Chemistry of period 3 elements

This chapter compares the Chemistry of the elements in period 3 of the periodic table. Each element in a period provides representative Chemistry of the group into which it exists.

The elements of period 3 are Na, Mg, Al, Si, P, S, Cl and Ar.

Electronic structure

For each of these elements the total number of electrons in the outer most shells is equal to the group number in which it belongs (table 6.1).

Table 1 The electron configurations of period 3 elements

Elements	Na	Mg	Al	Si	P	S	Cl	Ar
valence configuration	$3s^1$	$3s^2$	$3s^23p^1$	$3s^23p^2$	$3s^23p^3$	$3s^23p^4$	$3s^23p^5$	$3s^23p^6$

Physical properties

Sodium, magnesium and aluminium are metals whose melting points increase in that order due to increase in the number of electrons contributed to form metallic bonds. Silicon, phosphorus, sulphur, chlorine and argon are nonmetals. Silicon, phosphorus and sulphur are solids while chlorine and argon are gases at room temperature.

Reactions of the elements

a) Reaction with water

Reactivity with water decreases across the period because there is a decrease in electropositivity of these elements across the period.

i) Sodium reacts vigorously with cold water to form sodium hydroxide and hydrogen gas.

$$2Na\ (s) + 2H_2O\ (l) \longrightarrow 2NaOH\ (aq) + H_2\ (g)$$

ii) Magnesium does not react with cold water but reacts with steam to form magnesium oxide and hydrogen gas.

$Mg\ (s) + 2H_2O\ (g) \rightarrow MgO\ (aq) + H_2\ (g)$

iii) Aluminium reacts with steam very slowly to form aluminium hydroxide and hydrogen gas.

$2Al\ (s) + 6H_2O\ (l) \longrightarrow 2Al(OH)_3\ (s) + 3H_2\ (g)$

iv) Silicon, phosphorus, sulphur and argon have no reaction with water.

v) Chlorine reacts with water to form chloric (I) acid and hydrochloric acid.
$Cl_2\ (g) + H_2O\ (l) \rightarrow HOCl\ (aq) + HCl\ (aq)$

b. Reaction with NaOH

i) Sodium and magnesium have no reaction with sodium hydroxide because they are metals and magnesium falls below sodium in the reactivity series.

ii) Aluminium reacts with aqueous NaOH to produce hydrogen and a complex salt -sodium aluminate.
$2Al\ (s) + 2NaOH\ (aq) + 6H_2O\ (l) \rightarrow 2NaAl(OH)_4\ (aq) + 3H_2\ (g)$

This is because aluminium is amphoteric, i.e., possesses both acidic and basic properties.

ii) Chlorine reacts to form sodium chlorate (I), sodium chloride and water.

$Cl_2\ (g) + 2NaOH\ (aq) \longrightarrow NaOCl\ (aq) + NaCl\ (aq) + H_2O\ (l)$

Sodium hypochlorate (I) is used as a bleaching and antiseptic agent such as in Jik (fig. 6.1)

iii) Phosphorus reacts with hot concentrated NaOH to produce phosphine

$P_4\ (s) + 3OH^-\ (aq) + 3H_2O\ (l) \longrightarrow PH_3\ (g) + 3H_2PO_2^-\ (aq)$

iv) Na, Mg, Si, S have no reaction with sodium hydroxide.

Fig.6.1 Sodium chlorate (I) is used in Jik, a household detergent

c. Reaction with HCl.

Reactivity decreases across the period due to decrease in metallic properties.

i) Na, Mg, Al react to form H_2 and metal salts.

$2Na\ (s) + 2HCl\ (aq) \longrightarrow 2NaCl\ (aq) + H_2\ (g)$
$Mg\ (s) + 2HCl\ (aq) \longrightarrow MgCl_2\ (aq) + H_2\ (g)$
$2Al\ (s) + 6HCl\ (aq) \longrightarrow 2AlCl_3\ (aq) + 3H_2\ (g)$

ii) Si, P, S, Cl have no reaction with hydrochloric acid.

d) Oxides

They are formed by reacting the elements with oxygen and the formulae of oxides are given in table 6.2.

