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CHEMISTRY

9701/21

Paper 2 AS Level Structured Questions

May/June 2016

1 hour 15 minutes

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

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Write in dark blue or black pen.

You may use an HB pencil for any diagrams or graphs.

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Answer **all** questions.

Electronic calculators may be used.

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The number of marks is given in brackets [] at the end of each question or part question.

This document consists of **12** printed pages.



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

- 1 (a) Complete the table to show the composition and identity of some atoms and ions.

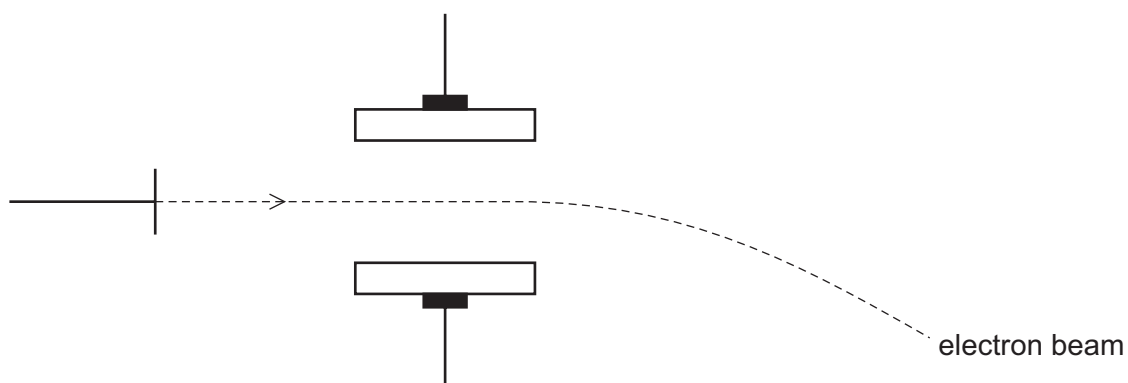
name of element	nucleon number	atomic number	number of protons	number of neutrons	number of electrons	overall charge
lithium	6	3	.....	.....	.....	+1
oxygen	.....	.....	.....	9	10	.....
.....	54	26	26	.....	24	.....
.....	.....	.....	17	18	.....	0

[4]

- (b) Beams of protons, neutrons and electrons behave differently in an electric field due to their differing properties.

The diagram shows the path of a beam of electrons in an electric field.

Add and label lines to represent the paths of beams of protons and neutrons in the same field.



[3]

- (c) The fifth to eighth ionisation energies of three elements in the third period of the Periodic Table are given. The symbols used for reference are **not** the actual symbols of the elements.

	ionisation energies, kJ mol^{-1}			
	fifth	sixth	seventh	eighth
X	6274	21 269	25 398	29 855
Y	7012	8496	27 107	31 671
Z	6542	9362	11 018	33 606

- (i) State and explain the group number of element **Y**.

group number

explanation

[1]

- (ii) State and explain the general trend in **first** ionisation energies across the third period.

.....

.....

..... [2]

- (iii) Explain why the **first** ionisation energy of element **Y** is less than that of element **X**.

.....

.....

.....

..... [2]

- (iv) Complete the electronic configuration of element **Z**.

$1s^2$ [1]

- (d) A sample of strontium exists as a mixture of four isotopes. Information about three of these isotopes is given in the table.

mass number	86	87	88
abundance	9.86%	7.00%	82.58%

- (i) Calculate the abundance of the fourth isotope.

abundance = ... % [1]

- (ii) The relative atomic mass of this sample of strontium is 87.71.

Calculate the mass number of the fourth isotope.

mass number = ... [2]

[Total: 16]

- 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, 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 G_8 molecules. **G** burns in air to form GO_2 which dissolves in water to form an acidic solution. This solution reacts with sodium hydroxide to form the salt Na_2GO_3 .

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

D **G** [1]

- (b) Write equations for the reactions of D_2O_3 with

- (i) hydrochloric acid,

..... [2]

- (ii) sodium hydroxide.

..... [2]

- (c) Suggest the type of bonding and structure in D_2O_3 .

..... [1]

- (d) Write an equation for the formation of an acidic solution when GO_2 dissolves in water.

