

# Raffles Institution Year 5 H2 Chemistry 2022 Lecture Notes 12 – The Periodic Table I

#### Content

- Periodicity of atomic and physical properties of the elements: variation with proton number across the third period (sodium to chlorine) of:
  - (i) electronic configuration
  - (ii) atomic radius and ionic radius
  - (iii) ionisation energy
  - (iv) electronegativity
  - (v) melting point
  - (vi) electrical conductivity
  - Periodicity of chemical properties of the elements in the third period:
  - (i) variation in oxidation number and bonding of the oxides (sodium to sulfur only) and of the chlorides (sodium to phosphorus only)
  - (ii) reactions of these oxides and chlorides with water
  - (iii) acid/base behaviour of these oxides and the corresponding hydroxides

#### Learning Outcomes

Trends and variations in atomic and physical properties

For elements in the third period (sodium to chlorine), candidates should be able to:

- (a) recognise variation in the electronic configurations across a Period
- (b) describe and explain qualitatively the trends and variations in atomic radius, ionic radius, first ionisation energy and electronegativity:
  - (i) across a Period in terms of shielding and nuclear charge
- (c) interpret the variation in melting point and in electrical conductivity across a Period in terms of structure and bonding in the elements (metallic, giant molecular, or simple molecular)

# Trends and variations in chemical properties

For elements in the third period (section to chlorine) candidates should be able to:

- (d) (i) state and explain the variation in the highest oxidation number of the elements in oxides (for Na<sub>2</sub>O; MgO; Al<sub>2</sub>O<sub>3</sub>; SiO<sub>2</sub>; F<sub>4</sub>O<sub>10</sub>; SO<sub>3</sub>) and chlorides (for NaC*l*; MgC*l*<sub>2</sub>; AlC*l*<sub>3</sub>; SiC*l*<sub>4</sub>; PC*l*<sub>5</sub>)
  - (ii) state and explain the variation in bonding in oxides and chlorides in terms of electronegativity (with the exception of A/Cl<sub>3</sub>)
  - (iii) describe the reactions of the oxides with water (for 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>3</sub>)
  - (iv) describe and explain the acid/base behaviour of oxides (for 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>3</sub>) and hydroxides (for NaOH; Mg(OH)<sub>2</sub>; A/(OH)<sub>3</sub>), including, where relevant, amphoteric behaviour in reaction with sodium hydroxide (only) and acids
  - (v) describe and explain the reactions of the chlorides with water (for NaCl; MgCl2; AlCl3; SiCl4; PCl5)
  - (vi) suggest the types of structure and bonding present in the oxides and chlorides from observations of their chemical and physical properties

In addition, candidates should be able to:

- (e) predict the characteristic properties of an element in a given Group by using knowledge of chemical periodicity
- (f) deduce the nature, possible position in the Periodic Table, and identity of unknown elements from given information of physical and chemical properties

Le	cture Outline	Re	ferences
1 2	The Periodic Table Trends and variations in atomic and physical	1	Chemistry for advanced level (by Peter Cann and Peter Hughes)
3	properties Trends and variations in chemical properties	2	Chemistry in Context (by Hill and Holman)
5		3	Chemistry: The Molecular Nature of Matter and Change (by Martin S. Silberberg)
		4	Website: http://www.chemguide.co.uk

# 1 THE PERIODIC TABLE

The **Periodic Table** is the arrangement of the elements in increasing order of proton number such that elements with similar physical and chemical properties are grouped together.

- Horizontal rows in the Periodic Table are called periods.
  - Elements in the same period have the same number of electronic shells.
- Vertical columns are called groups.
  - Elements in the same group have the same outer electron configuration.

**Periodicity** refers to the recurrence of similar properties at regular intervals when elements are arranged in increasing atomic number.



The elements are further grouped into four blocks.