Table 2 The oxides of period 3 elements

LEMENTS	Na	Mg	Al	Si	P	S	Cl
OXIDES	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl_2O_7
PRINCIPAL BONDING	Ionic	Ionic	Ionic-covalent	Covalent	Covalent	Covalent	Covalent
CHARACTER	Basic	Basic	Amphoteric	Acidic	Acidic	Acidic	Acidic
MP\$^0$C	1193	3075	2300	1728	563	30	-91

Trial 1

(a) Complete the table below ($4\frac{1}{2}$marks)

Element	Formulae of oxides	Type of bonding in oxide	Structures of oxides
Al			
Si			
P			

(b) Write an equation for the reaction between the oxide of aluminium and sodium hydroxide (1½)

a. Physical properties of oxides of period 3 elements

i) Across the period there is a gradual change in character of oxides from strongly basic to strongly acidic. Al_2O_3 is amphoteric oxide, i.e., possesses both basic and acidic properties.

ii) - Na_2O, MgO and Al_2O_3 have high melting points due to the strength of ionic bonding.
- The melting point of magnesium is higher than that of Na_2O because MgO, stronger electrostatic forces since Mg^{2+} has 2 positive charge, secondary, it has higher molecular mass.
- The melting point of Al_2O_3 is lower than that of MgO because Al_2O_3 has bigger covalent character due to high polarizing power of Al^{3+} ions.
- SiO_2, although covalent, has a high melting point because the crystal of SiO_2 is a giant structure in which silicon and oxygen atoms are bonded together by strong single covalent bonds.
- P_2O_5 (white solid) consists of P_4O_{10} molecules; these contain electric dipoles due to electron displacements in their bonds and are quite strongly attracted to each other. This is why its melting point is high compared with that of P_4O_{10} which consists of simple SO_3 molecules.

Cl_2O_7 has a low melting point because the molecules are held together by the weak van der Waals forces.

b. Reaction

I) Reaction of oxides of period 3 elements with water.

- Na_2O and MgO react with water to form hydroxides.

  $Na_2O\ (s) + H_2O\ (l) \longrightarrow 2NaOH\ (aq)$

  $MgO(s) + H_2O\ (l) \longrightarrow Mg(OH)_2\ (aq)$
- Al_2O_3 and SiO_2 have no reaction with water because they are insoluble oxides.
- P_2O_5, SO_3, Cl_2O_7 are acid anhydrides, i.e., react with water to form phosphoric, sulpuric and perchloric acids respectively.

  $P_2O_5\ (s) + 3H_2O\ (l) \longrightarrow 2H_3PO_4\ (aq)$

  $SO_3\ (s) + H_2O\ (l) \longrightarrow H_2SO_4\ (aq)$

  $Cl_2O_7\ (g) + H_2O\ (l) \longrightarrow 2HClO4\ (aq)$

II) Reaction of period 3 oxides with NaOH.

- Na_2O, MgO are basic, therefore, have no reaction with water.
- Al_2O_3 being amphoteric reacts with dilute NaOH to produce sodium aluminate and water.

  $Al_2O_3\ (g) + 2NaOH\ (aq) \longrightarrow 2NaAlO_2\ (aq) + H_2O\ (l)$
- SiO_2 reacts to form sodium silicate and water.

  $SiO_2\ (s) + 2NaOH\ (aq) \longrightarrow Na_2SiO_3\ (aq) + H_2O\ (l)$
- P_2O_5, SO_3 and Cl_2O_7 react to form salts and water

  $SO_3\ (g) + 2NaOH\ (aq) \longrightarrow Na_2SO_4\ (aq) + H_2O\ (l)$

  $P_2O_5\ (s) + 2NaOH\ (aq) \longrightarrow 2NaPO_3\ (aq) + H_2O\ (l)$

  $Cl_2O_7\ (g) + 2NaOH\ (aq) \longrightarrow 2NaClO_4\ (aq) + H_2O\ (l)$

Trial 2

Write ionic equations for the reactions between sodium hydroxide and (1½ mark each)

(a) Silicon (IV) oxide.
(b) Lead (II) oxide.
(c) Aluminium oxide.

e. Chlorides of period 3 elements

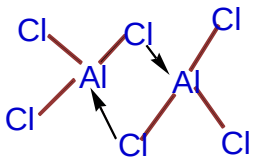
These are formed by reacting the elements with chlorine gas and the physical properties of their chlorides are shown in table 3.