..... [1]

[Total: 7]

3 The elements in Group 2, and their compounds, show many similarities and trends in their properties.

(a) Magnesium, calcium, strontium and barium all react with cold water.

(i) Describe what you would **see** when some calcium is added to cold water.

.....
.....
..... [3]

(ii) Write an equation for the reaction taking place in (i).

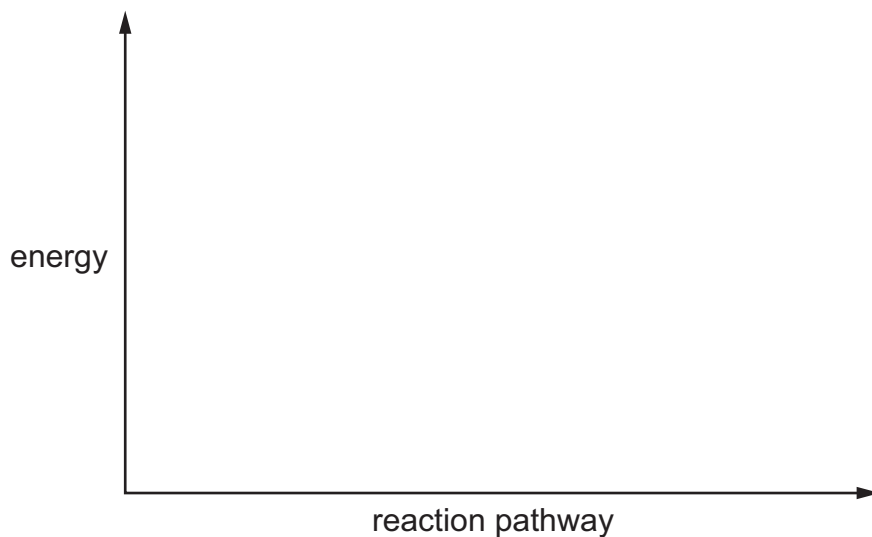
..... [1]

(iii) Describe how the reaction of barium with cold water would differ from the reaction of calcium in (i) in terms of what you would **see**.

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

(b) Magnesium oxide can be formed by the reaction of magnesium and oxygen in the air.

(i) Draw a **fully labelled** reaction pathway diagram for the reaction between magnesium and oxygen.



[2]

(ii) Explain why there is no visible reaction when a piece of magnesium ribbon is exposed to the air.

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

- (iii) Magnesium oxide is used to manufacture heat-resistant bricks for furnace linings in the steel-making industry.

State and explain the property of magnesium oxide that makes it suitable for this use.

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

- (iv) Suggest a reason why magnesium oxide cannot be used as a lining for any furnaces containing acidic materials.

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

- (c) The nitrates and carbonates of the Group 2 elements, from magnesium to barium, decompose when heated.

- (i) State the trend in the temperature of thermal decomposition of these Group 2 nitrates and carbonates.

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

- (ii) Give the equation for the thermal decomposition of magnesium carbonate.

..... [1]

- (iii) Give the equation for the thermal decomposition of calcium nitrate.

..... [1]

[Total: 15]

4 This question is about molecules with molecular formula C_4H_8 .

(a) Give the structures of a pair of **positional** isomers with the formula C_4H_8 .



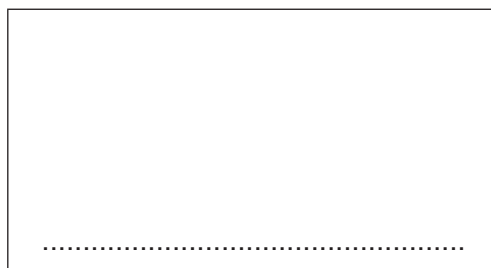
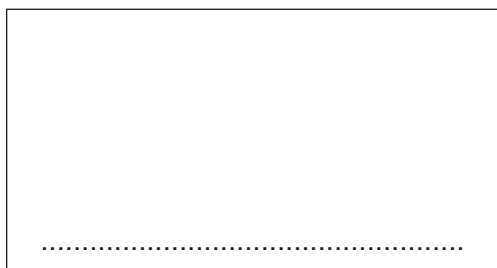
[1]

(b) Give the structures of a pair of **chain** isomers with the formula C_4H_8 , that do **not** exhibit stereoisomerism.



