Cambridge AS & A Level

CHEMISTRY

Paper 2

Topical Past Paper Questions

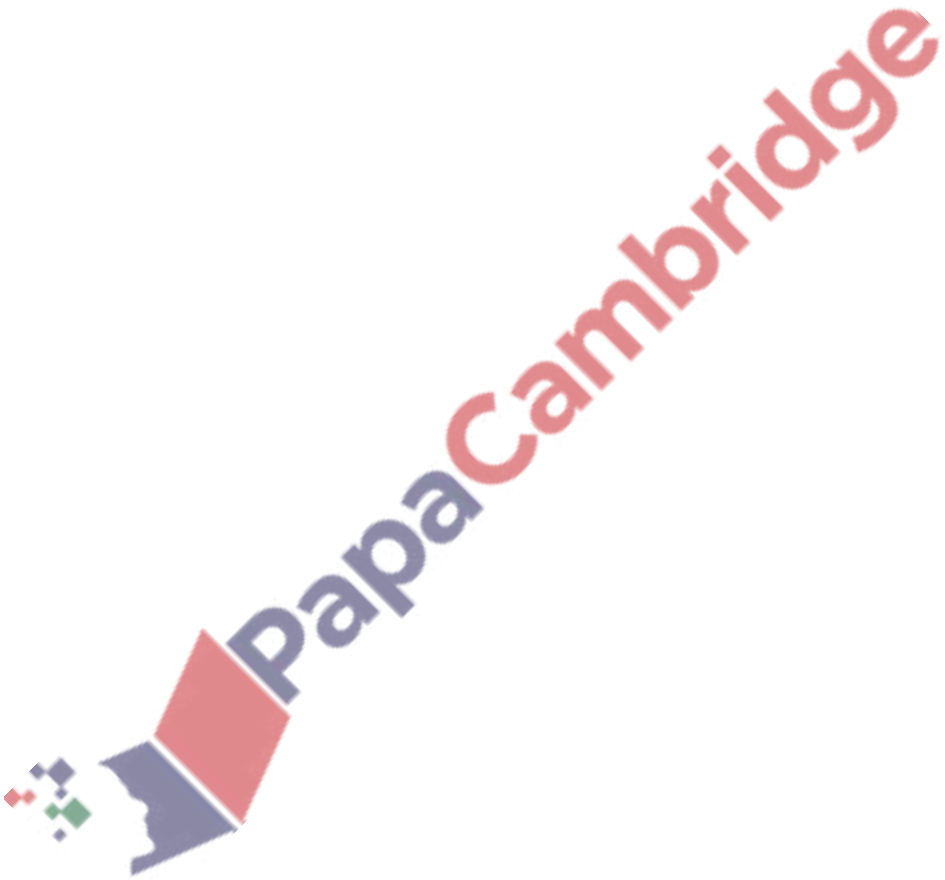
+ Answer Scheme

2015 - 2021

PapaCambridge

Chapter 9

The Periodic Table: chemical periodicity



9.1 Periodicity of physical properties of the elements in Period 3

36. 9701_s19_qp_21 Q: 2

Magnesium silicide, Mg_2Si, is a compound made by heating magnesium with sand.

(a) Draw a 'dot-and-cross' diagram to show the arrangement of outer electrons present in a formula unit of Mg_2Si. Assume magnesium silicide is an ionic compound.

[2]

(b) When solid Mg_2Si is added to water, silane gas, SiH_4, and a solution of magnesium hydroxide are produced.

Construct the equation for this reaction. Include state symbols.

..... [2]

(c) Suggest, with reference to structure and bonding, why SiH_4 is a gas at room temperature.

.....

.....

..... [2]

(d) The table shows the electronegativity values of carbon, hydrogen and silicon.

element	carbon	hydrogen	silicon
electronegativity	2.5	2.1	1.8

(i) C–H and Si–H bonds have weak dipoles.

Use the electronegativity values in the table to show the polarity of the C–H and Si–H bonds.

C—H Si—H

[2]

(ii) Explain why methane, CH_4, has no overall dipole moment.

.....

.....

..... [2]

(e) SiH_4 reacts in air without heating but CH_4 must be ignited before combustion occurs.

$$SiH_4 + 2O_2 \rightarrow SiO_2 + 2H_2O$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Suggest, with reference to bond energies from the *Data Booklet*, why SiH_4 reacts in air without heating but CH_4 must be ignited.

.....

.....

..... [2]

(f) Silicon dioxide reacts with hot, concentrated sodium hydroxide.

