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CHEMISTRY

9701/21

Paper 2 AS Level Structured Questions

May/June 2019

1 hour 15 minutes

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

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Answer **all** the questions in the spaces provided.

1 (a) Group 2 elements share common chemical properties.

- (i) Calcium reacts in cold water more quickly than magnesium because more energy is required to remove the outer electrons in magnesium. This occurs even though calcium atoms have a greater nuclear charge.

Explain why more energy is required to remove the outer electrons in magnesium than in calcium.

.....
.....
..... [2]

- (ii) 0.001 mol of strontium reacts with an excess of cold water. When the reaction is complete a colourless solution is seen.

Construct the equation for the reaction of strontium with cold water. Include state symbols.

..... [2]

- (iii) 0.005 mol of calcium and 0.005 mol of strontium are added separately to two beakers. Each beaker contains 100 cm³ of cold water.
At the end of each reaction a white solid and a colourless solution are seen in both beakers.

Predict which element, calcium or strontium, produces the more alkaline solution. Explain your answer.

.....
.....
..... [2]

- (iv) Describe one observation when magnesium carbonate is added to excess dilute sulfuric acid.

.....
..... [1]

(b) Element **X** is a metal. **X** reacts with oxygen to form a black solid oxide. The oxidation state of **X** in this oxide is +2. The carbonate of **X**, XCO_3 , is a green solid. It decomposes on heating to form the oxide and a colourless gas.

(i) From the information given, state two similarities and one difference that metal **X** and its compounds have with Group 2 metals and their compounds.

similarity 1

.....

similarity 2

.....

difference 1

.....

[3]

(ii) Write the formula of the oxide of **X**.

..... [1]

(iii) Write an equation for the reaction of XCO_3 when it is heated.

..... [1]

[Total: 12]

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.



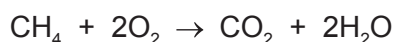
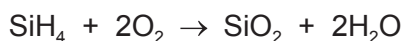
[2]

- (ii) Explain why methane, CH₄, has no overall dipole moment.

.....

 [2]

- (e) SiH₄ reacts in air without heating but CH₄ must be ignited before combustion occurs.



Suggest, with reference to bond energies from the *Data Booklet*, why SiH₄ reacts in air without heating but CH₄ 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]

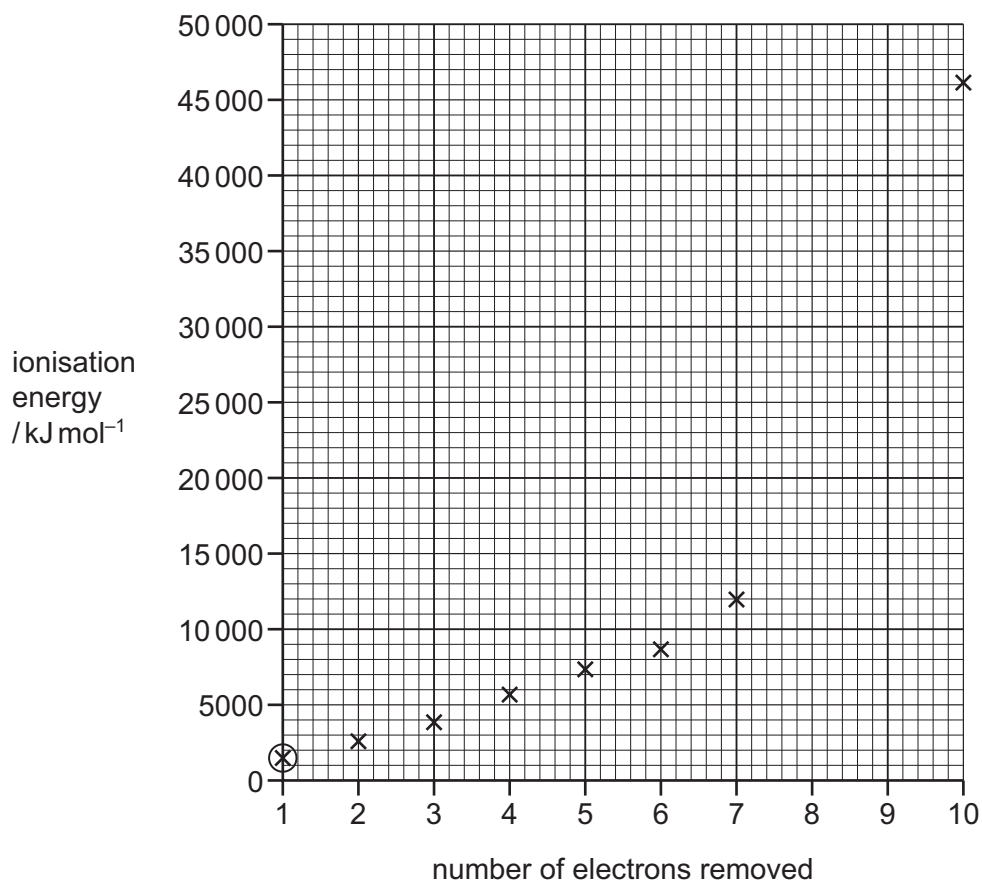
[Total: 15]