[1]

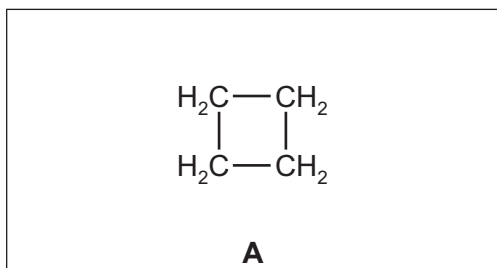
(c) Give the structures and full names of a pair of **stereoisomers** with the formula C_4H_8 .



[2]

(d) The structure of a molecule, **A**, of formula C_4H_8 is shown.

Draw a functional group isomer of molecule **A** in box **B**. Explain how molecules **A** and **B** could be distinguished by a chemical test.



.....

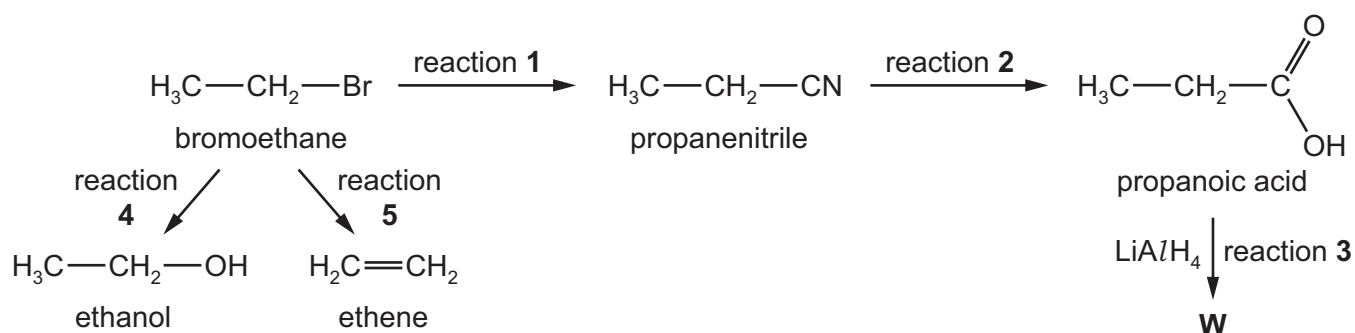
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..... [3]

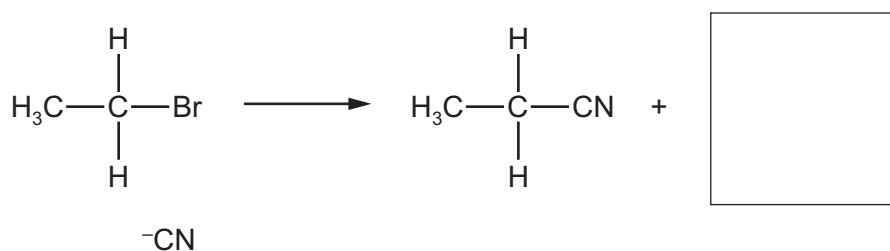
[Total: 7]

Question 5 starts on the next page.

5 A reaction sequence is shown.



(a) Complete the diagram to show the mechanism of reaction 1. Include all necessary charges, partial charges, lone pairs and curly arrows.