- (i) **s-block** (electronic configuration of valence shell: *ns*<sup>1</sup>, *ns*<sup>2</sup>)
  - consists of metallic elements from <u>Group 1</u> (alkali metals) and <u>Group 2</u> (alkaline earth metals) and the non-metal, <u>hydrogen</u>
  - the metals of Group 1 and Group 2 have lower densities, melting points and boiling points than other metals
  - the metals are reactive, i.e. high in the electrochemical series
  - the metals form stable, non-volatile ionic compounds with non-metals
- (ii) **p-block** (electronic configuration of valence shell:  $ns^2np^1$  to  $ns^2np^6$ )
  - electronic configuration of helium is 1s<sup>2</sup>
  - consists of elements from Group 13 to Group 18
  - generally have low densities, melting points and boiling points (with exceptions, e.g. diamond)
  - generally form ionic compounds with metals and molecular compounds (which may be macromolecules or simple molecules) with other non-metals
  - noble gases are generally chemically inert
- (iii) **d-block** (electronic configuration, e.g.  $[Ar]3d^{1}4s^{2}$  to  $[Ar]3d^{10}4s^{2}$ )
  - includes transition metals
  - higher densities, melting points and boiling points than s-block metals
  - less reactive than s–block metals
  - marked similarities across a period, e.g. form coloured complexes
- (iv) f-block
  - lanthanoids and actinoids
    - starts from the sixth period

# 2 TRENDS AND VARIATIONS IN ATOMIC AND PHYSICAL PROPERTIES OF ELEMENTS

# 2.1 Variations in atomic properties





# 2.2 Variations in physical properties



# 3 TRENDS AND VARIATIONS IN CHEMICAL PROPERTIES

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Element	Reaction with dry oxygen and heat	Reaction with dry chlorine and heat	Reaction with water
	$4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$ white	$2Na(s) + C_{2}(g) \rightarrow 2NaC_{1}(s)$	$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$
Na	very vigorous reaction	very vigorous reaction	<ul> <li>very vigorous reaction with <u>cold water</u></li> <li>H<sub>2</sub>(g) evolved</li> </ul>
	$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$	$Mg(s) + Cl_2(g) \rightarrow MgCl_2(s)$	$Mg(s) + 2H_2O(I) \rightarrow Mg(OH)_2(s) + H_2(g)$
Mg	very vigorous reaction	<u>vigorous</u> reaction	very slow reaction with <u>cold water</u>
			$Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)$
			<u>vigorous</u> reaction with <u>steam</u>
	$4AI(s) + 3O_2(g) \rightarrow 2AI_2O_3(s)$	$2AI(s) + 3CI_2(g) \rightarrow 2AICI_3(s)$	No reaction with cold water
	<u>vigorous reaction initially</u>	<u>vigorous</u> reaction	$2AI(s) + 3H_2O(g) \rightarrow AI_2O_3(s) + 3H_2(g)$
AI	(oxide layer formed soon prevents further reaction)	<ul> <li>Often done by passing dry Cl<sub>2</sub> over Al foil heated in a long tube</li> </ul>	<ul> <li><u>vigorous</u> reaction with <u>steam</u> initially</li> </ul>
	,	<ul> <li>A very pale yellow A/C/<sub>3</sub> is formed which sublimes</li> </ul>	
		and collects further down the tube where it is cooler.	
Si	$Si(s) + O_2(g) \rightarrow SiO_2(s)$	$Si(s) + 2Cl_2(g) \rightarrow SiCl_4(l)$	No reaction with water
	slow reaction	<u>slow</u> reaction	
	$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s)$	$P_4(s) \ + \ 10Cl_2(g) \ \rightarrow \ 4PCl_5(s)$	No reaction with water
P	<u>vigorous</u> reaction	<u>vigorous</u> reaction	
	$S(s) + O_2(g) \rightarrow SO_2(g)$ $2SO_2(g) + O_2(g) \rightarrow 2SO_2(g)$	Not in syllabus	No reaction with water
s	<ul> <li><u>slow</u> reaction</li> <li>SO<sub>2</sub> formed can be</li> </ul>		
	further oxidised to form SO <sub>3</sub> under controlled		
	condition (i.e. presence of catalyst)		
	No reaction with oxygen		$C_{2}(g) + H_{2}O(l) \rightleftharpoons HOC(aq) + HC(aq)$
			Disproportionation reaction
C/			Acidic solution formed     HC/: strong acid & HOC/: weak acid
			(In the presence of sunlight, HOCI slowly
			decomposes to form hydrochloric acid and oxygen: $2HOCI \longrightarrow 2HCI + O_2$