(i) Identify the **two** products formed during this reaction.

.....

..... [2]

(ii) Describe the behaviour of the silicon dioxide during this reaction.

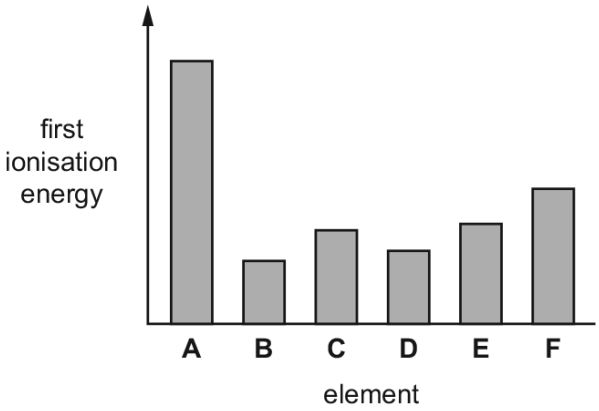
..... [1]

[Total: 15]

37. 9701_m18_qp_22 Q: 1

(a) The graph shows a sketch of the first ionisation energies of six successive elements in the Periodic Table.

The letters are **not** the symbols of the elements.



(i) Explain what is meant by the term *first ionisation energy*.

.....

.....

.....

..... [3]

(ii) Suggest why the first ionisation energy of **B** is much less than that of **A**.

.....

.....

.....

.....

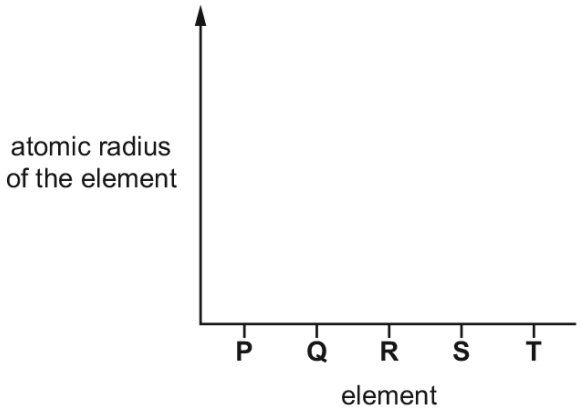
..... [3]

(b) **P–T** are successive elements in Period 3 of the Periodic Table.

The letters are **not** the symbols of the elements.

On the axes, sketch a graph to show the trend in the atomic radius of the elements **P–T**.

Explain your answer.



explanation .....

.....

.....

.....

.....

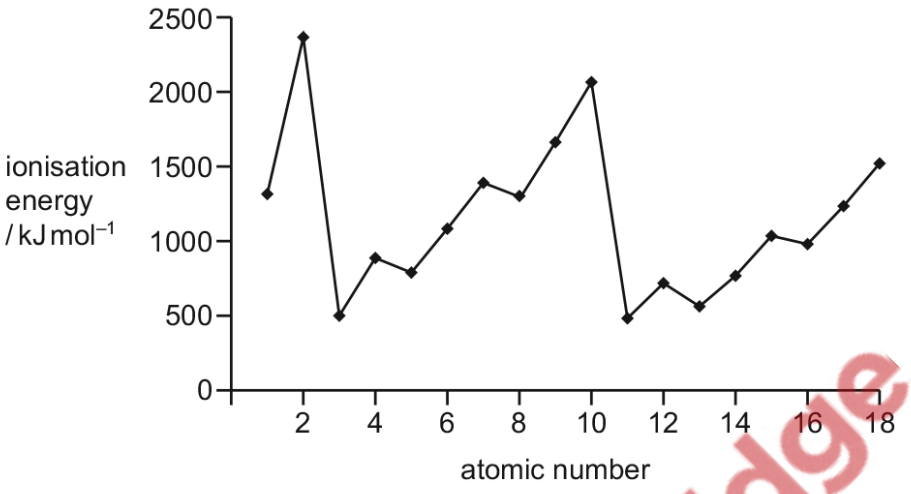
[3]

[Total: 9]

38. 9701_w16_qp_22 Q: 3

The Periodic Table is arranged such that the properties of the elements show a number of trends.

(a) A plot of the first ionisation energies for the first 18 elements is shown.



(i) Explain why the values show a general increase from atomic number 11 to 18.

.....

.....

..... [2]

(ii) Explain the decreases in first ionisation energies between

- atomic numbers 12 and 13,

.....

.....

.....

- atomic numbers 15 and 16.

.....

.....

