

9.2 PERIODICITY OF CHEMICAL PROPERTIES OF ELEMENTS IN PERIOD 3

Learning outcomes

Candidates should be able to:

1. describe, and write equations for, the reactions of the elements with oxygen (to give Na_2O , MgO , Al_2O_3 , P_4O_{10} , SO_2), chlorine (to give NaCl , MgCl_2 , AlCl_3 , SiCl_4 , PCl_5) and water (Na and Mg only)
2. state and explain the variation in the oxidation number of the oxides (Na_2O , MgO , Al_2O_3 , P_4O_{10} , SO_2 and SO_3 only) and chlorides (NaCl , MgCl_2 , AlCl_3 , SiCl_4 , PCl_5 only) in terms of their outer shell (valence shell) electrons
3. describe, and write equations for, the reactions, if any, of the oxides Na_2O , MgO , Al_2O_3 , SiO_2 , P_4O_{10} , SO_2 and SO_3 with water including the likely pHs of the solutions obtained
4. describe, explain, and write equations for, the acid / base behaviour of the oxides Na_2O , MgO , Al_2O_3 , P_4O_{10} , SO_2 and SO_3 and the hydroxides NaOH , $\text{Mg}(\text{OH})_2$, $\text{Al}(\text{OH})_3$ including, where relevant, amphoteric behaviour in reactions with acids and bases (sodium hydroxide only)
5. describe, explain, and write equations for, the reactions of the chlorides NaCl , MgCl_2 , AlCl_3 , SiCl_4 , PCl_5 with water including the likely pHs of the solutions obtained
6. explain the variations and trends in 9.2.2, 9.2.3, 9.2.4 and 9.2.5 in terms of bonding and electronegativity
7. suggest the types of chemical bonding present in the chlorides and oxides from observations of their chemical and physical properties

Reaction with oxygen

Write the reactions of the period three elements with oxygen gas. Include the state symbols.
Examine how the oxidation numbers of the elements vary in these oxides.

- **Sodium reacts vigorously** when heated and placed in a gas jar of oxygen. The sodium burns with a **bright yellow flame** to give **white products**.
- **Magnesium reacts vigorously** when heated in oxygen with **bright white flames**.
- Aluminium metal is protected by a layer of aluminium oxide, but **powdered aluminium** does react well with oxygen, with **bright white flames** to give white products.
- **Silicon** reacts **slowly** with oxygen and **burns if heated** strongly
- **Phosphorus reacts vigorously** with oxygen. A **yellow or white flame** is seen, and clouds of **white phosphorus(V) oxide** are produced.
- **Sulfur** powder, once ignited, burns gently with a **blue flame** in a gas jar of oxygen gas. Toxic fumes of **sulfur dioxide** gas are produced.
Further oxidation of sulfur dioxide gives sulfur trioxide. Their systematic names are **sulfur(IV) oxide** and **sulfur(VI) oxide**, respectively.
- **Chlorine does not** react directly with oxygen.

1. Magnesium, Mg, burns in oxygen, O_2 .
The activation energy, E_a , for this reaction is $+148\text{kJmol}^{-1}$.
State *one* observation when magnesium burns in oxygen.
Do *not* refer to temperature changes in your answer.

[1]

2. Gallium is a metal in Group 13 of the Periodic Table.
Gallium and its compounds show similar properties to aluminium and its compounds.
Gallium metal reacts rapidly when exposed to air. A white solid layer is formed on its surface.

Suggest an equation to describe the reaction occurring when gallium metal is exposed to air.

[1]

3. Which element requires the least number of moles of oxygen for the complete combustion of 1 mol of its atoms?

A aluminium

B magnesium

C phosphorus

D sodium

4. A student reacts 0.100 mol of each of sodium, magnesium, and phosphorus atoms separately with an excess of oxygen. Which rows are correct?

	oxide	mass of oxide formed / g
1	sodium	3.10
2	magnesium	4.03
3	phosphorus	7.10

A 1, 2, and 3

B 1 and 2 only

C 1 and 3 only

D 2 and 3 only

Reaction with Chlorine

Write the reactions of the period three elements with chlorine gas. Include the state symbols.

Sodium	Burns with a bright orange flame, giving a white product
Magnesium	Burns with a bright white flame, giving a white product
Aluminium	Burns with a yellow flame, giving a pale-yellow product
Silicon	Reacts when chlorine gas is passed over it to form a colourless liquid
Phosphorus	Burns with a yellow flame to form a mixture of chlorides

➤ SiCl_4 , PCl_5 are liquids. The chlorides of metals are solids.

Calculate and discuss the oxidation number of the period three elements in their oxides and chlorides.

[Reactions of Chlorine and period 3 - YouTube](#)

5. Chlorine is a reactive element. It forms many compounds.

(i) Complete Table 2.1 to show the maximum oxidation number of the elements Na to P in their chlorides. [1]

element	Na	Mg	Al	Si	P
maximum oxidation number					

(ii) State what determines the maximum oxidation number of elements in Period 3. [1]

6. PCl_5 , PCl_3 and NCl_3 are halides of Group 15 elements.

PCl_5 can be formed from the reaction of phosphorus with chlorine. PCl_5 has a melting point of 161°C .