# 3.1 Reactions of elements in the third period with oxygen, chlorine and water

# 3.2 Variation in highest oxidation number and type of bonding in oxides and chlorides formed by elements in the third period

• The maximum attainable oxidation numbers are periodic.

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- Oxidation numbers exhibited by the element correspond to
  - the number of valence electrons <u>gained</u> or <u>lost</u> by an atom of the element to achieve an electronic configuration of ns<sup>2</sup>np<sup>6</sup> in the formation of ionic compounds OR
  - (ii) the number of electrons <u>shared</u> by an atom of the element in the formation of covalent bonds.

Element	Na	Mg	Al	Si	Р	S
Oxide of highest oxidation state	Na₂O	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO2	P4O10	SO₃
Maximum oxidation number	+1	+2	+3	+4	+5	+6 ·
No. of valence electrons	1	2	3	4	5	6
Chloride formed	NaCl	MgCl <sub>2</sub>	AlCl <sub>3</sub>	SiCl <sub>4</sub>	PCl <sub>5</sub>	
Maximum oxidation number	+1	+2	+3	+4	+5	Not in syllabus
No. of valence electrons	1	2	3	4	5	

- Moving (from left to right) across the <u>third period</u>, the oxidation number of each element in its respective oxide and chloride is always a <u>positive integer because</u> <u>both oxygen and</u> <u>chlorine are more electronegative</u> than each of them.
- The <u>maximum</u> attainable oxidation number of each element corresponds to the number of valence electron(s) in each atom of the element, i.e. <u>all the valence electrons can be used for bonding</u>.

This is because Period 3 elements have <u>unoccupied</u>, <u>low–lying 3d orbitals</u> which can be used for bonding through the expansion of the octet structure.



E.g. in the formation of  $PCI_5$ ,  $P_4O_{10}$  and  $SO_3$ .

# 3.3 Electronegativity difference and nature of bonding

- In general,
  - (i) a large difference in electronegativity gives rise to an ionic bond.
  - (ii) small or no difference in electronegativity gives rise to a covalent bond.
- Across the period, both the oxides and chlorides formed by the Period 3 elements become less ionic and more covalent due to the decreasing difference in electronegativity values between oxygen / chlorine and the element

# 3.4 Oxides formed by elements in the third period and their properties

# 3.4.1 Physical properties of oxides

Oxide	Na <sub>2</sub> O	MgO	A/2O3	SiO <sub>2</sub>	P <sub>4</sub> O <sub>10</sub>	SO <sub>3</sub>
Melting point / °C	1132	2830	^2054	1710	422	17
Physical state at r.t.p.		solid			liquid	
Electrical conductivity (in molten state)	(due to preser can act a	Good nce of free-movi s mobile charge	ng ions which carriers)	(a		
Structure		lonic		Giant molecular Simple molecular		
Type of bonding / intermolecular forces	Strong ionic attraction betw	bonds / electrostatic force of ween oppositely charged ions		Strong covalent bonds between Si and O atoms	Is Relatively weaker instantaneous dipole–in dipole interactions between molecule Strength of id–id interactions ∝ no. of electrons / size of electron clo	

Note: Possible reasons to explain the deviation from expected trend for melting points of ionic oxides (i.e. melting point did not increase from Na<sub>2</sub>O to A/<sub>2</sub>O<sub>3</sub>):

(i) difference in their packing in the solid state and

(ii) slight covalent character of A/2O3 due to the high charge density and hance high polarising power of A/3+.