- 3 (a) Construct an equation for the **second** ionisation energy of argon.

..... [1]

- (b) The graph shows successive ionisation energies for the element argon.

Complete the graph with predictions for the eighth and ninth ionisation energies of argon. Use a cross (x) for each data point. [2]



- (c) The energy value required to remove the first electron from an atom of argon is circled on the graph.

Sketch the shape of the orbital that contains this electron.

[1]

(d) Chlorine exists as a diatomic gas, $\text{Cl}_2(\text{g})$. A sample of $\text{Cl}_2(\text{g})$ was made during a chemical reaction. When measured at 404 kPa and 25 °C the sample occupied a volume of 20.0 cm³.

(i) Calculate the mass, in grams, of $\text{Cl}_2(\text{g})$ formed.

For this calculation, assume that chlorine behaves as an ideal gas under these conditions.

mass of $\text{Cl}_2(\text{g})$ = ... g [3]

(ii) Calculate the number of chlorine atoms in this sample of $\text{Cl}_2(\text{g})$. You may find it helpful to use your answer to (d)(i).

If you are unable to calculate an answer to (d)(i), use 0.36 g of Cl_2 . This is **not** the correct answer.

number of chlorine atoms = ... [2]

(iii) $\text{Cl}_2(\text{g})$ does **not** behave as an ideal gas under these conditions.

Explain why $\text{Cl}_2(\text{g})$ behaves even **less** ideally at:

- very high pressures

.....

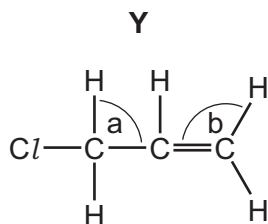
- very low temperatures.

.....

[2]

[Total: 11]

4 The structure of compound **Y** is shown.



(a) Give the systematic name for **Y**.

..... [1]

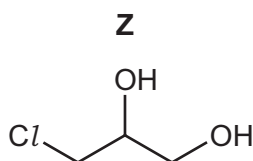
(b) Predict the values for the bond angles *a* and *b* shown in the diagram.

a

b

[2]

(c) When **Y** reacts with cold, dilute, acidified manganate(VII) ions, compound **Z** is produced.



(i) State the molecular formula of **Z**.

..... [1]

(ii) Name the type of reaction occurring when **Y** is converted into **Z**.

..... [1]

(iii) Alcohols can be classified as primary, secondary or tertiary.

Identify with a tick (✓) the alcohol group(s) present in **Z**.

	alcohol group present in Z
primary	
secondary	
tertiary	

[1]

(d) Samples of organic compounds, **A**, **B**, **C** and **D**, are placed in unlabelled bottles.