(i) Write an equation for the formation of PCl_5 from the reaction of phosphorus and chlorine.

(ii) State the type of structure and bonding shown by liquid PCl_5 . [1]

7. The chlorides of some of the Period 3 elements are shown in Table 2.1.

Period 3 chloride	NaCl	AlCl_3	SiCl_4	PCl_5	PCl_3	SCl_2
bonding					C	C
structure					S	S

Complete Table 2.1.

- Identify the bonding shown by each chloride under standard conditions.
Use C = covalent, I = ionic, M = metallic.
- Identify the structure shown by each chloride under standard conditions.
Use G = giant, S = simple.

[3]

8. Element X requires strong heating to react with oxygen.
Element X reacts with chlorine to give a covalently-bonded chloride.
What could be the identity of element X?

A magnesium **B** phosphorus **C** sodium **D** silicon

9. Which row describes the structure and bonding of SiO_2 and SiCl_4 ?

	SiCl_4		SiO_2	
	structure	bonding	structure	bonding
A	giant	covalent	giant	covalent
B	giant	covalent	simple	covalent
C	giant	ionic	giant	covalent
D	giant	ionic	simple	covalent

10. In which structure are three atoms bonded together in a straight line?

A poly(ethene), $(\text{CH}_2\text{CH}_2)_n$
B propane, C_3H_8
C silicon tetrachloride, SiCl_4
D sulfur hexafluoride, SF_6

Reaction with water

Write the reactions of sodium and magnesium with water. Include the state symbols.

Sodium reacts vigorously with cold water, melting into a ball of molten metal. It moves across the surface of the water, giving off hydrogen gas. It quickly gets smaller and smaller until it disappears, leaving a strongly alkaline solution (e.g. pH 14) of sodium hydroxide.



By contrast, fresh magnesium reacts extremely slowly with cold water, taking several days to produce a test tube of hydrogen gas. The solution formed is very weakly alkaline (e.g., pH 11), as any magnesium hydroxide formed is only slightly soluble. Therefore, a lower concentration of OH^- (aq) ions enters the solution compared with the result when sodium is added to water. This is because sodium hydroxide is much more soluble in water than magnesium hydroxide.

When heated, magnesium does react vigorously with water in the form of steam to make magnesium oxide and hydrogen gas.

11. Write an equation for the reaction of magnesium with cold water.

[1]

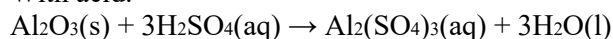
Properties of the Oxides of the period 3 elements

Reaction with water/ acidic or basic nature

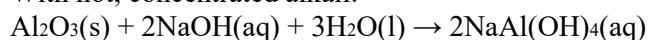
Write the balanced chemical equation for the reaction of sodium and magnesium oxides with water. Include state symbols.

- The **oxides of sodium and magnesium** react with water to **form hydroxides**. The presence of excess aqueous hydroxide ions, OH^- (aq.), makes these **solutions alkaline**.
- Aluminium oxide does not react or dissolve in water, which is why an oxide layer can protect aluminium metal from corrosion. However, it does react and dissolve when added to acidic or alkaline solutions.

With acid:



With hot, concentrated alkali:



When aluminium oxide reacts with an acid, it behaves like a base: it forms a salt (aluminium sulfate in the example with dilute sulfuric acid above) plus water.

When it reacts with an alkali, it behaves like an acid: reacting to form a salt (sodium tetrahydroxoaluminate in the example with sodium hydroxide above).

Compounds that can act as both acids and bases, such as aluminium oxide, are called **amphoteric**.

- Silicon dioxide is also insoluble in water. Water cannot break down its giant molecular structure. However, it will react with and dissolve in hot, concentrated alkali:

$$\text{SiO}_2(\text{s}) + 2\text{NaOH}(\text{aq}) \rightarrow \text{Na}_2\text{SiO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$$
 Silicon dioxide acts as an acid when it reacts with sodium hydroxide, forming a salt (sodium silicate) plus water. It does not react with acids, so it is classed as an acidic oxide.

- Phosphorus (V) oxide reacts vigorously and dissolves in water to form an acidic solution of phosphoric (V) acid (pH = 2):

$$\text{P}_4\text{O}_{10}(\text{s}) + 6 \text{H}_2\text{O}(\text{l}) \rightarrow 4 \text{H}_3\text{PO}_4(\text{aq.})$$
- The oxides of sulfur, SO_2 and SO_3 , both react and dissolve in water, forming acidic solutions (sulfurous or sulfuric (IV) acid and sulfuric (VI) acid) (pH = 1):

The effect of bonding and electronegativity on the structure and acidic / basic nature of 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

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
Electrical conductivity when in liquid state	good	good	good	none	none	none
Chemical bonding	ionic	ionic	ionic (with a degree of covalent character)	covalent	covalent	covalent
Structure	giant ionic	giant ionic	giant ionic	giant covalent	simple molecular	simple molecular

IMPORTANT

As we go across Period 3, the structure of the oxides changes from ionic metal oxides (which are basic oxides) to giant covalent oxides to simple molecular oxides (which are acidic oxides).

acid / base behaviour of the hydroxides NaOH , $\text{Mg}(\text{OH})_2$, $\text{Al}(\text{OH})_3$

12. Write an equation for the reaction of Na_2O with water. [1]

13. Separate samples of sodium and sodium oxide are each added to an excess of cold water.

(i) Write an equation for the reaction of sodium with cold water.