# 3.4.2 Reactions of oxides with water

Oxide	Na <sub>2</sub> O	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	P4O10	SO3
Structure		Ionic	<b>A</b>	Giant molecular	Simple n	nolecular
Effect of Adding Oxide into Water	solid dissolves	slightly soluble	inse	oluble	reacts readily with acidic s	h water to form an solution
pH of resultant mixture	13 – 14	9 - 10	(i.e. the pH o	7 f water at 25 °C)	:	2
Explanation	<ul> <li>Na<sub>2</sub>O(s) + H<sub>2</sub>O(<i>l</i>) → 2N</li> <li>react vigorously with <u>alkaline solution</u>.</li> <li>MgO(s) + H<sub>2</sub>O(<i>l</i>) ≓ Mg</li> <li>do not react so readil</li> <li>MgO is only <u>slightly s</u> lattice energy is highl break the ionic lattice</li> </ul>	NaOH(aq) water to form a <u>strongly</u> $(OH)_2(s) \Rightarrow Mg(OH)_2(aq)$ y with water. <u>oluble</u> in water because its y negative (difficult to )	<ul> <li>Al<sub>2</sub>O<sub>3</sub> <u>does not</u> Energy needed to lattice is more the on hydrating the</li> <li>SiO<sub>2</sub> <u>does not</u> A large amount to break the strong the giant molect</li> </ul>	ot dissolve in water. to break down the ionic an the energy released ions. t dissolve in water. of energy needed to Si–O covalent bonds in alar structure.	<ul> <li>P<sub>4</sub>O<sub>10</sub>(s) + 6H<sub>2</sub>O(<i>l</i>)</li> <li>H<sub>3</sub>PO<sub>4</sub> is a weal</li> <li>Note: Oxidation in unchanged, i.e. +5 in SO<sub>3</sub>(g) + H<sub>2</sub>O(<i>l</i>) -</li> <li>This reaction is An acidic mist is</li> <li>Note: Oxidation in unchanged, i.e. +6</li> </ul>	) → $4H_3PO_4(aq)$ phosphoric(V) acid k acid number of P remains in both P4O <sub>10</sub> and H <sub>3</sub> PO <sub>4</sub> . → H <sub>2</sub> SO <sub>4</sub> (aq) sulfuric(VI) acid highly exothermic. s formed number of S remains in both SO <sub>3</sub> and H <sub>2</sub> SO <sub>4</sub> .

Note: For the ionic oxides to react with water, they must first be able to dissolve. The oxide ion released is a very strong Bronsted–Lowry base and will accept a H<sup>+</sup> from water:  $O^{2-} + H_2O \rightarrow 2OH^-$ 

For the covalent oxides, the highly electronegative O atom causes the other element (e.g. S) to be highly electron deficient. It is hence susceptible to a nucleophilic attack by water molecules, resulting in the formation of oxo-acids.