(i) Identify all of the compound(s), **A–D**, that contain a carbonyl group.

..... [1]

(ii) **A–D** are reacted separately with the reagents given in the table.

Complete the table to:

- identify which of the compounds, **A–D**, reacts with the reagents
- give an appropriate observation when a reaction occurs.

reagent	compounds identified	observation when a reaction occurs
Tollens' reagent		
alkaline solution of iodine		
sodium metal		

[8]

[Total: 15]

- 5 Ethanal reacts with a mixture of HCN and NaCN to make 2-hydroxypropanenitrile, $\text{CH}_3\text{CH}(\text{OH})\text{CN}$.

The reaction mechanism is nucleophilic addition.

- (a) Explain the meaning of the term *nucleophile* and identify the species which acts as the nucleophile during this reaction.

.....
.....

species acting as nucleophile [2]

- (b) $\text{CH}_3\text{CH}(\text{OH})\text{CN}$ exists as a pair of stereoisomers.

- (i) Name the type of stereoisomerism shown by $\text{CH}_3\text{CH}(\text{OH})\text{CN}$.

..... [1]

- (ii) Draw three-dimensional diagrams of this pair of stereoisomers.

Indicate with an asterisk (*) the chiral centre on one of the structures drawn.

[3]

- (c) Give the structure of the organic product of the reaction of $\text{CH}_3\text{CH}(\text{OH})\text{CN}$ with dilute sulfuric acid.

..... [1]

[Total: 7]

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Answer **all** the questions in the spaces provided.

1 Methylpropane, $(\text{CH}_3)_2\text{CHCH}_3$, is an isomer of butane, $\text{CH}_3(\text{CH}_2)_2\text{CH}_3$.

(a) (i) Explain why methylpropane and butane are a pair of isomers.

.....
..... [2]

(ii) Identify the type of isomerism shown by methylpropane and butane.

..... [1]

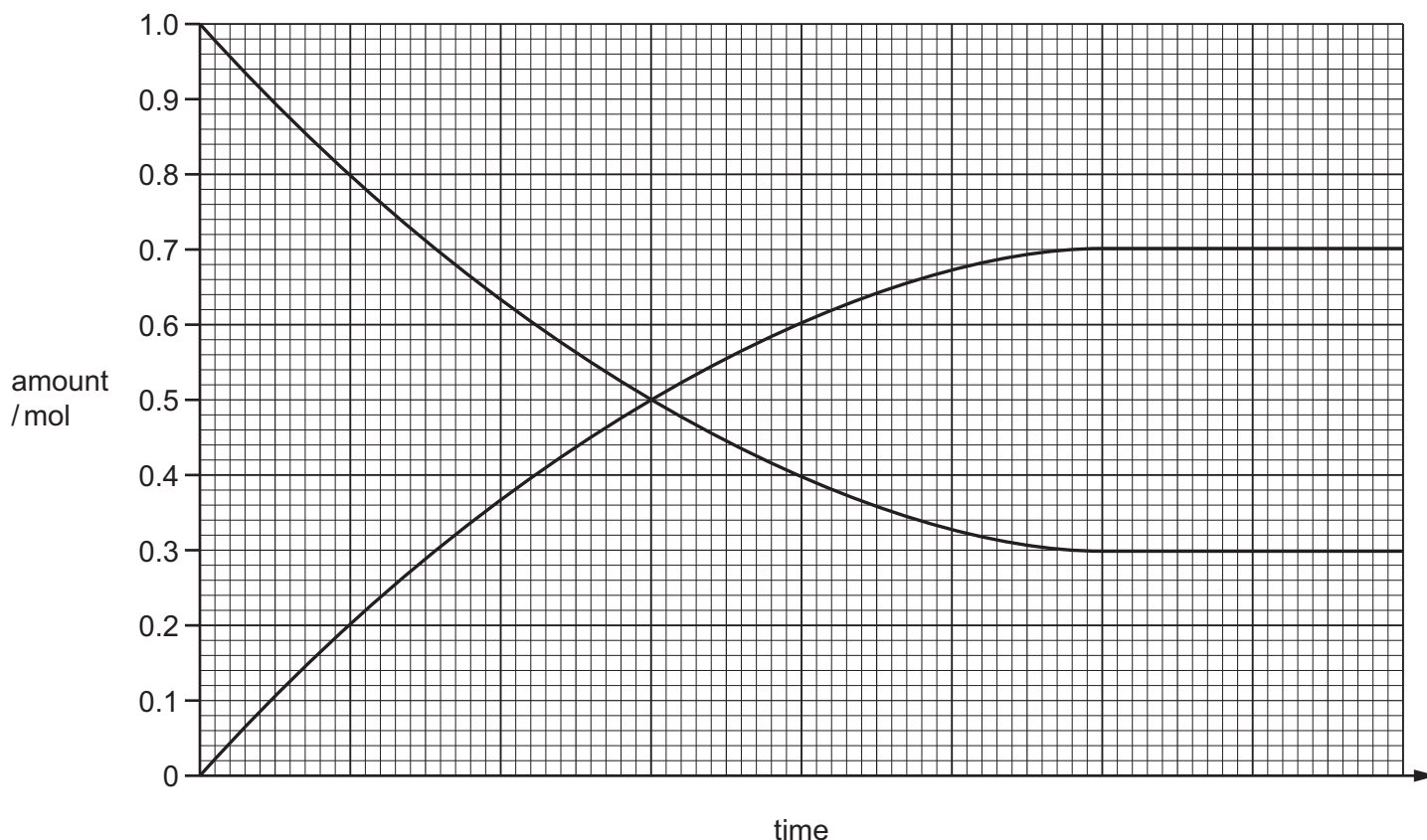
(b) When a sample of butane is heated to 373 K, in the presence of a catalyst, and allowed to reach equilibrium the following reaction occurs.