..... [1]

(ii) Write an equation for the reaction of sodium oxide with cold water.

..... [1]

(iii) Complete Table 1.1.

Do not refer to temperature changes when considering observations for these reactions.

[2]

Table 1.1

	sodium	sodium oxide
one similarity in observation on addition to cold water		
one difference in observation on addition to cold water		

14. Al_2O_3 is an amphoteric oxide found in bauxite.

(i) State what is meant by amphoteric.

[1]

(ii) Al_2O_3 is purified from bauxite in several steps. The first step involves heating Al_2O_3 with an excess of $NaOH(aq)$. A colourless solution forms.
Write an equation for this reaction. [1]

15. The reaction of pure aluminium is only observed if the aluminium oxide layer is removed first.
When pure aluminium is added to cold water, bubbles of gas are seen.
(i) State one property of aluminium oxide that explains why an aluminium object does not react with cold water until the aluminium oxide layer is removed. [1]

(ii) Write an equation, with state symbols, for the reaction of aluminium oxide with an excess of $NaOH(aq)$. [2]

(iii) Name one other Period 3 element that also produces bubbles of gas when added to cold water. [1]

16. Aluminium hydroxide is amphoteric.
(i) Explain what is meant by amphoteric. [1]
(ii) Write an equation to describe the reaction that occurs when aluminium hydroxide, $Al(OH)_3$, reacts with $NaOH(aq)$. [1]

17. Unlike the other oxides of Group 2 metals, beryllium oxide is amphoteric.
Beryllium oxide and aluminium oxide have similar chemical properties.
The $Be(OH)_4^{2-}$ anion is a product of the reaction between beryllium oxide and excess concentrated $OH^-(aq)$.
Construct an equation for this reaction. [1]

18. Gallium oxide, Ga_2O_3 , and aluminium oxide react in the same way with $HCl(aq)$ and with $NaOH(aq)$.
(i) Suggest the equation for the reaction between Ga_2O_3 and $HCl(aq)$. [1]
(ii) Suggest an equation for the reaction between gallium oxide and $NaOH(aq)$. [1]

19. Gallium is a metal in Group 13 of the Periodic Table.
Gallium and its compounds show similar properties to aluminium and its compounds.
The table gives the formula of each gallium-containing product formed when gallium oxide reacts separately with hot aqueous hydrochloric acid and hot aqueous sodium hydroxide.

	formula of gallium-containing product
hot aqueous hydrochloric acid	GaCl_3
hot aqueous sodium hydroxide	NaGa(OH)_4

Give the name of the type of behaviour shown by gallium oxide in these reactions.

[1]

20. Indium and aluminium are elements in Group 13 of the Periodic Table.

Indium has very similar chemical properties to aluminium.

- Indium reacts vigorously with hydrochloric acid to form a colourless gas and a salt in solution.
- Indium oxide, In_2O_3 , is amphoteric.
- Gaseous indium bromide has the formula In_2Br_6 . This molecule contains coordinate bonds.

(i) Identify the formula of the salt formed when indium reacts with hydrochloric acid.

[1]

(ii) Construct an equation for the reaction of In_2O_3 with excess aqueous NaOH .

[1]

(iii) Draw a diagram that clearly shows the types of bond present in $\text{In}_2\text{Br}_6(\text{g})$.

[2]

21. Separate samples of aluminium oxide, Al_2O_3 , and phosphorus(V) oxide, P_4O_{10} , react with an excess of $\text{NaOH}(\text{aq})$ at room temperature.

(i) Give the state of Al_2O_3 and P_4O_{10} at room temperature.

Al_2O_3

P_4O_{10}

[1]

(ii) Write an equation for the reaction of each oxide with an excess of $\text{NaOH}(\text{aq})$ at room temperature.

$\text{Al}_2\text{O}_3 + \dots$

$\text{P}_4\text{O}_{10} + \dots$

[2]

22. P_4O_6 is a white solid that has a melting point of 24°C . Solid P_4O_6 reacts with water to form H_3PO_3 . Deduce the type of structure and bonding shown by P_4O_6 . Explain your answer.

[2]

23. CO_2 and SO_2 are acidic gases.

(i) Write an equation for the reaction of SO_2 with H_2O .

[1]

(ii) Write an equation for the reaction of SO_2 with NaOH . [1]

(iii) Construct an equation for the reaction of CO_2 with $\text{Mg}(\text{OH})_2$. [1]

24. Two Period 3 elements react with an excess of oxygen at room pressure.

(i) Complete Table 1.2.

1	2	3
Period 3 element	state of oxide at room temperature and pressure	approximate pH of solution made when oxide is added to water
Na		
S		

(ii) The solutions made in column 3 above table are mixed together. Name the type of reaction that occurs.

(iii) Write an equation to describe the reaction between P_4O_{10} and an excess of water.

25. Some oxides are amphoteric.

(i) Describe what is meant by amphoteric.

..... [1]

(ii) Identify the formula of a Period 3 oxide that is amphoteric.