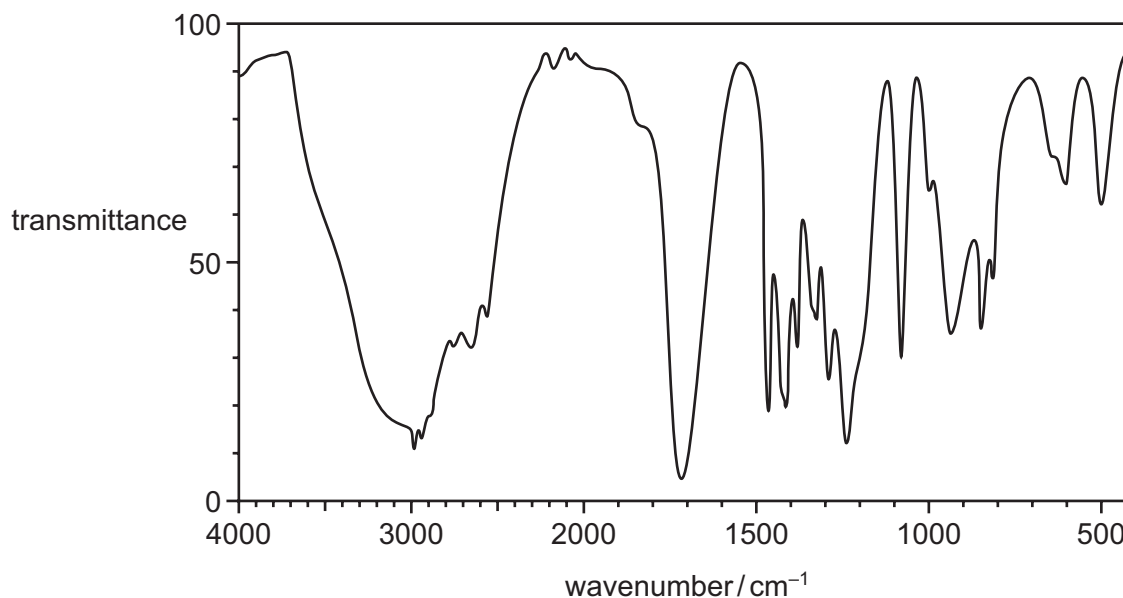


[2]

(b) (i) Give the name of the type of reaction involved in reaction 3.

..... [1]

The infra-red spectrum of the propanoic acid produced by reaction 2 is shown.



(ii) Describe and explain the main difference between the infra-red spectrum of **W** and that of propanoic acid.

..... [2]

- (c) (i) Reactions 4 and 5 use the same reagent.

Give the reagent and conditions needed for reaction 4.

reagent

conditions [2]

- (ii) Give the conditions needed for reaction 5.

..... [1]

- (d) Under appropriate conditions, ethanol and propanoic acid undergo a condensation reaction.

- (i) State the condition necessary for the reaction.

..... [1]

- (ii) Draw the skeletal formula of the organic product of this reaction.

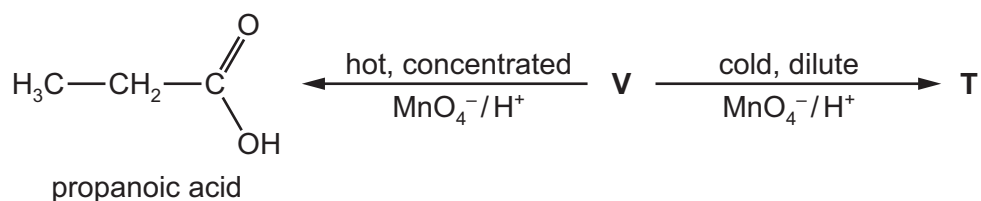
[1]

- (iii) Name the organic product of this reaction.

..... [1]

Question 5 continues over the page.

- (e) **V** reacts with acidified manganate(VII) ions in two different ways depending on the conditions, as shown in the reaction sequence below.



V decolourises bromine water.

When the acidified manganate(VII) is hot and concentrated, propanoic acid is the only organic product.

When the acidified manganate(VII) is cold and dilute, the organic product is **T** which has two chiral centres.

- (i) Give the structural formulae of **V** and **T**.

V **T** [2]

- (ii) Identify the types of stereoisomerism shown by **V** and **T**.

V **T** [2]

[Total: 15]

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- 1 (a) Complete the table to show the composition and identity of some atoms and ions.

name of element	nucleon number	atomic number	number of protons	number of neutrons	number of electrons	overall charge
boron	10	5	.....	.....	.....	0
nitrogen	.....	.....	.....	8	10	.....
.....	208	82	82	.....	80	.....
.....	.....	.....	3	3	.....	+1

[4]

- (b) The fifth to eighth ionisation energies of three elements in the third period of the Periodic Table are given. The symbols used for reference are **not** the actual symbols of the elements.

	ionisation energies, kJ mol ⁻¹			
	fifth	sixth	seventh	eighth
X	7012	8496	27 107	31 671
Y	6542	9362	11 018	33 606
Z	7238	8781	11 996	13 842

- (i) State and explain the group number of element **Y**.

group number

explanation

[1]

- (ii) State and explain the general trend in **first** ionisation energies across the third period.