State and explain the effect on the composition of this equilibrium mixture when the temperature is increased to 473 K.

.....
.....
..... [2]

- (c) 1 mole of butane gas was added to a 1 dm^3 closed system, at a constant temperature and pressure. The amount of butane and methylpropane was measured at regular time intervals.



- (i) Label the graph with a t to show the time taken to reach dynamic equilibrium. [1]

- (ii) Use the graph to find the concentration of butane and methylpropane in the mixture at equilibrium.

concentration of butane = ... mol dm^{-3}

concentration of methylpropane = ... mol dm^{-3}

[1]

- (iii) Write an expression for K_c for this reaction.

[1]

- (iv) Calculate a value for K_c and state its units.

$K_c = \dots\dots\dots$ units = ... [2]

[Total: 10]

2 Group 17 elements are commonly referred to as the halogens.

(a) State and explain the trend in volatility of chlorine, bromine and iodine down the group.

.....

.....

.....

..... [3]

Hydrogen gas reacts with the different halogens under different conditions.

(b) (i) State the conditions required for chlorine to react with hydrogen at room temperature.

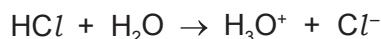
..... [1]

(ii) On heating, iodine reacts with hydrogen in a reversible reaction.

Give the equation for this reaction. Include state symbols.

..... [2]

(c) Hydrogen chloride reacts with water.



(i) In this reaction, one of the reactants behaves as a Brønsted-Lowry acid.

What is meant by the term *Brønsted-Lowry acid*?

.....

..... [1]

(ii) Identify the reactant behaving as an acid and its conjugate base.

acid

conjugate base [1]

(iii) Name the type of bond formed between H^+ and H_2O to make H_3O^+ .

..... [1]

(iv) For H_3O^+ , predict its shape and the H–O–H bond angle.

shape

bond angle [2]

[Total: 11]

3 Period 3 elements react with chlorine gas, $\text{Cl}_2(\text{g})$, to form chlorides.

(a) The table shows the differences in observations which occur when two Period 3 chlorides are added to water.