..... [1]

26. LiAlH_4 cannot be used in aqueous solution because it reacts with water to produce $\text{LiOH}(\text{aq})$, $\text{H}_2(\text{g})$ and a white precipitate, which is soluble in excess sodium hydroxide. Identify the white precipitate. [1]

{Ans : $\text{Al}(\text{OH})_3$ / aluminium hydroxide}

27. Which row is correct?

	element with the greater fifth ionisation energy	element with an amphoteric oxide
A	aluminium	aluminium only
B	aluminium	both aluminium and phosphorus
C	phosphorus	aluminium only
D	phosphorus	both aluminium and phosphorus

28. Element X has the second-largest atomic radius in its period. An atom of X has three occupied electron shells only. The oxide of X is shaken with water. What could be the pH of the resulting solution?

A 5

B 7

C 9

D 14

29. T is an element in Period 3.

The first ionisation energy of T is lower than that of the element with one less proton.

The oxide of T does not react with water.

What is the identity of T?

A aluminium

B silicon

C sodium

D sulfur

30. Two oxides of Period 3 elements are added separately to water. Both react to form colourless solutions. One solution is alkaline, the other is acidic.
What could be the two oxides?

A Al_2O_3 and SiO_2 B Al_2O_3 and P_4O_{10} C Na_2O and P_4O_{10} D Na_2O and SiO_2

31. A mixture of two Period 3 oxides is added to water. A solution forms with a pH of just below 7.
What could be the constituents of the mixture?

A Al_2O_3 and MgO B Na_2O and MgO C Na_2O and P_4O_{10} D SO_3 and P_4O_{10}

32. X and Y are oxides of different Period 3 elements.
If one mole of X is added to water, the solution formed is neutralised by exactly one mole of Y.
What could be the identities of X and Y?

	X	Y
A	P_4O_{10}	Al_2O_3
B	SO_3	Al_2O_3
C	P_4O_{10}	Na_2O
D	SO_3	Na_2O

33. Two Period 3 elements, X and Y, burn separately in oxygen to form solid oxides.
The oxide of X is insoluble in water.
The oxide of Y dissolves in water to form a solution which dissolves the oxide of X.
What could X and Y be?

	X	Y
A	aluminium	sodium
B	magnesium	sodium
C	silicon	phosphorus
D	silicon	sulfur

34. Element X is in Period 3. Element X forms a solid oxide Y.
Y reacts with hot concentrated hydrochloric acid. Y reacts with hot aqueous sodium hydroxide to form a compound in which X is part of an anion.
How many p electrons does one atom of X have in its outer shell?

A 0

B 1

C 2

D 3

35. The elements in Period 3 and their compounds show trends across the period from sodium to chlorine.
Which row is correct?

	electronegativity of the elements	acid / base behaviour of the oxides of the elements
A	decreases	basic → amphoteric → acidic
B	decreases	acidic → amphoteric → basic
C	increases	basic → amphoteric → acidic
D	increases	acidic → amphoteric → basic

36. SiO_2 has a melting point of 1713°C . It reacts with hot $\text{NaOH}(\text{aq})$ to form sodium silicate, Na_2SiO_3 , and water. No reaction occurs when SiO_2 is added to hot $\text{H}_2\text{SO}_4(\text{aq})$. What can be deduced from this information?

	Chemical behaviour of SiO_2	Structure of SiO_2
A	amphoteric	giant
B	amphoteric	simple
C	acidic	giant
D	acidic	simple

37. The table shows the melting points of SiO_2 and P_4O_6 .

oxide	SiO_2	P_4O_6
melting point / K	1883	297

Which statement explains the difference between the melting points of SiO_2 and P_4O_6 ?

- A** The bonding of the oxides changes from ionic to covalent.
B The metallic character of the elements decreases across Period 3.
C The oxidation number of the element increases from Si to P.
D The structure changes from giant molecular to simple molecular.

38. Aluminium, silicon and phosphorus are elements in Period 3 of the Periodic Table. Each element forms an oxide. Which row is correct?

	Al_2O_3	SiO_2	P_4O_{10}
A	basic	amphoteric	acidic
B	giant ionic	giant ionic	simple molecular
C	high melting point	high melting point	low melting point
D	vigorous reaction with water	slight reaction with water	vigorous reaction with water

39. Magnesium, aluminium and silicon are elements in the Periodic Table. Each element forms an oxide. Which row is correct?

	MgO	Al_2O_3	SiO_2
A	basic	amphoteric	amphoteric
B	giant ionic	simple molecular	giant ionic
C	high melting point	high melting point	low melting point
D	slight reaction with water	no reaction with water	no reaction with water

40. Sodium, magnesium and aluminium are three elements in Period 3 of the Periodic Table. Each element forms an oxide. Which row is correct?

	sodium oxide	magnesium oxide	aluminium oxide
A	basic	amphoteric	amphoteric
B	giant ionic	giant ionic	simple molecular
C	high melting point	high melting point	low melting point
D	readily reacts with water	slight reaction with water	no reaction with water