.....

.....

..... [2]

- (iii) Complete the electronic configuration of element **X**.

1s² [1]

- (c) A sample of oxygen exists as a mixture of three isotopes. Information about two of these isotopes is given in the table.

mass number	16	17
abundance	99.76%	0.04%

- (i) Calculate the abundance of the third isotope.

abundance = ... % [1]

- (ii) The relative atomic mass of this sample of oxygen is 16.0044.

Calculate the mass number of the third isotope. You **must** show your working.

mass number = ... [2]

[Total: 11]

- 2 The elements in Group 17, the halogens, and their compounds, show many similarities and trends in their properties. Some data are given for the elements fluorine to iodine.

element	bond energy /kJ mol ⁻¹	standard enthalpy change of atomisation, $\Delta H_{\text{at}}^{\ominus}$ /kJ mol ⁻¹	boiling point of element /K	boiling point of hydrogen halide /K
fluorine, F–F	158	79	85	293
chlorine, Cl–Cl	242	121	238	188
bromine, Br–Br	193	112	332	206
iodine, I–I	151	107	457	238

- (a) (i) Explain the meaning of the term *standard enthalpy change of atomisation*.

.....

 [3]

- (ii) For fluorine and chlorine, the enthalpy changes of atomisation are half the value of the bond energies.

For bromine and iodine, the enthalpy changes of atomisation are much more than half the value of the bond energies.

Suggest a reason for this difference.

.....

 [1]

- (iii) The standard enthalpy of formation of iodine monochloride, ICl, is –24.0 kJ mol⁻¹.

Use this information and the bond energies of iodine and chlorine to calculate the I–Cl bond energy.

I–Cl bond energy = ... kJ mol⁻¹ [2]

- (b) (i) Explain the trend in the boiling points of the hydrogen halides, HCl , HBr and HI .

.....

 [2]

- (ii) Suggest why the hydrogen halide HF does not follow the trend in boiling points shown by HCl , HBr and HI .

.....

 [2]

- (c) In an experiment, two of the halogens are represented as P_2 and Q_2 .

P_2 combines with hydrogen on heating to form HP , which can be easily broken down into its elements. A solution of HP in water reacts with aqueous silver ions to form a yellow precipitate that is insoluble in dilute aqueous ammonia.

Q_2 combines explosively with hydrogen in sunlight to form HQ , which is stable to heat. A solution of HQ in water reacts with aqueous silver ions to form a white precipitate that is soluble in dilute aqueous ammonia.

- (i) Identify the halogens P_2 and Q_2 .

$\text{P}_2 =$ $\text{Q}_2 =$ [1]

- (ii) HP readily decomposes into its elements when heated but HQ is stable to heat. Explain this with reference to bond energies.

.....

 [2]

- (iii) Write an equation for the thermal decomposition of HP .

..... [1]

(iv) Write ionic equations, including state symbols, for

1. the formation of the white precipitate on addition of aqueous silver ions to aqueous HQ,

.....

2. the subsequent dissolving of this precipitate in dilute aqueous ammonia.

.....

[2]

(d) Chlorine reacts directly with many elements to form chlorides. Three such compounds are MgCl_2 , AlCl_3 and SiCl_4 .

(i) State and explain the pattern shown by the formulae of these three chlorides.

.....

.....

..... [2]

(ii) Write equations to show the behaviour of each of these chlorides when added to water.

MgCl_2

AlCl_3

SiCl_4

[3]

[Total: 21]

- 3 Acidified potassium dichromate(VI) can oxidise ethanedioic acid, $\text{H}_2\text{C}_2\text{O}_4$.
The relevant half-equations are shown.



- (a) State the overall equation for the reaction between acidified dichromate(VI) ions and ethanedioic acid.