Period 3 chloride	observations when added to water	pH of solution formed with water
NaCl	White solid disappears. Colourless solution made.	7
SiCl_4	Pale yellow solution forms. Bubbles form and the test-tube feels hot. White precipitate forms.	1–2

(i) Write an equation for the reaction occurring when SiCl_4 is added to cold water. Include state symbols.

..... [1]

(ii) Name the type of reaction occurring when SiCl_4 is added to water. Ignore the exothermic/endothermic nature of the reaction.

..... [1]

(iii) Explain, in terms of bonding, why NaCl and SiCl_4 behave differently when added to water.

.....

.....

..... [2]

(iv) Explain, in terms of electronegativity, why the bonding in NaCl is different from the bonding in SiCl_4 .

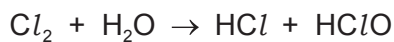
.....

.....

.....

..... [3]

(b) $\text{Cl}_2(\text{g})$ dissolves in cold water and reacts with it.



(i) Identify the oxidation number of chlorine in each of the chlorine-containing species in this reaction.

chlorine-containing species	Cl_2	HCl	HClO
oxidation number of chlorine			

[2]

(ii) Name the type of reaction occurring.

..... [1]

(iii) Explain why chlorine is used in the purification of water.

.....
 [1]

(c) A mixture of HCl and HClO is added to cold dilute NaOH . One of the products behaves as a bleach.

Suggest the equation for the reaction occurring.

..... [2]

[Total: 13]

4 There are many different types of aliphatic and aromatic hydrocarbons.

- (a) Name a naturally occurring source of aliphatic and aromatic hydrocarbons and outline how different hydrocarbons are separated from this source.

name of source

outline of separation of hydrocarbons

..... [2]

- (b) When alkanes are heated to high temperatures, in the absence of air, the molecules can break into smaller molecules.

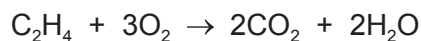
- (i) Identify the type of reaction occurring.

..... [1]

- (ii) Write an equation which describes the reaction occurring when heptane, C_7H_{16} , is heated in the absence of air, to form hexane, butane and ethene only.

..... [1]

- (c) The equation for the complete combustion of ethene is shown.



Calculate the volume, in dm^3 , of carbon dioxide formed in the complete combustion of 1.00 g of ethene at room temperature and pressure.

volume of CO_2 = ... dm^3 [3]

(d) The table compares the reactivity of alkanes and alkenes with chlorine.

	alkanes	alkenes
name of the type of reaction with chlorine	substitution	addition and substitution
name of the type of reacting species	free radical	electrophile and free radical

(i) During the first stage in the substitution reaction chlorine forms chlorine free radicals.

Explain what is meant by the term *free radical*.

..... [1]

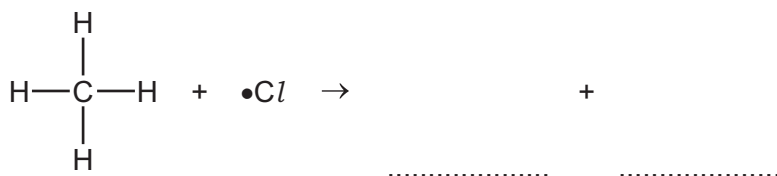
(ii) Name and explain the type of bond breaking which occurs to form chlorine free radicals.

.....
 [2]

(iii) Name the stage of the reaction mechanism which occurs when a methane molecule reacts with a chlorine free radical.

..... [1]

(iv) Complete the equation for the reaction which occurs when a methane molecule reacts with a chlorine free radical.



[1]

(v) Carbon atoms can form σ and π bonds within hydrocarbon molecules.

Explain the following statement with reference to σ and π bonds.

Alkenes react with electrophiles but alkanes do not.

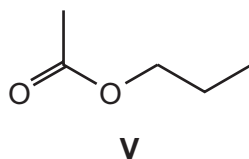
.....