.....

[4]

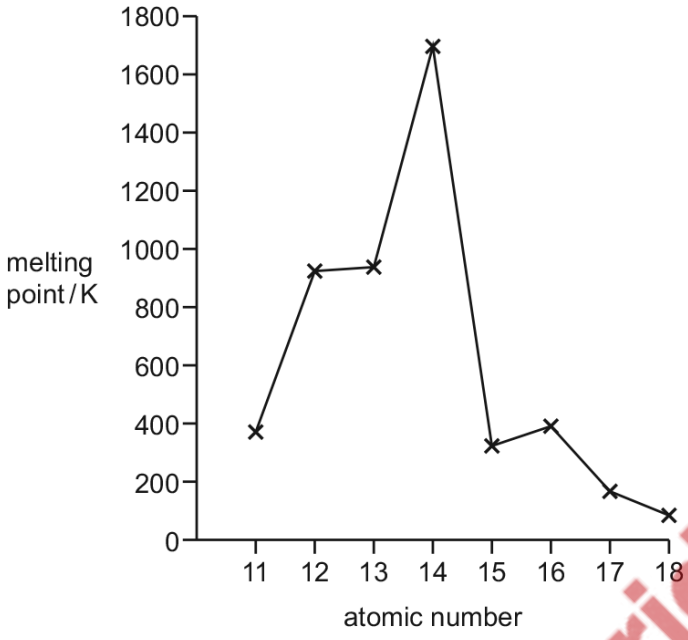
(iii) Suggest an explanation for the trend in the first ionisation energies of the elements with atomic numbers 2, 10 and 18.

.....

.....

..... [2]

(b) A plot of the melting points of the elements across the third period is shown.



(i) Explain the increase in melting point from atomic number 11 to 12.

.....

.....

..... [2]

(ii) Suggest a reason why the increase from atomic number 12 to 13 is much smaller than the increase from atomic number 11 to 12.

.....

..... [1]

(iii) State and explain the pattern of the melting points from atomic number 15 to 18.

.....

.....

.....

..... [3]

(iv) Explain why the element with atomic number 14 has a melting point so much higher than the rest of the elements in the third period.

.....

..... [1]

[Total: 15]

39. 9701_S15_qp_22 Q: 1

(a) Chemists recognise that atoms are made of three types of particle.

Complete the following table with their names and properties.

name of particle	relative mass	relative charge
		+1
	1/1836	

[3]

(b) Most elements exist naturally as a mixture of isotopes, each with their own relative isotopic mass. The mass spectrum of an element reveals the abundances of these isotopes, which can be used to calculate the relative atomic mass of the element.

Magnesium has three stable isotopes. Information about two of these isotopes is given.

isotope	relative isotopic mass	percentage abundance
^{24}Mg	24.0	79.0
^{26}Mg	26.0	11.0

(i) Define the term *relative isotopic mass*.

.....

.....

..... [2]

(ii) The relative atomic mass of magnesium is 24.3.

Calculate the percentage abundance and hence the relative isotopic mass of the third isotope of magnesium. Give your answer to **three** significant figures

percentage abundance = ...

isotopic mass = ...

[3]

(c) Magnesium can be produced by electrolysis of magnesium chloride in a molten mixture of salts.

(i) Give equations for the anode and cathode reactions during the electrolysis of molten magnesium chloride, $MgCl_2$.

anode .....

cathode .....

[2]

The electrolysis is carried out under an atmosphere of hydrogen chloride gas to convert any magnesium oxide impurity into magnesium chloride.

(ii) An investigation of the reaction between magnesium oxide and hydrogen chloride gas showed that an intermediate product was formed with the composition by mass Mg, 31.65%; O, 20.84%; H, 1.31% and Cl, 46.20%.

Calculate the empirical formula of this intermediate compound.

empirical formula ..... [2]

(d) The acid/base behaviour of the oxides in the third period varies across the period.

(i) Describe this behaviour and explain it with reference to the structure and bonding of sodium oxide, Na_2O, aluminium oxide, Al_2O_3, and sulfur trioxide, SO_3.

.....

.....

..... [2]

(ii) Write equations for reactions of these three oxides with hydrochloric acid and/or sodium hydroxide as appropriate.

.....

.....

.....

..... [4]

[Total: 18]

9.2 Periodicity of chemical properties of the elements in Period 3

40. 9701_s20_qp_21 Q: 1

Gallium is a metal in Group 13 of the Periodic Table.

(a) There are two stable isotopes of gallium, ^{69}Ga and ^{71}Ga.