..... [2]

- (b) In an experiment a 0.242 g sample of hydrated ethanedioic acid, $\text{H}_2\text{C}_2\text{O}_4 \cdot x\text{H}_2\text{O}$, was reacted with a $0.0200 \text{ mol dm}^{-3}$ solution of acidified potassium dichromate(VI).

32.0 cm^3 of the acidified potassium dichromate(VI) solution was required for complete oxidation of the ethanedioic acid.

- (i) Calculate the amount, in moles, of dichromate(VI) ions used to react with the sample of ethanedioic acid.

amount = ... mol [1]

- (ii) Calculate the amount, in moles, of ethanedioic acid in the sample.

amount = ... mol [1]

- (iii) Calculate the relative molecular mass, M_r , of the hydrated ethanedioic acid.

M_r = ... [1]

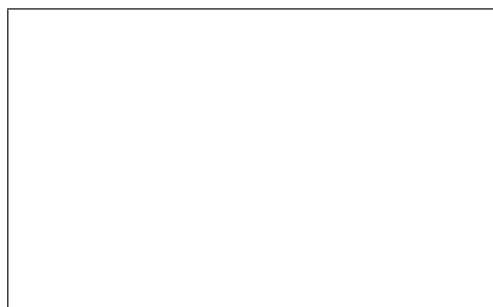
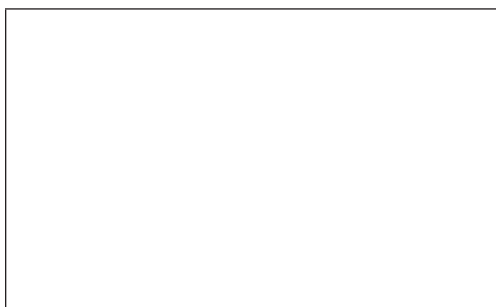
- (iv) Calculate the value of x in $\text{H}_2\text{C}_2\text{O}_4 \cdot x\text{H}_2\text{O}$.

x = ... [1]

[Total: 6]

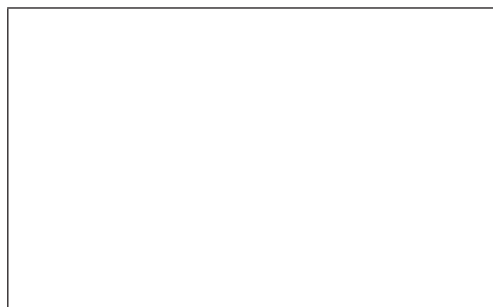
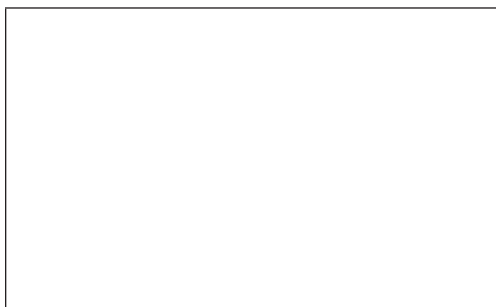
4 This question is about molecules with molecular formula $C_4H_8O_2$.

- (a) Give the structural formulae of the pair of **chain** isomers with the formula $C_4H_8O_2$ that are carboxylic acids.



[2]

- (b) (i) Give the structural formulae of a pair of **positional** isomers with the formula $C_4H_8O_2$ that are esters.



[2]