Table 3 The chlorides of period 3 elements

ELEMENTS	Na	Mg	Al	Si	P	S	Cl
CHLORIDES	NaCl	$MgCl_2$	$AlCl_3$	$SiCl_4$	PCl_5	S_2Cl_2	Cl_2
BONDING	Ionic	Ionic	Covalent	Covalent	Covalent	Covalent	Covalent
STATES	Solid	Solid	Solid	Liquid	Solid	Liquid	Gas
MP\$^0$C	808	714	192	-68	160	-76	

I. Physical properties of period 3 chlorides.

NaCl and $MgCl_2$ have high melting points due to the strength of the ionic bonding. $AlCl_3$ has a fairly high melting point because in the solid state, it consists of Al_2Cl_6 molecules and not simple $AlCl_3$. These molecules are produced through dative bonding between Al and Cl in the Al_2Cl_6 molecules.



$SiCl_4$ and S_2Cl_2 are liquids and consist of respective simple $SiCl_4$ and S_2Cl_2 molecules and in the solid state the molecules are held by weak van der Waals force which explains their very low melting points. PCl_5 a pale yellow solid has a fairly high melting point because the solid undergoes partial ionisation.

$2PCl_5 \quad \leftrightarrow \quad PCl_4^+ + PCl_6^-$

Trial 3

Explain the following observations:

(a) Sodium chloride melts at 800^0C whereas aluminium chloride sublimes at 180^0C. (3marks)

II Reactions of chlorides

i) Reaction with water.

NaCl and $MgCl_2$ have no reaction with water but simply dissociate into ions.

$NaCl\ (s) + (aq) \rightarrow Na^+\ (aq) + Cl^-\ (aq)$

$MgCl_2\ (s) + (aq) \rightarrow Mg^{2+}\ (aq) + 2Cl^-\ (aq)$

ii) $AlCl_3$, $SiCl_4$, PCl_5, Cl_2 are hydrolyzed by water. However, the extent of the hydrolysis of these chlorides varies across the period.

$AlCl_3$ is slightly hydrolyzed liberating HCl and $Al(OH)_3$.

$AlCl_3\ (s) + 3H_2O\ (l) \rightarrow Al(OH)_3(s) + 3HCl\ (aq)$

However, when aluminium chloride is added to water, it reacts exothermically to give hydrated aluminium ions, $[Al(H_2O)_6]^{3+}$ and chloride ions, Cl^-. The energy needed to break the Al-Cl covalent bond is derived from the high enthalpy of hydration of small highly charged Al^{3+} ions.

$Al_2Cl_6\ (s) + 12\ H_2O\ (l) \rightarrow 2[Al(H_2O)_6]^{3+}(Cl^-)_3\ (aq)$

covalent ionic

Hydrated aluminium chloride is readily soluble in water yielding

$[Al(H_2O)_6]^{3+}\ (aq) + 3Cl^-\ (aq)$ ions

$SiCl_4$, PCl_5, and S_2Cl_2 are completely hydrolyzed liberating hydrogen chloride.

$PCl_5\ (s) + 4H_2O\ (l) \rightarrow 5HCl\ (aq) + H_3PO_4\ (aq)$ [phosphoric acid]

$SiCl_4\ (l) + 3H_2O\ (l) \rightarrow 4HCl\ (aq) + H_2SiO_3\ (aq)$ [silicic (IV) acid]

$2S_2Cl_2 + 3H_2O\ (l) \rightarrow 4HCl\ (aq) + H_2SO_3\ (aq) + 3S\ (s)$

Hydrogen chloride under moist conditions appears as white fumes. For this reason, $SiCl_4$, PCl_5, S_2Cl_2 fume in moist air since their hydrolysis leads to formation of HCl.

Trial 4

The melting points of the chlorides of some elements are given in table 6.4 below.

Table 6.4 Melting points of chlorides

chlorides	*$MgCl_2$*	*$FeCl_3$*	*PCl_5*
Mp/^0C	*712*	*282*	*-112*
Type bonding			

(a) State the type of bonding that exists in each of the chlorides in the table above. *(1 ½ marks)*

(b) State what would be observed and write an equation for the reaction that takes place when water is added to each of the chlorides in the table above. *(2½ marks each)*

f, The hydrides of period 3 elements.

The hydrides formed by period 3 elements are NaH, MgH_2, AlH_3, SiH_4, PH_3, H_2S, HCl. These hydrides are formed by action of hydrogen on the elements.