(i) State, with reference to subatomic particles, how the isotopes ^{69}Ga and ^{71}Ga differ from each other.

.....

..... [1]

(ii) State what further information is needed to calculate the relative atomic mass of gallium.

..... [1]

(b) Gallium and its compounds show similar properties to aluminium and its compounds. Gallium reacts with excess chlorine to form gallium trichloride.

(i) At 500 °C, gallium trichloride is a gas.

Suggest the type of attraction that exists at 500 °C

- between atoms within a gallium trichloride molecule

.....

- between gallium trichloride molecules.

.....

[2]

(ii) When gallium trichloride is cooled a solid, Ga_2Cl_6, forms.

Suggest the name of the attraction formed between two gallium trichloride molecules to form Ga_2Cl_6.

..... [1]

(c) Gallium metal reacts rapidly when exposed to air. A white solid layer is formed on its surface.

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

..... [2]

(ii) 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.

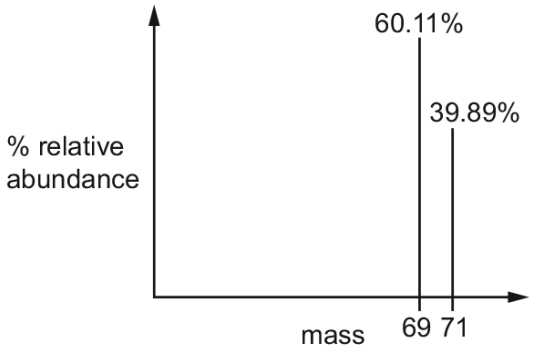
..... [1]

[Total: 8]

41. 9701_s20_qp_22 Q: 1

Gallium is an element in Group 13.

A sample of gallium is analysed using a mass spectrometer. The mass spectrum produced is shown.



(a) Explain what is meant by the term *relative atomic mass*.

.....

..... [2]

(b) Calculate the relative atomic mass of gallium in this sample. Give your answer to 4 significant figures.

Show your working.

relative atomic mass = ... [2]

(c) Complete the table which describes a gaseous atom of gallium.

isotope	nucleon number	total number of electrons in **lowest** energy level	type of orbital which contains the electron in the **highest** energy level
^{71}Ga			

[3]

(d) When gallium is heated in excess chlorine, gallium trichloride, $GaCl_3$, is made.

Draw the shape of the gallium trichloride molecule and suggest the Cl–Ga–Cl bond angle.

shape of molecule

bond angle .....

[2]

(e) 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).

..... [2]

[Total: 12]

42. 9701_w19_qp_21 Q: 2

(a) Complete the table to give details of the type of bonding and structure shown by some of the oxides of Period 3 elements.

	Na_2O	MgO	Al_2O_3	SiO_2	SO_3
boiling point/°C	1275	3670	2977	2950	45
nature of oxide	basic	basic	amphoteric	acidic	acidic
bonding					
structure					

[2]

(b) (i) Explain why the boiling point of SiO_2 is much higher than the boiling point of SO_3.

.....

.....

.....

..... [3]

(ii) Al_2O_3 is an amphoteric oxide.

Explain what is meant by the term *amphoteric*. Use chemical equations to illustrate your answer.

.....

.....

..... [3]

(iii) State what you would observe when a small sample of Na_2O is placed in water.

..... [1]

(c) Selenium is a Group 16 element which shows similar chemical reactions to sulfur.

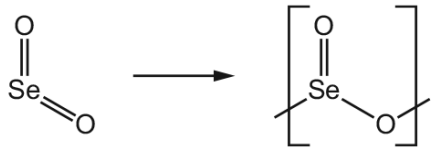
(i) Selenium reacts with fluorine to form SeF_6 molecules.

Predict the shape of a molecule of SeF_6.

..... [1]

(ii) The most stable oxide of selenium is SeO_2.

Gaseous SeO_2 reacts to form a solid polymer, as shown. In the reaction one Se=O is replaced by two Se–O to form a polymer.



$\Delta H = -346\ kJ\,mol^{-1}$

The bond enthalpy of Se=O is $514\ kJ\,mol^{-1}$.

Use these data to calculate the bond enthalpy, in $kJ\,mol^{-1}$, of Se–O.

bond enthalpy of Se–O = ... $kJ\,mol^{-1}$
[2]

(iii) SeO_2 shows similar chemical reactions to SO_2.

Suggest an equation to show the reaction of SeO_2 with aqueous sodium hydroxide, NaOH.

