PERIOD 3 ELEMENTS AND THEIR COMPOUNDS

Introduction

- the first two periods in the periodic table are not typical
- the first contains only two elements (H, He)
- the second (Li - Ne) contains the top elements of each group; these have small sizes and relatively high ionisation energies so are atypical
- Period 3 is best for studying periodic trends.

ELEMENTS

Structure

As you move from left to right the elements go from highly electropositive metals through metalloids with giant structures to the simple molecular structure of non-metals.

<table>
<thead>
<tr>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>P₄</th>
<th>S₈</th>
<th>Cl₂</th>
<th>Ar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>&lt; - - - - metals - - - - &gt;</td>
<td>metalloid</td>
<td>&lt; - non metals (simple molecules) - &gt;</td>
<td></td>
<td></td>
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</tbody>
</table>

Reactions with...

Water

As you move from left to right across a period the metals become less reactive

Sodium

two Na(s) + 2H₂O(g) ———> 2NaOH(aq) + H₂(g)
very soluble

Magnesium

two Mg(s) + 2H₂O(g) ———> Mg(OH)₂(s) + H₂(g)
sparingly soluble

vigorous reaction with steam

Mg(s) + H₂O(g) ———> MgO(s) + H₂(g)

Oxygen

- elements must be heated to react; however...
- dry phosphorus can ignite spontaneously which is why it is stored under water
- the reactivity depends a lot on the state of subdivision

Sodium

vigorous reaction with ignited sodium
ionic sodium oxide formed

4Na(s) + 2O₂(g) ———> 2Na₂O(s)

Magnesium

vigorous reaction with ignited magnesium
ionic magnesium chloride formed

2Mg(s) + O₂(g) ———> 2MgO(s)
Aluminium

sheets of aluminium get slowly coated with thin oxide layer
powdered aluminium shows a vigorous reaction with sparks
ionic aluminium oxide formed

\[ 4\text{Al}(s) + 3\text{O}_2(g) \rightarrow 2\text{Al}_2\text{O}_3(s) \]

Silicon

vigorous reaction with silicon powder
covalent giant molecular silicon dioxide formed

\[ \text{Si}(s) + \text{O}_2(g) \rightarrow \text{SiO}_2(s) \]

Phosphorus

ignites spontaneously in oxygen - white solid produced

\[ \text{P}_4(s) + 5\text{O}_2(g) \rightarrow \text{P}_4\text{O}_{10}(s) \]

Sulphur

burns with a lilac flame to give a choking gas which fumes in moist air
covalent molecules of sulphur dioxide formed

\[ \text{S}(s) + \text{O}_2(g) \rightarrow \text{SO}_2(g) \]

Chlorine

Most can be prepared by direct combination by passing the gas over the heated element
If two chlorides are possible, the higher oxidation state one is formed - get PCl\(_5\) not PCl\(_3\)

e.g. Sodium

\[ 2\text{Na}(s) + \text{Cl}_2(g) \rightarrow 2\text{NaCl}(s) \]

Magnesium

\[ \text{Mg}(s) + \text{Cl}_2(g) \rightarrow \text{MgCl}_2(s) \]

Aluminium

\[ 2\text{Al}(s) + 3\text{Cl}_2(g) \rightarrow 2\text{AlCl}_3(s) \]

Silicon

\[ \text{Si}(s) + 2\text{Cl}_2(g) \rightarrow \text{SiCl}_4(l) \]

Phosphorus

\[ 2\text{P}(s) + 5\text{Cl}_2(g) \rightarrow 2\text{PCl}_5(s) \]

Structures

sodium chloride  \( \text{giant ionic lattice} \)
magnesium chloride  \( \text{giant ionic lattice} \)
aluminium chloride  \( \text{covalent molecule which can exist as a dimer} \)
Lewis acid - 6 electrons in outer shell of aluminium

silicon(IV) chloride  \( \text{covalent molecule} \)  tetrahedral

phosphorus(V) chloride  \( \text{covalent molecule} \)  trigonal bipyramidal
PERIODICITY IN COMPOUNDS

Chlorides - Summary

<table>
<thead>
<tr>
<th></th>
<th>NaCl</th>
<th>MgCl₂</th>
<th>AlCl₃</th>
<th>SiCl₄</th>
<th>PCl₅</th>
<th>SCl₂</th>
<th>Cl₂</th>
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</thead>
<tbody>
<tr>
<td>melting point / K</td>
<td>1074</td>
<td>987</td>
<td>450 (sub)</td>
<td>203</td>
<td>435 (sub)</td>
<td>195</td>
<td>172</td>
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<td>molecular</td>
<td>molecular</td>
<td>molecular</td>
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<td>solubility in water</td>
<td>very</td>
<td>very</td>
<td>hydrolysed</td>
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<tr>
<td>pH of solution</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**NaCl, MgCl₂**  Typical **ionic solids** existing as giant ionic lattices with high melting points. Both dissolve in water to give neutral solutions containing separate aqueous ions.