# 3.4.3 Acid-base nature of oxides (and hydroxides)

Oxide (Hydroxide)	Structure	Acid-base nature	Explanation		
Na <sub>2</sub> O			<u>For oxide</u> : Na <sub>2</sub> O(s) + 2HC <i>l</i> (aq) $\rightarrow$ 2NaC <i>l</i> (aq) + H <sub>2</sub> O( <i>l</i> )		
(NaOH)	lonic	Basic	<u>For hydroxide</u> : NaOH(aq) + HC <i>l</i> (aq) $\rightarrow$ NaC <i>l</i> (aq) + H <sub>2</sub> O( <i>l</i> )		
MgO	lonio	Dasie	<u>For oxide</u> : MgO(s) + 2HC <i>l</i> (aq) $\rightarrow$ MgC <i>l</i> <sub>2</sub> (aq) + H <sub>2</sub> O( <i>l</i> )		
( Mg(OH) <sub>2</sub> )			<u>For hydroxide:</u> Mg(OH) <sub>2</sub> (s) + 2HC <i>l</i> (aq) $\rightarrow$ MgC <i>l</i> <sub>2</sub> (aq) + 2H <sub>2</sub> O( <i>l</i> )		
	lonic (with some covalent character)	Amphoteric	For oxide:With acid: $Al_2O_3(s)$ + $6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2O(l)$		
410			With NaOH: $A_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \rightarrow 2Na^+[A_1(OH)_4]^-(aq)$		
( A/2O <sub>3</sub> ( A/(OH) <sub>3</sub> )			For hydroxide:		
			With acid: $A/(OH)_3(s) + 3HC/(aq) \rightarrow A/CI_3(aq) + 3H_2O(l)$ (acting as Brønsted base)		
			With NaOH: $A/(OH)_3(s) + NaOH(aq) \rightarrow Na^+[A/(OH)_4]^-(aq)$ (acting as Lewis acid)		
SiO <sub>2</sub>	Giant molecular	A - 1 - 11 -	$\begin{array}{rl} SiO_2(s) \ + \ 2NaOH \rightarrow \ Na_2SiO_3(aq) \ + \ H_2O(l) \\ & (conc.) \end{array}$		
P <sub>4</sub> O <sub>10</sub>	Simple molecular	Acidic	$P_4O_{10}(s) + 12NaOH(aq) \rightarrow 4Na_3PO_4(aq) + 6H_2O(l)$		
SO <sub>3</sub>			$SO_3(g) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$		

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#### 3.5 Chlorides formed by elements in the third period and their properties

#### 3.5.1 Physical properties of chlorides

Chloride	NaC/	MgCl <sub>2</sub>	*A/C/3	SiCl <sub>4</sub>	PCI <sub>5</sub>
Boiling point / °C	1465	^1418	178 (sublimes)	58	167
Physical state at r.t.p.		Solid		Liquid	Solid
Electrical conductivity (in molten state)	Go (due to presence of free) act as mobile o	ood —moving ions which can charge carriers)	Nil (absence of mobile charge carriers)		
Structure	Ionic		Simple Molecular		
Type of bonding / intermolecular forces	Strong ionic bonds / attraction between of	electrostatic force of epositely charged ions	Relatively weaker in:	r instantaneous dipole-induced dipole interactions between molecules	

Note: A possible reason to explain the unexpected boiling point of MgCl<sub>2</sub> is the slight covalent character of MgC/2 due to the high charge density and hence high polarising power of Mg2+.





solid state crystal structure



dimer (liquid and gas phases)



(high temperature gas phase)