..... [1]

[Total: 13]

43. 9701_w19_qp_22 Q: 2

Oxygen is the most abundant element in the Earth's crust. It reacts with other elements to form stable compounds, ions and molecules.

(a) Complete the table to give the formulae and acid/base behaviour of some of the oxides of the Period 3 elements.

element	sodium	aluminium	silicon	phosphorus	sulfur
formula of oxide	Na_2O				SO_3
acid/base behaviour		amphoteric			

[2]

(b) Group 2 elements form stable hydroxides, with general formula $M(OH)_2$, where M is the Group 2 element.

(i) Beryllium hydroxide, $Be(OH)_2$, is an amphoteric compound that shows similar chemical reactions to aluminium oxide.

State the meaning of the term *amphoteric*.

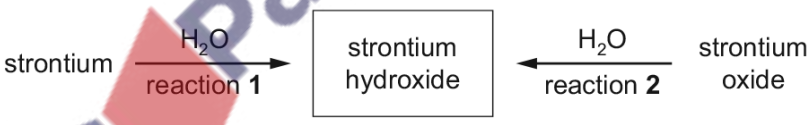
.....

..... [1]

(ii) Write an **ionic** equation for the reaction of magnesium hydroxide, $Mg(OH)_2$, with hydrochloric acid.

..... [1]

(iii) Two methods of preparing strontium hydroxide are shown.



State **one** difference between the observations you would make for reaction **1** and reaction **2**.

.....

.....

..... [1]

(iv) State how the solubility of the Group 2 hydroxides changes down the group.

..... [1]

(c) Sodium peroxide, Na_2O_2, reacts with CO_2.

$$Na_2O_2(s) + CO_2(g) \rightarrow Na_2CO_3(s) + \tfrac{1}{2}O_2(g)$$

The partial pressure of $CO_2(g)$ in a 0.500 dm^3 sample of air is 5.37 kPa at 20 °C.

(i) Calculate the amount, in moles, of $CO_2(g)$ present in the sample of air at 20 °C.

amount of $CO_2(g)$ = ... mol [2]

(ii) Calculate the mass of $Na_2O_2(s)$ that would react fully with the amount of $CO_2(g)$ calculated in **(i)**.

mass of $Na_2O_2(s)$ = ... g [1]

(iii) The peroxide ion, O_2^{2-}, has a single covalent bond between the two oxygen atoms. Each oxygen atom carries a negative charge.

Draw a 'dot-and-cross' diagram for the peroxide ion. Show outer electrons only.

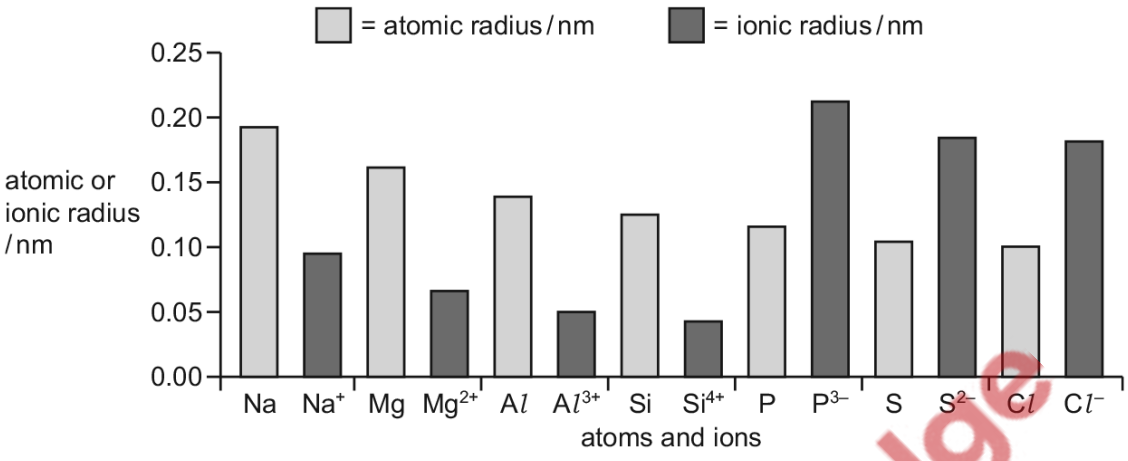
[2]

[Total: 11]

44. 9701_s18_qp_21 Q: 3

The elements in the third period exhibit periodicity in both their chemical and physical properties.

(a) A graph of the atomic and ionic radii across the third period is shown.