- Sodium: \( \text{NaCl(s)} \rightarrow \text{Na}^+(aq) + \text{Cl}^-(aq) \)
- Magnesium: \( \text{MgCl}_2(s) \rightarrow \text{Mg}^{2+}(aq) + 2\text{Cl}^-(aq) \)

**AlCl₃**  High charge density of Al³⁺ favours covalency. It is readily hydrolysed giving an acidic solution.

\[
\text{AlCl}_3(s) + 6\text{H}_2\text{O}(l) \rightarrow [\text{Al}((\text{H}_2\text{O})_6)]^{3+}(aq) + 3\text{Cl}^-(aq)
\]

**SiCl₄**  Availability of 3d orbitals means that it is easily hydrolysed producing an acidic solution.

\[
\text{SiCl}_4(l) + 4\text{H}_2\text{O}(l) \rightarrow \text{SiO}_2.2\text{H}_2\text{O}(s) + 4\text{HCl}(aq)
\]

**PCl₅**  Unusual for a non-metallic chloride, it exists as \([\text{PCl}_4^+][\text{PCl}_6^-]\). Hydrolysed giving acidic solution.

\[
\text{PCl}_5(s) + 4\text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{PO}_4(aq) + 5\text{HCl}(aq)
\]

**Across the period...**

- bonding changes from ionic to covalent (more likely to be hydrolysed)
- react with water rather than dissolve in it
- change from giving neutral solutions to acidic solutions
Oxides - Summary

<table>
<thead>
<tr>
<th></th>
<th>Na₂O</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>P₄O₁₀</th>
<th>SO₂</th>
<th>SO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>melting point / K</td>
<td>1548</td>
<td>3125</td>
<td>2345</td>
<td>1833</td>
<td>573 (subl)</td>
<td>200</td>
<td>290</td>
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<td>ionic</td>
<td>ionic/cov</td>
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<tr>
<td>solubility in water</td>
<td>very</td>
<td>sparingly</td>
<td>insoluble</td>
<td>insoluble</td>
<td>reacts</td>
<td>reacts</td>
<td>reacts</td>
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<tr>
<td>pH of solution</td>
<td>14</td>
<td>9</td>
<td>7</td>
<td>7</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

**Preparation**
- metals produce basic, non-metals produce acidic oxides
- aluminium oxide is an *amphoteric* oxide (it shows acidic and basic properties)
- ionic oxides have high melting points and conduct electricity when molten
- most oxides can be prepared by direct combination (EXC. SO₃)

\[
\begin{align*}
2\text{Mg}(s) + \text{O}_2(g) & \rightarrow 2\text{MgO}(s) \\
\text{S}(s) + \text{O}_2(g) & \rightarrow \text{SO}_2(g)
\end{align*}
\]

**Na₂O**
*Basic*, hydrolysed by water to form a strongly alkaline solution.
\[
\text{Na}_2\text{O}(s) + \text{H}_2\text{O}(l) \rightarrow 2\text{NaOH}(aq)
\]

**MgO**
Very low solubility due to metal’s greater charge density
*Basic*, reacts with acids to form salts.
\[
\begin{align*}
\text{e.g. } & \text{MgO}(s) + 2\text{HCl}(aq) \rightarrow \text{MgCl}_2(aq) + \text{H}_2\text{O}(l) \\
& \text{MgO}(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{MgSO}_4(aq) + \text{H}_2\text{O}(l)
\end{align*}
\]

**Al₂O₃**
Insoluble in water.
*Amphoteric*, it reacts with acids and alkalis to give salts.
\[
\begin{align*}
\text{with acids } & \text{Al}_2\text{O}_3(s) + 6\text{HCl}(aq) \rightarrow 2\text{AlCl}_3(aq) + 3\text{H}_2\text{O}(l) \\
\text{with alkalis } & \text{Al}_2\text{O}_3(s) + 2\text{NaOH}(aq) + 3\text{H}_2\text{O}(l) \rightarrow 2\text{NaAl(OH)}_4(aq)
\end{align*}
\]

**SiO₂**
Insoluble in water
*Weakly acidic* and reacts with alkalis giving silicates.
\[
\text{SiO}_2(s) + 2\text{NaOH}(aq) \rightarrow \text{Na}_2\text{SiO}_3(aq) + \text{H}_2\text{O}(l)
\]
P₄O₁₀ Dissolves to give an acidic solution.

\[
P₄O₁₀(s) + 6H₂O(l) \rightarrow 4H₃PO₄(aq)
\]

SO₂ / SO₃ Acidic, non-metal oxides
Both very soluble and react with water to give acidic solutions.

\[
\begin{align*}
SO₂(g) + H₂O(l) & \rightarrow 2H^+(aq) + SO₃^{2-}(aq) & \text{weak acid} \\
SO₃(l) + H₂O(l) & \rightarrow 2H^+(aq) + SO₄^{2-}(aq) & \text{strong acid}
\end{align*}
\]

Across the period...
- bonding changes from ionic to covalent
- basic metal oxides change to acidic non-metal oxides
- change from giving alkaline solutions to acidic solutions

Q.1 What are Fajans’ Rules? How can they applied to predict covalency?

Q.2 What is the difference between a weak acid and a strong acid?

Q.3 What shapes have the following ions/molecules; 
  SO₂  \quad SO₃^{2-} 
  SO₃  \quad SO₄^{2-}

Q.4 Write an equation for the reaction between MgO and nitric acid.

Q.5 Explain, in terms of its structure and bonding, why silica has a high melting point.