# 3.5.2 Reactions of chlorides with water

				NaC/ MgC/2 A/C/3 SiC/4 PC/5
Chloride	Structure	Effect of Adding Chloride into Water	pH of resultant mixture	Explanation
NaC/	lonic	dissolves readily	7	Hydration: NaCl(s) + aq $\rightarrow$ Na <sup>+</sup> (aq) + Cl <sup>-</sup> (aq)
MgCI <sub>2</sub>	lonic (with some covalent character)	dissolves readily with <u>slight</u> hydrolysis	6.5	$\begin{array}{rll} \mbox{Hydration:} & \mbox{MgC}l_2(s) + 6H_2O(l) \rightarrow [\mbox{Mg}(H_2O)_6]^{2*}(aq) + 2Cl^{-}(aq) \\ & \mbox{aqua complex} \\ \mbox{``Hydrolysis:} & [\mbox{Mg}(H_2O)_6]^{2*}(aq) \rightleftharpoons [\mbox{Mg}(H_2O)_5(OH)]^{*}(aq) + H^{*}(aq) \\ & \mbox{OR} & [\mbox{Mg}(H_2O)_6]^{2*}(aq) + H_2O(l) \rightleftharpoons [\mbox{Mg}(H_2O)_5(OH)]^{*}(aq) + H_3O^{*}(aq) \\ \end{array}$
A/Cl <sub>3</sub>	Simple molecular	dissolves readily with <u>appreciable</u> hydrolysis	3	Hydration: $A/Cl_3(s) + 6H_2O(l) \rightarrow [Al(H_2O)_6]^{3*}(aq) + 3Cl^{-}(aq)$ aqua complex#Hydrolysis: $[Al(H_2O)_6]^{3*}(aq) \rightleftharpoons [Al(H_2O)_5(OH)]^{2*}(aq) + H^*(aq)$ $OR [Al(H_2O)_6]^{3*}(aq) + H_2O(l) \rightleftharpoons [Al(H_2O)_5(OH)]^{2*}(aq) + H_3O^*(aq)$ With a few drops of water: (i.e. limited amount of water) $A/Cl_3(s) + 3H_2O(l) \rightarrow Al(OH)_3(s) + 3HCl(g)$ white fumes
SiC/4 PC/5	Simple molecular	<sup>@</sup> Hydrolyses to produce white fumes of HC <i>I</i> (g) which dissolves in excess water to give HC <i>I</i> (aq)	2	With limited amount of water: $SiCl_4(l) + 2H_2O(l) \rightarrow SiO_2(s) + 4HC/(g)$ white fumes When excess water is added: $SiCl_4(l) + 2H_2O(l) \rightarrow SiO_2(s) + 4HCl(aq)$ When <u>excess</u> water is added <b>AND</b> water is <u>not cold</u> : $PCl_5(s) + 4H_2O(l) \rightarrow H_3PO_4(aq) + 5HCl(aq)$ With limited amount of water (i.e. $PCl_5: H_2O = 1:1$ ) or when the water is cold: $PCl_5(s) + H_2O(l) \rightarrow POCl_3(l) + 2HCl(g)$ white fumes When <u>more</u> water is added: $POCl_3(l) + 3H_2O(l) \rightarrow H_3PO_4(aq) + 3HCl(aq)$

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# refer to page 13; @ refer to page 13

"Note: When a salt is dissolved in water, the cations are naturally hydrated by the water molecules due to the formation of ion-dipole interactions.

E.g.: NaCl(s) + aq 
$$\rightarrow$$
 Na<sup>+</sup>(aq) + Cl<sup>-</sup>(aq)



As a result, water molecules coordinate to the cation via the lone pair of electrons on the oxygen.

Cations with <u>high charge density</u> and hence <u>high polarising power</u> are able to <u>distort</u> <u>the electron cloud of the water molecules</u>, <u>weakening the O–H bond</u>. As a result, the O–H bond undergoes <u>heterolytic fission</u> readily to release  $H^+$ .



The stronger the <u>polarising power</u> of the cation, the greater the <u>extent of hydrolysis</u>, i.e. more  $H_3O^+$  will be formed / pH of soluton will be lower.

<sup>®</sup>Note: For covalent chlorides, during hydrolysis, the central atom needs to accept the lone pair of electrons from water.

Observation: SiCl<sub>4</sub> can undergo hydrolysis. CCl<sub>4</sub> cannot undergo hydrolysis.

SiCl<sub>4</sub> can undergo hydrolysis when added to water due to the following reasons:

- (i) As silicon atom is larger in size than carbon atom, there is less steric hindrance around the Si atom for the water molecule (nucleophile) to attack;
- (ii) Si has <u>empty</u>, <u>low-lying 3d orbitals to accept the lone pair of electrons from water</u> as its valence shell corresponds to principal quantum number, n = 3.



CCl<sub>4</sub> is unable to undergo hydrolysis when added to water due to the following reasons:

- (i) The electron deficient carbon atom is attached to <u>four large chlorine atoms which</u> <u>hinder the approach of the H<sub>2</sub>O nucleophile</u>.
- (ii) Unlike silicon, carbon has <u>no low-lying empty orbitals to accept the lone pair of electrons from water</u>, since carbon's valence shell corresponds to principal quantum number, n = 2, which has only 4 orbitals (sp<sup>3</sup> hybrid orbitals), all of which are fully filled.

[More reading on Chemguide: http://www.chemguideforcie.co.uk/section93/learningc.html]



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#### Self-check Questions

#### MCQs

#### 1 [RVHS 2014/1/14]

The ionic radii of  $P^{3-}$ ,  $S^{2-}$  and  $Cl^{-}$  are 0.212 nm, 0.184 nm and 0.181 nm respectively.