 [2]

[Total: 14]

5 Many naturally occurring esters are used as flavourings in food.

(a) The structure of ester **V** is shown.



(i) Name **V**.

..... [1]

V reacts with a reagent to form a salt of a carboxylic acid and an alcohol.

(ii) Identify a reagent that could be used in this reaction.

..... [1]

(iii) Draw the displayed formula of the alcohol made during this reaction.

[1]

(iv) State one other possible use for **V**, apart from as a food flavouring.

..... [1]

(b) Ester **W** is made up of 54.5% carbon, 9.1% hydrogen and 36.4% oxygen.

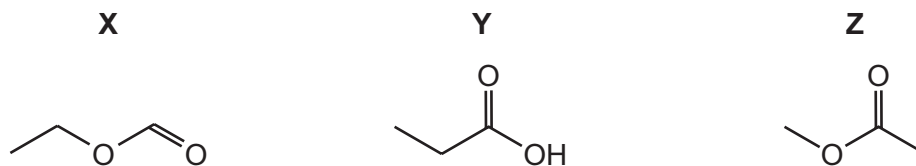
(i) Calculate the empirical formula of **W**.

[3]

(ii) State what additional information is required to determine the molecular formula of **W**.

..... [1]

(c) Compounds **X**, **Y** and **Z** are shown. They all have the same molecular formula.



(i) Deduce the molecular formula of **X**, **Y** and **Z**.

..... [1]

(ii) In three experiments, sodium is added to separate samples of **X**, **Y** and **Z**.

Complete the table to show the observations for each of these three experiments. Ignore any temperature changes which may occur.

experiment	observations
Na + X	
Na + Y	
Na + Z	

[2]

(d) Sodium carbonate solution reacts with methanoic acid.

Write the equation for this reaction.

..... [1]

[Total: 12]

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- 1 (a) A sample contains three different types of atom: ${}^{40}_{18}\text{Ar}$, ${}^{40}_{19}\text{K}$ and ${}^{40}_{20}\text{Ca}$.

- (i) State fully, in terms of the numbers of subatomic particles, what these three atoms have in common.

.....
 [1]

- (ii) State fully, in terms of the numbers of **all** subatomic particles, how these three atoms **differ** from each other.

.....
 [1]

- (b) A sample of sulfur contains only two isotopes, ${}^{32}\text{S}$ and ${}^{34}\text{S}$. The relative atomic mass of this sample is 32.09.

isotope	isotopic mass
${}^{32}\text{S}$	32.0
${}^{34}\text{S}$	34.0

Calculate the percentage abundance of the isotopes present in this sample.

% abundance ${}^{32}\text{S}$ = ...

% abundance ${}^{34}\text{S}$ = ...

[3]

(c) The electronic configuration of a sulfur atom is $1s^2 2s^2 2p^6 3s^2 3p^4$.

(i) Identify which orbital in a sulfur atom has the lowest energy.

..... [1]

(ii) Sketch the shape of a p orbital.

[1]

(iii) During the process of ionisation a sulfur atom loses an electron.



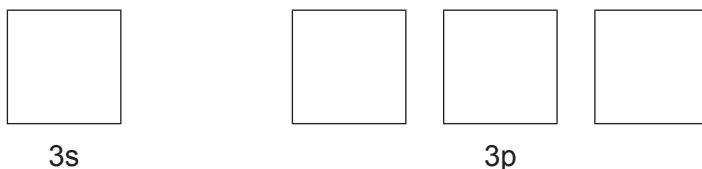
Identify the orbital from which this electron is removed. Explain your answer.

orbital

explanation

[2]

(d) (i) Complete the diagram to show the arrangement of electrons within the third shell of a phosphorus atom.



2 Iodine is an element in Group 17 of the Periodic Table.

(a) (i) At room temperature, iodine solid has a lattice structure.

Describe the arrangement of the iodine molecules within the solid.