Table 5 The properties of period 3 hydrides

ELEMENTS	NaH	MgH_2	AlH_3	SiH_4	PH_3	H_2S	HCl
BONDING	Ionic	Ionic	Ionic	Covalent	Covalent	Covalent	Covalent
MP\$^0$C	804	-	-	-	-134	-86	-144
Bpt.\0C	1413				-88	-60	-85

NaH and MgH_2 have high melting and boiling points due to the strength of ionic bonds. H_2S and HCl have relatively higher melting and boiling points than SiH_4 and PH_3 because their molecules are polar molecules and are held together by hydrogen bonds whereas the molecules of SiH_4 and PH_3 are non-polar and therefore, held together by the weak van der Waals forces.

Reactions

i) Reaction of hydrides of period 3 elements with water.

Due to the high polarity of the bonds in the hydrides NaH and MgH_2, they react with water readily producing hydrogen and the metal hydroxides.

$NaH\ (s) + H_2O\ (l) \longrightarrow NaOH\ (aq) + H_2\ (g)$

$MgH_2\ (s) + 2H_2O\ (l) \longrightarrow Mg(OH)_2\ (aq) + 2H_2\ (g)$

AlH_3, SiH_4, and PH_3 have no reaction with water due to lack of polarity in their bonds.

H_2S and HCl dissociate in water producing acids.

$H_2S\ (g) + 2H_2O\ (l) \rightleftharpoons H_3O^+\ (aq) + HS^-\ (aq) + H_2O\ (l) \rightleftharpoons 2H_3O^+\ (aq) + S^{2-}\ (aq)$

$HCl\ (g) + H_2O\ (l) \longrightarrow H_3O^+\ (aq) + Cl^-\ (aq)$

ii) Reactions of hydrides of period 3 elements with hydroxides (NaOH)

HCl and H_2S react with hydroxides to form salts.

$HCl\ (g) + OH^-\ (aq) \longrightarrow Cl^-\ (aq) + H_2O\ (l)$

$H_2S\ (g) + OH^-\ (aq) \longrightarrow HS^-\ (aq) + H_2O\ (l)$

then $HS^-\ (aq) + OH^-\ (aq) \longrightarrow S^{2-}\ (aq) + H_2O\ (l)$

iii) Reaction with HCl.

NaH and MgH_2 react to form hydrogen and metal salts.

$NaH\ (s) + HCl\ (aq) \longrightarrow NaCl\ (aq) + H_2\ (g)$

$MgH_2\ (s) + 2HCl\ (aq) \longrightarrow MgCl_2 + 2H_2\ (g)$

Trial 5

The elements contained in the third short period of the periodic table, given in alphabetic order are; aluminium, argon, chlorine, magnesium, phosphorus, silicon, sodium and sulphur.

(a) In the table below, write the formulae of the hydrides formed by the elements listed. State the oxidation states (or valences) of the elements in these hydrides and classify the bonding in the hydroxides as ionic or covalent. (6marks)

Elements	Formula of hydride	Oxidation(or valence) of the elements in these hydrides	Type of bonding
Aluminium			
Chlorine			
Magnesium			
Phosporus			
Silcon			

(b) The hydrides formed by sodium and sulphur were separately shaken with water.
Write the equations to show the reactions that took place, if any with; (3marks)

(i) sodium hydride.

(ii) Sulphur hydride. (3marks)

Trial 6

(a) Describe how sodium hydroxide can be prepared on industrial scale (Your answer should include equations for the relevant reaction)

(b) Write equation and state the conditions under which sodium hydroxide can react with

(i) Aluminium

(ii) Phosphorous

(iii) Chlorine

Trial 7

The atomic number and melting points of oxides of elements of period III of The Periodic Table are shown in the table below

Element	Na	Mg	Al	Si	P	S	Cl
Atomic number	11	12	13	14	15	16	17
Oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl_2O_7
Melting point of oxide	1275	2327	2007	1607	560	30	-91

(a) (i) Plot a graph of melting point of oxide against atomic number. (04marks)
(ii) Explain the shape of the graph you have drawn in (a)(i) above

(b) Write equation to show the reaction between
(i) Water and P_2O_5 (1 ½ marks)
(ii) Sodium hydroxide and
- Al_2O_3 (2 ½ marks)
- SiO_2 (2 ½ marks)
- SO_3 (1 ½ marks)

(iii) Hydrochloric acid and Al2O3 (1 ½ marks)

Trial 7

(a) Write an equation for the reaction between and the hydride of
(i) Sodium
(ii) Silcon
(iii) Sulphur

(b) Write an equation for the reaction between sodium hydroxide solution
(i) Aluminium oxide
(ii) Phosphorus pentoxide
(iii) Sulphur dioxide