(i) Explain the decrease in atomic radius across the third period.

.....

.....

.....

..... [2]

(ii) Explain why, for sodium to silicon, the ionic radii are less than the atomic radii.

.....

..... [1]

(iii) Explain why, for phosphorus to chlorine, the ionic radii are greater than the atomic radii.

.....

.....

..... [2]

(b) The first ionisation energies of the elements across the third period show a general increase.

Aluminium and sulfur do **not** follow this general trend.

(i) Explain why aluminium has a lower first ionisation energy than magnesium.

.....

.....

..... [2]

(ii) Explain why sulfur has a lower first ionisation energy than phosphorus.

.....

.....

..... [2]

(c) The elements in the third period, from sodium to silicon, can react with chlorine to form chlorides.

(i) State and explain the pattern of change of oxidation number which occurs to both chlorine and the different Period 3 elements when they react together.

.....

.....

.....

..... [3]

(ii) Give the equations to show the reactions of sodium chloride and silicon(IV) chloride when separately added to water.

sodium chloride .....

silicon(IV) chloride .....

[2]

(iii) Complete the table to describe the structure and bonding in sodium chloride and silicon(IV) chloride.

	structure	bonding
sodium chloride		
silicon(IV) chloride		

[2]

[Total: 16]

45. 9701_m17_qp_22 Q: 1

(a) The table shows information about some of the elements in the third period.

element	Na	Mg	A*l*	P	S	C*l*
atomic radius/nm	0.186	0.160	0.143	0.110	0.104	0.099
radius of most common ion/nm	0.095	0.065	0.050	0.212	0.184	0.181
maximum oxidation number of the element in its compounds	+1					+7

(i) Complete the table to show the maximum oxidation number of each element in its compounds. [1]

(ii) Explain why the atomic radius of elements in the third period decreases from Na to C*l*.

.....

.....

.....

.....

..... [3]

(iii) The radius of the most common ion of Mg is much smaller than the radius of the most common ion of S.

Identify both ions and explain the difference in their radii.

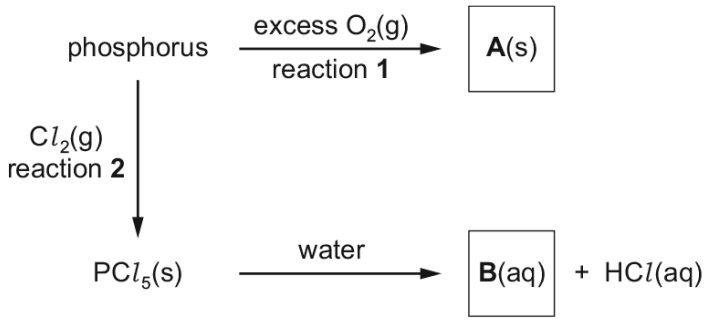
.....

.....

..... [2]

(b) Phosphorus is a non-metal in the third period. It reacts vigorously with excess oxygen but slowly with chlorine.

Some reactions of phosphorus are shown.



(i) Write an equation to represent reaction **1**, the formation of compound **A**.

..... [1]

(ii) Give **two** observations you could make in reaction **2**.

1. .....

2. .....

[2]

(iii) Name compound **B**.

..... [1]

(c) Cerium is a lanthanoid metal that shows similar chemical reactions to some elements in the third period. Most of cerium's compounds contain Ce^{3+} or Ce^{4+} ions.

(i) Cerium shows the same structure and bonding as a typical metal.

Draw a labelled diagram to show the structure and bonding in cerium.

[2]

(ii) Cerium(IV) oxide, CeO_2, is a ceramic.

Suggest **two** physical properties of cerium(IV) oxide.

1. .....

2. .....

[2]

(iii) A naturally occurring sample of cerium contains only **four** isotopes. Data for **three** of the isotopes are shown in the table.

isotope	^{136}Ce	^{138}Ce	^{140}Ce	^{142}Ce
relative isotopic mass	135.907	137.906	139.905	to be calculated
percentage abundance	0.185	0.251	88.450	to be calculated

The A_r of the sample is 140.116.

Use these data to calculate the **relative isotopic mass** of the fourth isotope in this sample of cerium.

Give your answer to **three** decimal places.