41. Nitrogen reacts with oxygen to form nitrogen monoxide, NO, and nitrogen dioxide, NO₂. Nitrogen dioxide reacts with water and with hydroxide ions.
- $$\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$$
- $$2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$$
- $$2\text{NO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HNO}_2(\text{aq}) + \text{H}^+(\text{aq}) + \text{NO}_3^-(\text{aq})$$
- $$2\text{NO}_2(\text{g}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{NO}_2^-(\text{aq}) + \text{NO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$$
- What can be deduced using only the information from these equations?
- A HNO₂ is a strong acid.
 B HNO₃ is a weak acid.
 C NO₂ is a neutral gas.
 D NO is a reducing agent.
42. Which element, when burned in oxygen, can form an oxide that is a reducing agent?
- A Na B Mg C Al D S
43. X and Y are two elements in Period 3 of the Periodic Table. They combine to form compound Z.
 X forms a soluble acidic oxide. The oxidation number of X in this oxide is +4.
 Y forms an amphoteric oxide.
 What is the formula of compound Z?
- A A/P B Al₂S₃ C Si₂P₅ D SiS₂

Properties of the Chlorides of the period 3 elements

Reaction with water

- Both sodium and magnesium chlorides exist as typical ionic lattices in the solid phase.
 Sodium chloride dissolves in water with no further reaction, giving a solution of pH 7.0.
- Magnesium chloride also dissolves in water to give an almost neutral solution (pH between 6.5 and 7.0)
 The reason that concentrated solutions of MgCl₂ can be very slightly acidic is that the charge density of the hydrated Mg²⁺(aq) ion is large enough to polarise some adjacent water molecules, resulting in slight **hydrolysis**.

$$[\text{Mg}(\text{H}_2\text{O})_6]^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow [\text{Mg}(\text{H}_2\text{O})_5(\text{OH})]^+(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$$
- Because it only has a single positive charge, the charge density on the hydrated Na⁺(aq) ion, [Na(H₂O)₆]⁺, is not large enough for hydrolysis to occur.

Anhydrous aluminium chloride is covalent: AlCl₃(g) at high temperatures, Al₂Cl₆(g) at lower temperatures and a covalent layer lattice (AlCl₃)_n(s) in the solid phase at low temperatures.

- When added to water it reacts **exothermically** to form a weakly acidic solution containing ions.

$$\text{AlCl}_3(\text{s}) + 6\text{H}_2\text{O} \rightarrow [\text{Al}(\text{H}_2\text{O})_6]^{3+}(\text{aq}) + 3\text{Cl}^-(\text{aq})$$
 The triply-charged hydrated aluminium ion has quite a large charge density, and so hydrolysis is much more significant than with the hydrated magnesium ion. The resulting **pH is between 3 and 4**.

$$[\text{Al}(\text{H}_2\text{O})_6]^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{aq}) \rightarrow [\text{Al}(\text{H}_2\text{O})_5(\text{OH})]^{2+}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$$
- If a small amount of water is dripped onto anhydrous AlCl₃(s), a reaction similar to those between water and SiCl₄ or PCl₅ occurs: **steamy fumes** of HCl(g) are evolved and **a white solid** is left.

$$2\text{AlCl}_3(\text{s}) + 3\text{H}_2\text{O}(\text{l}) \rightarrow \text{Al}_2\text{O}_3(\text{s}) + 6\text{HCl}(\text{g})$$

Adding water to pure liquid SiCl_4 produces an insoluble white solid and steamy fume of HCl(g) .



The silicon dioxide formed will be more or less hydrated, as $\text{SiO}_2 \cdot n\text{H}_2\text{O}$, depending on temperature and concentration. Since the HCl(g) is produced quantitatively, some will dissolve in water to give a strongly acidic solution (pH between 0 and 2).

Phosphorus pentachloride reacts with water in a similar way, producing steamy fumes of HCl(g) . This time, however, a clear solution is formed, containing phosphoric and hydrochloric acids (pH between 0 and 2)



Formula of chloride	NaCl	MgCl ₂	Al ₂ Cl ₆	SiCl ₄	PCl ₅	SCl ₂
Chemical bonding	ionic	ionic	covalent	covalent	covalent	covalent
Structure	giant ionic	giant ionic	simple molecular	simple molecular	simple molecular	simple molecular
Observations when added to water	white solids dissolve to form colourless solutions		chlorides react with water, giving off white fumes of hydrogen chloride gas			
pH of solution formed with water	7	6.5	3	2	2	2

As we go across Period 3, the structures of the chlorides change from ionic metal chlorides (which are neutral) to metallic chlorides (which can be hydrolysed by water to form acids as one of the products) to simple molecular chlorides (which form acids when added to water).

44. Chlorine is a very reactive element.

Chlorine reacts with silicon to form silicon(IV) chloride.

Describe the appearance of silicon(IV) chloride at room temperature and pressure. State its structure and bonding.

appearance

structure and bonding..... [2]

45. Write equations for the reactions of NaCl and PCl₅ with water.

Include state symbols in both equations. [3]

46. An excess of cold water is added to the chloride of silicon.

(i) Write an equation for the reaction between an excess of cold water and the chloride of silicon. [1]

(ii) Suggest the pH of the solution produced in (i). [1]

47. An excess of cold water is added to the chloride of phosphorus.

(i) Write an equation for the reaction between an excess of cold water and the chloride of phosphorus. [1]

(ii) Suggest the pH of the solution produced in (i). [1]

48. PCl₅, PCl₃ and NCl₃ are halides of Group 15 elements.

A small amount of PCl₅ is added to excess water. The PCl₅ reacts vigorously to form a colourless solution.