Which of the following statements correctly explains the decrease in radius from  $P^{3-}$  to  $Cl^{-}$ ?

- A an increase in the nuclear charge and a constant total number of electrons
- B an increase in the nuclear charge and total number of electrons
- C an increase in total number of electrons while nuclear charge remains constant
- D a decrease in nuclear charge while total number of electrons remains constant

#### 2 [N2013/I/13]

For the elements in the third period of the Periodic Table, which property decreases consistently from sodium to chlorine?

A Electrical conductivity B lonisation energy C Melting point D Radius of the atom

#### 3 [TJC 2014/I/14]

When 0.10 mol of chloride of Period 3 element A is reacted with limited amount of water, white fumes are observed. Upon dissolving the white fumes in water, the resultant solution is found to react with 0.20 mol of aqueous sodium hydroxide.

To which Group of the Periodic Table does A belong?

A 2 B 13 C 14 D 15

#### 4 [ACJC 2014/I/39]

The elements **X**, **Y** and **Z** belong to the same period of the Periodic Table.

The oxide of X reacts with both strong acids and strong alkalis. The oxide of Y will give an aqueous of pH < 7 and the oxide of Z gives an aqueous solution of pH > 7.

Which statement(s) about elements X, Y and Z is/are correct?

- 1 The electronegativity of the elements decreases in the order Y, X, Z.
- 2 **X**, **Y** and **Z** could be aluminium, phosphorus and sodium respectively.
- 3 The ionic radius decreases in the order Y, X, Z.

2 and 3 only

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

- 5 Explain the following phenomena using concept of bonding and structure, writing equations where applicable.
  - (a) Magnesium chloride is a solid with a high melting point while silicon tetrachloride is a volatile liquid.
  - (b) Magnesium oxide is insoluble in water whereas barium oxide dissolves to give an alkaline solution. An aqueous solution of sulfur trioxide is acidic

# 6 [N2006/III/4]

Sodium, silicon and phosphorus form the oxides  $Na_2O$ ,  $SiO_2$  and  $P_4O_{10}$ .

- (a) Explain why the oxides of sodium and silicon have these formulae. [2]
- (b) Describe the action of water on the oxides of sodium and phosphorus, write equations for any reactions that occur, and suggest the pH of each solution formed. [3]

# 7 [Modified N2004/III/5]

The melting points of the chlorides of the elements from sodium to silicon are given below.

Sodium Chloride	Magnesium Chloride	Aluminium Chloride	Silicon Chloride
801 °C	701 °C	178 °C	−70 °C

(a)	State	the formula of each of these chlorides.	[2]
(b)	State	the type of chemical bonding in each of these chlorides.	[2]
(c)	Desc where	ribe the reaction, if any, of each of these chlorides with water. Write equate appropriate.	ations [4]
(d)	Sulfu	r and chlorine react together to give a compound containing 31% S.	
	(i)	Calculate its empirical formula.	[1]
	(ii)	Predict the shape of its molecule, assuming its molecular formula is the sar its empirical formula. Explain your answer.	me as [1]
	(iii)	Predict the pH of its solution in water. Explain your answer.	[1]

# Practice Questions

# 8 [RI 2017 CT1/I/3]

Use of the Data Booklet is relevant to this question.

Which of the following shows the correct trend when the first ionisation energies of the elements Na, Mg, Al, Si and P are plotted against their electrical conductivities?



#### 9 [RI 2018/I/9]

Elements J, K and L are elements in Period 3 of the Periodic Table. The melting point of element J is higher than that of element K. Only the oxide of element L is insoluble in water.

Which row in the table gives the correct identities of elements J, K and L?

	J	К	L
Α	CI	Р	Mg
в	Na	Mg	Si
с	Р	S	Al
D	S	Р	Si

#### 10 [SAJC 2014/I/16]

The properties of the oxides of four Period 3 elements W, X, Y and Z are given below.