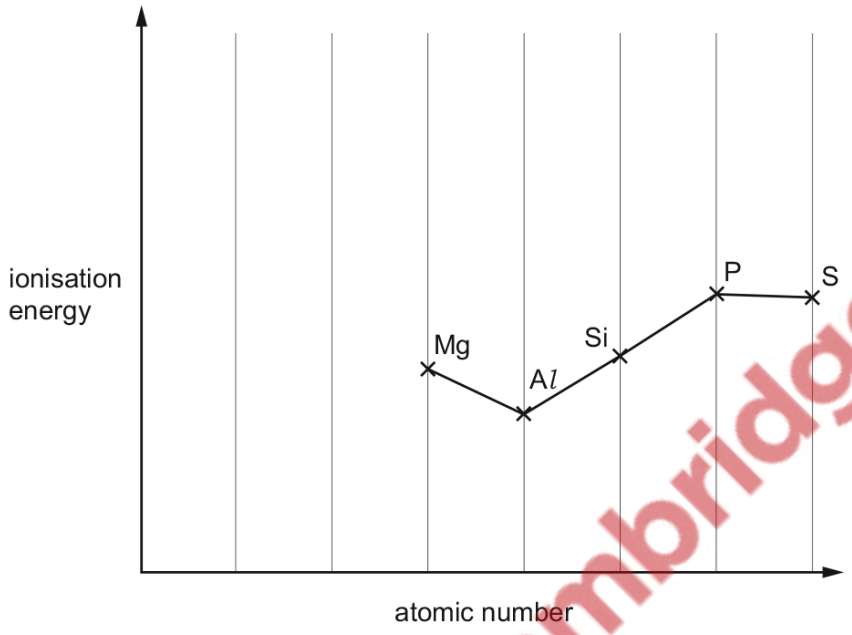
relative isotopic mass = ... [3]

[Total: 17]

46. 9701_w17_qp_21 Q: 2

The elements in the third period, and their compounds, show trends in their physical and chemical properties.

(a) A sketch graph of the first ionisation energies of five successive elements in the third period is shown.



(i) Explain why there is a general increase in the first ionisation energy across the third period.

.....

.....

..... [2]

(ii) Sketch, on the graph, the position of the ionisation energies of the two elements that come before Mg in this sequence. [2]

(iii) Explain, with reference to electron arrangements, the decreases in first ionisation energy between Mg and Al and between P and S.

Mg and Al .....

.....

.....

P and S .....

.....

.....

[4]

(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 and **M** are each a chloride of an element in Period 3. A student investigated **L** and **M** and their results are given.

L is a white crystalline solid with a melting point of 987 K. **L** dissolves in water to form an approximately neutral solution. Addition of NaOH(aq) to an aqueous solution of **L** produces a white precipitate.

M is a liquid with a boiling point of 331 K. **M** is hydrolysed rapidly by cold water to form a strongly acidic solution, a white solid and white fumes.

Identify **L** and **M**.
Explain any properties and observations described.
Give equations where appropriate.

(i) **L** is .....

.....

.....

.....

..... [3]

(ii) **M** is .....

.....

.....

.....

..... [3]

[Total: 14]

47. 9701_w15_qp_21 Q: 1

Aluminium is a metal in Period 3 and Group III of the Periodic Table.

(a) Describe the structure of solid aluminium.

.....

.....

..... [2]

(b) A common use of aluminium is to make the conducting cables in long distance overhead power lines.

(i) Suggest two properties of aluminium that make it suitable for this use.

.....

.....

..... [2]

The cables are attached to pylons by ceramic supports.

(ii) Describe the structure of a ceramic material.

.....

..... [1]

(iii) State the property of a ceramic material that makes it suitable for this use.

.....

..... [1]

(c) Aluminium reacts with chlorine to form a white, solid chloride that contains 79.7% chlorine and sublimes (changes straight from a solid to a gas) at 180 °C.

(i) Describe the structure and bonding in this compound. Suggest how it explains the low sublimation temperature.

.....

.....

.....

.....

..... [2]

(ii) Calculate the empirical formula of the chloride. You must show your working.

empirical formula = ... [2]

At 200 °C and 100 kPa, a 1.36 g sample of this chloride occupied a volume of 200 cm^3.

(iii) Calculate the relative molecular mass, M_r, of the chloride. Give your answer to **three** significant figures.

M_r = ... [2]

(iv) Deduce the molecular formula of this chloride at 200 °C.

..... [1]

[Total: 13]

9.3 Chemical periodicity of other elements

48. 9701_s21_qp_23 Q: 3

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 $Ba(OH)_2$, $NaCl$, P_4O_{10} or $SiCl_4$.

(a) (i) Use the observations in the table to identify each sample as one of $Ba(OH)_2$, $NaCl$, 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]

(b) Magnesium oxide and aluminium oxide have properties typical of ceramic materials.