(i) Give **one** other observation you would make when PCl_5 reacts with excess water. [1]

(ii) Write the equation for the reaction of PCl_5 with excess water. [1]

(iii) Estimate the pH of the resulting solution. [1]

49. Aluminium chloride and phosphorus chloride are both white solids.

(i) Write an equation for the reaction of solid phosphorus chloride and excess water. [1]

(ii) Name the type of reaction that occurs when aluminium chloride is added to water. [1]

(iii) Explain why the solution produced after aluminium chloride is added to water has a pH of 1–2. [1]

50. PCl_5 reacts with J to form H_3PO_4 .
Identify J and state the type of reaction.

J type of reaction[2]

51. Sulfur chloride, SCl_2 , is a liquid at room temperature. When SCl_2 is added to water, misty fumes are seen, and a solution is made that turns universal indicator red.

(i) Identify the type of reaction that occurs when SCl_2 is added to water. [1]

(ii) Name a chloride of a different Period 3 element that is also a liquid at room temperature and produces misty fumes when added to water. [1]

52. Complete Table 2.1 with information for sodium chloride and phosphorus (V) chloride. [3]

	sodium chloride	phosphorus(V) chloride
state at room temperature		
name of change which occurs on addition of water		
pH of final solution		

53. Chlorine, Cl_2 , reacts with many elements & compounds to form chlorides.

The table below shows information about some chlorides of Period 3 elements.

	Na	Mg	Si
formula of chloride			
structure of chloride	giant		
bonding of chloride			covalent
pH of the solution formed on addition of chloride to water		6.2	

Complete the above table.

[3]

54. Some of the common chlorides of Period 3 elements are shown in the list.

NaCl MgCl_2 AlCl_3 SiCl_4 PCl_5

From this list, identify:

(i) all the chlorides that have giant ionic structures in the solid state.

[1]

(ii) all the chlorides that react vigorously with water to form strongly acidic solutions.

[1]

(iii) the chloride that dissolves in water to form a neutral solution.

[1]

55. (i) Magnesium nitride reacts with an excess of water to produce ammonia and magnesium hydroxide only.

Construct an equation to describe this reaction.

[1]

(ii) Explain why the solution produced in the reaction in (i) has a pH greater than 7. Refer to the products of the reaction in your answer.

[2]

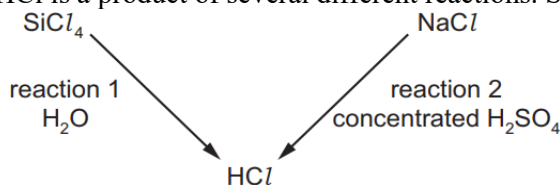
56. SCl_2 is a cherry-red liquid that reacts vigorously with water to form an acidic solution.

Use this information to deduce the bonding and structure shown by SCl_2 .

Explain your answer.

[2]

57. HCl is a product of several different reactions. Some of these are shown in the following figure.



(i) Write an equation for reaction 1. [1]

(ii) In reaction 2, NaCl reacts with concentrated H₂SO₄ to form HCl and NaHSO₄.
When NaBr reacts with concentrated H₂SO₄, the products include Br₂ and SO₂.
Identify the type(s) of reaction that occur in each case by completing Table 3.1.
Explain the difference in these reactions. [3]

reactants	type(s) of reaction
NaCl and concentrated H ₂ SO ₄	
NaBr and concentrated H ₂ SO ₄	

58. Samples of magnesium chloride and phosphorus(V) chloride are added to separate beakers of cold water.
Complete the following table. Ignore temperature changes when considering observations for these reactions. [4]

	magnesium chloride	phosphorus(V) chloride
appearance at room temperature		
one similarity in observation on addition to cold water		
one difference in observation on addition to cold water		
pH of final solution		

59. Bismuth reacts with chlorine to form BiCl₃.
BiCl₃ is a solid at room temperature. It melts when heated gently.
BiCl₃ reacts vigorously with water at room temperature to form an acidic solution.
Suggest the type of bonding and structure shown by BiCl₃. Explain your answer. [2]

60. Tellurium is an element in Group 16. The most common isotope of tellurium is ¹³⁰Te. Its electronic configuration is [Kr] 4d¹⁰ 5s² 5p⁴.
TeF_x reacts with water to form tellurium hydroxide and HF. The oxidation number of tellurium does not change during this reaction.

(i) Construct an equation for the reaction of TeF_x with water. [1]

(ii) Name the type of reaction that occurs when TeF_x reacts with water. [1]

61. 0.020mol of element Z reacts with excess Cl₂ to form 0.020mol of a liquid chloride.
The liquid chloride has formula ZCl_n, where n is an integer.

ZCln reacts vigorously with water at room temperature to give an acidic solution and a white solid. When excess $\text{AgNO}_3(\text{aq})$ is added to the solution, 11.54g of $\text{AgCl}(\text{s})$ forms.