..... [1]

(ii) List **all** of the forces of attraction present in solid iodine and identify which of these are overcome when solid iodine is heated to produce iodine vapour.

force(s) of attraction present

.....

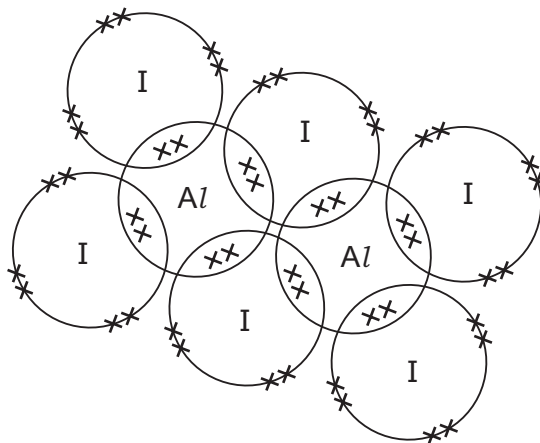
force(s) of attraction overcome

.....

[2]

Iodine reacts with aluminium to form a white solid, Al_2I_6 .

(b) The diagram shows the arrangement of the outer electrons within a molecule of Al_2I_6 .



(i) How many co-ordinate (dative covalent) bonds are made when a molecule of Al_2I_6 is formed from its atoms?

..... [1]

(ii) Describe how co-ordinate (dative covalent) bonds form within this molecule.

.....

..... [1]

(c) In a reaction between hydrogen iodide and concentrated sulfuric acid, the products are hydrogen sulfide, sulfur, iodine and water.

(i) Write an equation for this reaction.

You may wish to use oxidation numbers to help you.

..... [2]

(ii) Explain, with reference to oxidation numbers, why this reaction is a redox reaction.

.....

.....

..... [2]

[Total: 9]

- 3 (a) Magnesium reacts with oxygen to form magnesium oxide.

State **two** observations that would be made when magnesium is heated strongly and placed in a gas jar of pure oxygen.

.....
..... [1]

- (b) Acid indigestion is caused by an excess of hydrochloric acid in the stomach.
Magnesium oxide is commonly found in indigestion tablets.

- (i) Give the equation to show how magnesium oxide relieves acid indigestion.

..... [1]

- (ii) Name the type of reaction that occurs in (b)(i).

..... [1]

- (c) Magnesium oxide is described as a ceramic material. It has a high melting point.

State and explain why ceramic materials such as magnesium oxide have high melting points.

.....
.....
..... [2]

- (d) Magnesium oxide can be made from magnesium carbonate in a one-step reaction using heat.

- (i) Write an equation for this reaction. Include state symbols.

..... [1]

- (ii) Name the type of reaction occurring during this process.

..... [1]

[Total: 7]

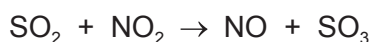
4 Release of sulfur dioxide, SO_2 , into the atmosphere causes acid rain.

- (a)** Explain why high levels of SO_2 may be found in the atmosphere near power stations that burn fossil fuels.

.....

 [2]

- (b)** The SO_2 released can be converted in the atmosphere into sulfuric acid, H_2SO_4 , by reaction with nitrogen dioxide gas, NO_2 , and water, H_2O .



During one year, 1590 tonnes of SO_2 was released into the atmosphere by a fossil-fuel burning power station.

- (i)** Use the equations to calculate how many tonnes of H_2SO_4 were formed in the atmosphere. Assume that all of the SO_2 released was converted into H_2SO_4 .

mass of H_2SO_4 = ... tonnes [2]

- (ii)** Describe how NO_2 is also produced by these power stations.

.....
 [2]

- (iii)** State one natural cause of NO_2 being formed in the atmosphere.

..... [1]

- (iv)** Explain why NO_2 can be described as a catalyst in the oxidation of atmospheric SO_2 .

.....