- The oxide of **W** is insoluble in water and in dilute acid but soluble in concentrated sodium hydroxide.
- The oxide of X is amphoteric.
- The oxide of Y reacts with dilute potassium hydroxide at room temperature.
- The oxide of Z dissolves in water to form a solution of pH = 13.

Which of the following is correct in order of increasing atomic number?

A	Z, X, W, Y	С	Z,	W, X,	Y
В	W, X, Y, Z	D	Z,	Y, W,	X

# 11 [N2008/III/4(a)–(d)]

When dry chlorine is passed over heated aluminium foil in a hard glass tube, a vapour is produced which condenses to a yellow-white solid in the cooler parts of the tube. At low temperatures, the vapour has the empirical formula  $A/Cl_3$ , and a  $M_r$  of 267.

(a) Suggest the molecular formula of the vapour, and draw a dot-and-cross diagram to describe its bonding. [2]

The yellow-white solid reacts with water in two different ways.

- When a few drops of water are added to the solid, steamy white fumes are evolved and a white solid remains, which is insoluble in water.
- When a large amount of water is added to the solid, a colourless weakly acidic solution results.
- (b) Write equations, including state symbols, for these reactions and explain the observations. [4]
- (c) Describe and explain what you would see when a sample of Na<sub>2</sub>O(s) is added to a solution of litmus in water. Write an equation for the reaction that occurs. [2] (Note: In neutral solution, litmus solution is purple.)
- (d) When magnesium is burned in air, a mixture of the ionic solids magnesium oxide and magnesium nitride, Mg<sub>3</sub>N<sub>2</sub>, is formed. Adding water to Mg<sub>3</sub>N<sub>2</sub> produces an alkaline gas and a white insoluble solid.
  - (i) Use a dot-and-cross diagram to describe the bonding in  $Mg_3N_2$ . [2]
  - (ii) Suggest an equation for the reaction between Mg<sub>3</sub>N<sub>2</sub> and water, and use it to calculate the mass of white insoluble solid that would be formed from 2.0 g of Mg<sub>3</sub>N<sub>2</sub>.

# 12 [Modified RVHS 2018/II/1(b)]

The chlorides of the elements in the third period behave in different ways when added to water, depending on their structure and bonding.

L is a chloride of an element in Period 3. A student investigated L and the results are as given below.

- L is a white crystalline solid with a melting point of 987 K.
- L dissolves in water to form a weakly acidic solution.
- Addition of NaOH(aq) to an aqueous solution of L produces a white precipitate, M.
- (a) Identify L and M.
- (b) With the aid of one equation, explain how the weakly acidic solution is formed.

# 13 [N11/II/4(b) & (c)]

Among the elements of Group 14, those towards the top, carbon to germanium, have very different properties from those at the bottom, tin and lead.

For example, the melting points show a marked change after germanium.

element	С	Si	Ge	Sn	Pb
mp/°C	>3550	1410	937	232	327

(a) Carbon, silicon, germanium each form a solid with the same type of structure.

- (i) What type of structure is present in solid carbon, silicon and germanium? [1]
- Suggest why the melting points of these elements decrease from carbon to germanium. [2]

Carbon and silicon each form a tetrachloride. CCl<sub>4</sub> has no reaction with water; SiCl<sub>4</sub> reacts violently with water.

- (b) (i) Write a balanced equation for the reaction SiCl<sub>4</sub> with water. [1]
  - (ii) Use the Data Booklet to obtain values for the C–Cl and Si–Cl bond energies.
  - (iii) Suggest an explanation for the inertness of CCl<sub>4</sub> to water. [1]

[1]

#### 14 [Modified RI 2011/III/4(b)]

The oxides, MgO,  $A_2O_3$  and SiO<sub>2</sub>, are all used as refractory materials due to their high melting points. If a sample of one of the oxides was provided as a white powder, describe the reactions you could carry out on the powder to determine which of the three oxides it was. Write balanced equations for the reactions involved, where applicable. [6]