(i) Suggest the type of bonding and structure shown by **ZCln**. [1]

(ii) Calculate the value of **n** in **ZCln**. [2]

62. Separate samples of **R**, **S**, **T** and **U** are added to cold water. The identity of each sample is unknown. However, each sample is known to be pure and can only be one of $\text{Ba}(\text{OH})_2$, NaCl , P_4O_{10} or SiCl_4 .

(i) Use the observations in the table to identify each sample as one of $\text{Ba}(\text{OH})_2$, NaCl , P_4O_{10} and SiCl_4 . Write your answers in the table.

	state at room temperature	observations on addition of sample to water	identity of sample
R	solid	alkaline, colourless solution is produced, some white solid remains	
S	solid	white solid disappears, solution is neutral	
T	liquid	misty fumes produced, white solid is made in vigorous reaction	
U	solid	acidic, colourless solution produced in vigorous reaction	

[4]

(ii) Identify the formula of the white solid made when sample **T** reacts with water. [1]

(iii) Name the solution formed when sample **U** reacts with water. [1]

63. Separate samples of phosphorus(V) chloride and silicon(IV) chloride are each added to an excess of cold water.

(i) Write an equation for each reaction.

.....

..... [2]

(ii) Describe the appearance of phosphorus(V) chloride and silicon(IV) chloride at room temperature.

phosphorus(V) chloride

silicon(IV) chloride [2]

(iii) Compare the appearance of the mixtures produced when each reaction is complete.

.....

..... [2]

64. The electrical conductivities of two compounds, Y and Z, are shown.

	for Y	for Z
conductivity of the compound in the liquid state	good	does not conduct
conductivity of the mixture obtained by adding the compound to water	good	good

What are compounds Y and Z?

	Y	Z
A	Al_2O_3	$SiCl_4$
B	$NaCl$	Al_2O_3
C	$NaCl$	$SiCl_4$
D	$SiCl_4$	Al_2O_3

65. Which observations are made when a sample of silicon chloride, $SiCl_4$, is added to a beaker of water?

- A** No visible change is observed.
- B** Steamy fumes and a precipitate are both observed.
- C** The appearance of a precipitate is the only observation.
- D** The appearance of steamy fumes is the only observation.

66. Which statement correctly describes what happens when silicon tetrachloride is added to water?

- A** The $SiCl_4$ dissolves to give a neutral solution only.
- B** The $SiCl_4$ reacts to give an acidic solution only.
- C** The $SiCl_4$ reacts to give a precipitate and an acidic solution.
- D** The $SiCl_4$ reacts to give a precipitate and a neutral solution.

67. A sample of $SiCl_4$ is added to cold water.

Which statement describes the mixture formed at the end of the reaction?

- A** acidic solution with no precipitate
- B** acidic solution with white precipitate
- C** neutral solution with no precipitate
- D** neutral solution with white precipitate

68. Each of the chlorides listed is added to water.

- 1 aluminium chloride
- 2 magnesium chloride
- 3 silicon tetrachloride
- 4 phosphorus pentachloride

Which chlorides form an aqueous solution that reacts with sodium carbonate to produce carbon dioxide?

- A** 1 and 2 only **B** 3 and 4 only **C** 1, 3 and 4 only **D** 1, 2, 3 and 4

69. L and M are elements in Period 3 of the Periodic Table.

- The oxide of L is a solid at room temperature. This oxide has a giant structure.
- The chloride of L does not react with water.
- Argon is the only element in Period 3 with a lower melting point than M.

Which formula represents a compound of elements L and M?

- A** Al_2S_3 **B** MgS **C** $NaCl$ **D** PCl_5

70. The elements magnesium and phosphorus are reacted separately with an excess of oxygen to form their oxides. Each oxide is then added separately to water and the pH values of the resulting solutions are measured. The same two elements are reacted separately with an excess of chlorine to form their chlorides. Each chloride is then added separately to water and the pH values of the resulting solutions are measured. Which row is correct?

	chloride giving the higher pH	oxide giving the higher pH
A	magnesium	magnesium
B	magnesium	phosphorus
C	phosphorus	magnesium
D	phosphorus	phosphorus

71. Separate 1.0 g samples of Na_2O , MgO , Al_2O_3 , SiO_2 , NaCl , MgCl_2 , Al_2Cl_6 and SiCl_4 are added to separate beakers containing water and stirred. The number of beakers containing a white solid is Q. An excess of NaOH(aq) is then added to each beaker and stirred. The number of beakers now containing a white solid is R. Which row is correct?

	Q	R
A	3	2
B	3	3
C	4	3
D	4	4

72. Which statement for the element in Period 3 and Group 13 of the Periodic Table is correct?

- A** It has the highest melting point of the elements in its period.
B It has exactly one electron in its shell with principal quantum number 3.
C It forms an oxide that reacts with aqueous sodium hydroxide.
D It forms a chloride that dissolves in water to give a neutral solution.

73. Silicon is heated in an excess of chlorine, producing compound J. An excess of water is added to the sample of J produced. Which row is correct?

	structure of J	Is HCl produced when water is added to J?
A	giant molecular	no
B	giant molecular	yes
C	simple molecular	no
D	simple molecular	yes

74. Sodium, magnesium, aluminium, silicon and phosphorus are all elements in Period 3 of the Periodic Table. Three statements about the oxides and chlorides of these elements are given.