 [2]

[Total: 9]

5 Halogenoalkanes react with a number of different reagents in nucleophilic substitution reactions.

- (a) A sample of potassium cyanide dissolved in ethanol is added to a sample of 1-bromobutane, $\text{CH}_3(\text{CH}_2)_3\text{Br}$, and heated under reflux. A nucleophilic substitution reaction occurs and compound **A** is formed.

(i) Name compound **A**.

..... [1]

(ii) What is meant by the term *nucleophile*?

.....

..... [1]

(iii) Identify the nucleophile in this reaction.

..... [1]

(iv) Explain why this reaction is described as a substitution reaction.

.....

..... [1]

- (b) State the reagent(s) and conditions needed for $\text{CH}_3(\text{CH}_2)_3\text{Br}$ to react to form $\text{CH}_3(\text{CH}_2)_3\text{NH}_2$.

reagent(s)

conditions

[2]

- (c) Equal amounts of three different halogenoalkanes are added to three separate test-tubes. An equal amount of aqueous silver nitrate and ethanol is added to each test-tube. The time taken for a precipitate to form is recorded for each halogenoalkane.

halogenoalkane	time taken for precipitate to form / s
$(\text{CH}_3)_3\text{CCl}$	460
$(\text{CH}_3)_3\text{CBr}$	190
$(\text{CH}_3)_3\text{CI}$	40

- (i) Describe and explain the trend in reactivity of the different halogenoalkanes shown in this experiment.

.....

 [2]

- (ii) All three halogenoalkanes tend to react via the $\text{S}_{\text{N}}1$ mechanism.

Explain why the $\text{S}_{\text{N}}1$ mechanism is favoured.

.....

 [3]

- (iii) Identify a halogenoalkane which tends to react with an aqueous solution of silver nitrate and ethanol via the $\text{S}_{\text{N}}2$ mechanism.

..... [1]

[Total: 12]

6 (a) Three alkenes, **X**, **Y** and **Z**, have the same molecular formula.

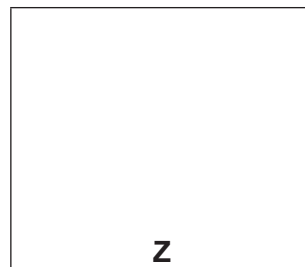
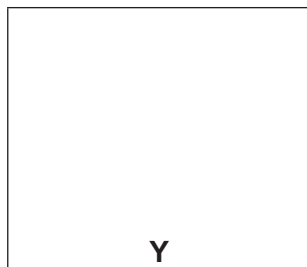
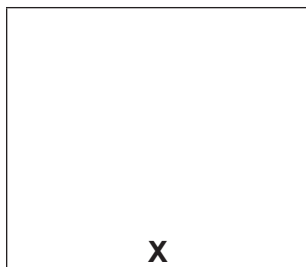
(i) Describe what is seen when aqueous bromine is added to **X**.

..... [1]

X, **Y** and **Z** are reacted separately with hot, concentrated, acidified manganate(VII) ions until no further reaction occurs. The carbon-containing products are shown in the table.

alkene	carbon-containing products
X	$\text{CO}_2 + (\text{CH}_3)_2\text{CO}$
Y	$\text{CO}_2 + \text{CH}_3\text{CH}_2\text{CO}_2\text{H}$
Z	$\text{CH}_3\text{CO}_2\text{H}$

(ii) Draw the structures of **X**, **Y** and **Z**.

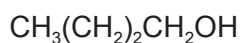


[3]

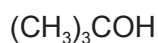
(iii) Deduce the molecular formula of **X**, **Y** and **Z**.

..... [1]

(b) The structures of **V** and **W** are shown.



V



W

(i) Name the class of compound that **V** and **W** each belong to.

V

W

[2]

(ii) **V** and **W** both react with sodium metal.

Write an equation for the reaction of **V** with sodium metal.

..... [1]

(iii) Name a reagent used to distinguish **V** from **W**. Describe any observations.

reagent

observations with **V**

observations with **W**

[3]

[Total: 11]

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