(i) Name **one** physical property typical of ceramic materials.

..... [1]

(ii) Give the formula of another Period 3 oxide which behaves as a ceramic material.

..... [1]

(c) Tungsten oxide, W_xO_y, is used to give colour to ceramic materials.

A sample of W_xO_y contains 79.29% tungsten by mass.

Calculate the empirical formula of W_xO_y.

Show your working.

empirical formula = ...
[3]

[Total: 11]

49. 9701_w21_qp_22 Q: 2

(a) Table 1 gives physical data for some of the Period 3 elements.

Table 1

atomic number, Z	11	12	13	14	15	16	17
bonding present in element	M						C
first ionisation energy / kJ mol^{-1}	494	736	577	786	1060	1000	1260
maximum oxidation number							+7
anionic radius / nm	–	–	–	0.271	0.212	0.184	0.181

(i) Complete the row in the table labelled 'bonding present in element'.

Use C = covalent, I = ionic, M = metallic, as appropriate. [1]

(ii) Explain the difference between the first ionisation energies of the elements with atomic numbers 11 and 17.

.....

.....

.....

.....

..... [2]

(iii) Explain the difference between the first ionisation energies of the elements with atomic numbers 15 and 16.

.....

.....

.....

.....

..... [2]

(iv) Complete the row in the table labelled 'maximum oxidation number'. [1]

(v) Explain the variation in anionic radius for the elements with atomic numbers 14 to 17.

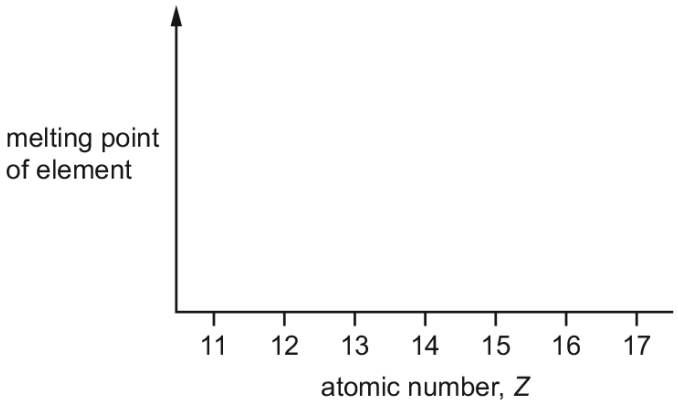
.....

.....

.....

..... [2]

(b) Use the axes to sketch a graph that shows the trend in melting points of the elements with atomic numbers 11 to 17.



[2]

(c) Dmitri Mendeleev published the first Periodic Table in 1869.

Mendeleev used his knowledge of chemical periodicity to propose the properties of gallium, $_{31}$Ga, a Group 13 element.

Table 2 gives some chemical and physical data of elements in Group 13.

Table 2

element	density / g cm^{-3}	boiling point / K	cationic radius / nm
$_{5}$B	2.34	3930	0.020
$_{13}$Al		2470	0.050
$_{31}$Ga	5.91	2400	
$_{49}$In	7.30		0.081
$_{81}$Tl	11.8	1460	0.095

Complete the table by predicting values for the missing data. [3]

(d) 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 $In_2Br_6(g)$.

[2]

[Total: 17]

50. 9701_s16_qp_21 Q: 2

D, **E**, **F**, and **G** are four consecutive elements in the **fourth** period of the Periodic Table. (The letters are **not** the actual symbols of the elements.)

D is a soft, silvery metal with a melting point just above room temperature. Its amphoteric oxide, $\mathbf{D}_2O_3$, has a melting point of 1900 °C and can be formed by heating **D** in oxygen.

G is a solid that can exist as several different allotropes, most of which contain $\mathbf{G}_8$ molecules. **G** burns in air to form $\mathbf{GO}_2$ which dissolves in water to form an acidic solution. This solution reacts with sodium hydroxide to form the salt $Na_2\mathbf{GO}_3$.

(a) Suggest the identities of **D** and **G**.

D ..... **G** .....
[1]

(b) Write equations for the reactions of $\mathbf{D}_2O_3$ with

(i) hydrochloric acid,

..... [2]

(ii) sodium hydroxide.

..... [2]

(c) Suggest the type of bonding and structure in $\mathbf{D}_2O_3$.

..... [1]

(d) Write an equation for the formation of an acidic solution when $\mathbf{GO}_2$ dissolves in water.

..... [1]

[Total: 7]