- 1 The ionically bonded oxides all react with dilute hydrochloric acid.
 2 All metal chlorides produce neutral solutions when added to water.
 3 The two most electronegative elements both form covalently bonded chlorides.

Which statements are correct?

A 1, 2 and 3

B 1 and 2 only

C 1 and 3 only

D 2 and 3 only

75. In reactions 1 and 2, X represents an element in Period 3.
In each reaction, X is forming a product where X is in its highest oxidation state.

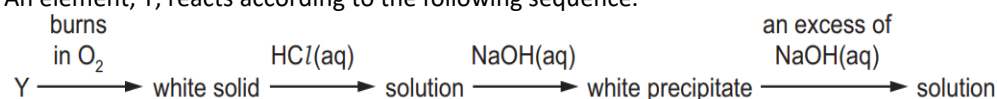
reaction 1: chlorine + element X $\rightarrow$ X_yCl_z

reaction 2: oxygen + element X $\rightarrow$ X_pO_q

Which ratios show a steady increase from sodium to phosphorus?

- A** neither $z : y$ nor $q : p$
B $z : y$ only
C $q : p$ only
D both $z : y$ and $q : p$

76. An element, Y, reacts according to the following sequence.



What could be element Y?

A Na

B Mg

C Al

D P

77. $NH_3(aq)$ is added to separate samples of $NaCl(aq)$, $MgCl_2(aq)$, $BaCl_2(aq)$ and $SiCl_4(l)$. Under the conditions of this experiment, only two samples will produce a white precipitate when $NH_3(aq)$ is added.
What are these two samples?

- A** $MgCl_2(aq)$ and $BaCl_2(aq)$
B $MgCl_2(aq)$ and $SiCl_4(l)$
C $NaCl(aq)$ and $BaCl_2(aq)$
D $NaCl(aq)$ and $SiCl_4(l)$

78. A student investigated the chloride of a Period 3 element. This is what the student wrote down as a record.
The compound was a white crystalline solid. It dissolved easily in water to give a solution of pH 12. When placed in a test-tube and heated in a roaring Bunsen flame, the compound melted after several minutes heating.
What can be deduced from this record?

- A** At least one of the recorded observations is incorrect.
B The compound was magnesium chloride, $MgCl_2$.
C The compound was phosphorus pentachloride, PCl_5 .
D The compound was sodium chloride, $NaCl$.

79. Elements Y and Z are both in Period 3 of the Periodic Table.
When the chloride of element Y is added to water, it reacts and a solution of pH 2 is produced.
When the chloride of element Z is added to water, it dissolves and a solution of pH 7 is produced.
Which statement explains these observations?

- A** Both chlorides hydrolyse in water.
B Element Y is magnesium and element Z is sodium.
C Element Y is phosphorus and element Z is aluminium.
D Element Y is silicon and element Z is sodium.

80. Four mixtures are added to four separate 50cm³ samples of water and stirred.
Which mixture results in a solution with the highest pH?
- A** 1.0 g of aluminium oxide and 1.0 g of aluminium chloride
B 1.0 g of magnesium oxide and 1.0 g of magnesium chloride
C 1.0 g of phosphorus oxide and 1.0 g of phosphorus chloride
D 1.0 g of silicon dioxide and 1.0 g of silicon chloride
81. Which statement about aluminium chloride is correct?
- A** Aluminium chloride has a much higher melting point than magnesium chloride due to the small size of the aluminium ion.
B Anhydrous aluminium chloride reacts vigorously with water to form a solution with a pH greater than 7.
C Each Al₂Cl₆ molecule found in aluminium chloride vapour contains two coordinate bonds.
D The bonding between aluminium and chlorine is strongly ionic due to the large difference in electronegativity.
82. Which statement is correct?
- A** Aluminium chloride has a giant ionic lattice of Al³⁺ and Cl⁻ ions.
B Sodium chloride dissolves in water, forming hydrogen chloride and sodium hydroxide.
C The strong covalent bonds in silicon chloride prevent it from reacting with water.
D When phosphorus(V) chloride is added to water, the resulting solution conducts electricity.
83. Sodium is added to water to form solution Y. The pH of solution Y is measured.
When powdered substance X is added to solution Y, the pH falls.
Which two compounds could each be substance X?
- A** MgCl₂ and Al(OH)₃
B MgCl₂ and K₂O
C NaCl and Al(OH)₃
D NaCl and K₂O
84. X and Y are two elements from Period 3 of the Periodic Table.
Element X has a higher electrical conductivity than element Y. Element Y has a higher melting point than element X.
Which formula is a compound formed from element X and element Y?
- A** MgS **B** Mg₂Si **C** NaCl **D** SiCl₄
85. Which statement is correct?
- A** Adding sodium oxide to water gives a lower pH solution than adding silicon oxide to water.
B The oxidation state of sodium in its chloride is higher than the oxidation state of silicon in its chloride.
C The atomic radius of sodium is larger than that of silicon.
D The melting point of the chloride of sodium is lower than the melting point of the chloride of silicon.
86. Element X is in Period 3. It reacts rapidly with water to form an alkaline solution.
Which statement about the chloride of element X is correct?
- A** It conducts electricity when molten.
B It has a melting point of less than 100 °C.
C It has covalent bonding.
D It reacts rapidly with cold water.