \rightarrow H_3PO_4(aq) + 3HCl(aq)$
sulphur chlorides S_2Cl_2, SCl_2 and SCl_4	molecular covalent liquid	Reacts to form hydrochloric acid $2S_2Cl_2(1) + 2H_2O(1) \rightarrow 3S(s) + SO_2(aq) + 4HCl(aq)$

Why does magnesium chloride give an acid solution when it dissolves in water, but sodium chloride a neutral solution?

When ionic solids like sodium and magnesium chlorides dissolve in water, the metal ion becomes surrounded by water molecules, as illustrated below:





Because the Mg^{2+} has a higher charge density than Na^+ (as it is both smaller and more highly charged), it further polarises the already polar O – H bonds in water, causing some deprotonation. The presence of the H^+ ion in solution causes some acidity.

Practice Questions

1. Period 3 elements Na→Cl react with oxygen:

   (a) Sodium reacts with oxygen to form basic oxides. Write equations for both its reaction with oxygen and to illustrate the basic nature of sodium oxide.

   (b) One of the Period 3 elements forms an amphoteric oxide. Write equations which illustrate the amphoteric nature of this oxide.

2. Write equations for the reactions of magnesium, chlorine and phosphorus(III) oxide with water. In each case suggest a likely pH of the solution formed.

3. Explain why sodium chloride forms a neutral solution, yet magnesium chloride forms a slightly acidic solution in water.

4. Explain why the heat evolved in formation of Period 3 chlorides decreases as we move from left to right across the period.

Answers

1. a) $4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$ and $2Na(s) + O_2(g) \rightarrow Na_2O_2(s)$
   The oxide is basic because it reacts with water to form a strong alkali.

   $Na_2O(s) + H_2O(1) \rightarrow 2NaOH(aq)$

   b) Aluminium oxide is amphoteric
   As a base: $Al_2O_3(s) + 6H^+(aq) \rightarrow 2Al^{3+}(aq) + 3H_2O(l)$
   As an acid: $Al_2O_3(s) + 2OH^-(aq) + 3H_2O(l) \rightarrow 2Al(OH)_4^-(aq)$

2. Mg with water: $Mg(s) + 2H_2O(1) \rightarrow Mg(OH)_2(aq) + H_2(g)$
   pH of soln: ~ 8-9 (weak alkali)

   Cl with water: $Cl_2(g) + H_2O(1) \rightarrow HCl(aq) + HOCl(aq)$
   pH of soln: ~ 1-2 (strong acid)

   P_4O_{10} with water: $P_4O_{10}(s) + 6H_2O(1) \rightarrow 4H_3PO_4(aq)$
   pH of soln: ~ 2 (acid)

3. Sodium chloride dissolves to give $Na^+(aq)$ and $Cl^-(aq)$ ions in solution. Magnesium chloride dissolves to give $Mg^{2+}(aq)$ and $Cl^-(aq)$.

   $Mg^{2+}(aq)$ is smaller and more positive than $Na^+(aq)$ and causes some deprotonation of water molecules, hence slightly acid solution.

4. s-block metals are very electropositive, so form strong ionic bonds with electronegative chlorine, releasing a great deal of energy.
   As we move across the period, bonds formed become more covalent in character and heat released on formation decreases.

Acknowledgements:
This Factsheet was researched and written by Kieron Heath
Curriculum Press, Unit 305B, The Big Peg, 120 Vyse Street, Birmingham, B18 6NF

ISSN 1351-5136