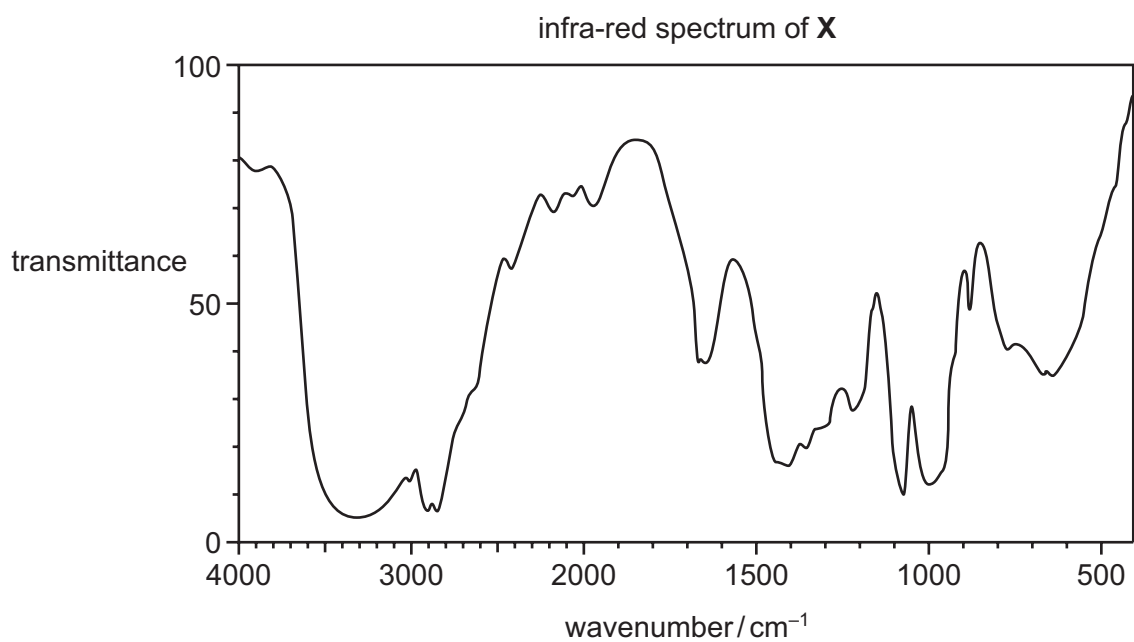
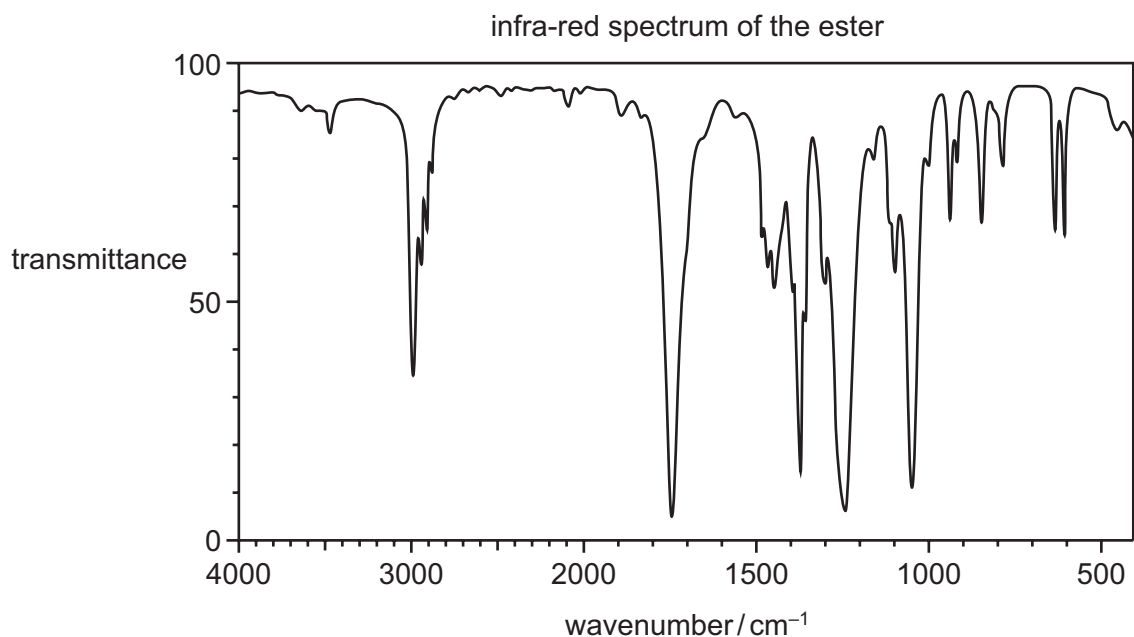
- (ii) Give the reagents and conditions needed to produce one of your esters in (i).

.....

..... [2]

(c) The infra-red spectra of one of the esters and of another isomer, **X**, are shown.

X decolourises bromine water and is not an ester or an acid.



Explain the differences between these two spectra, with particular reference to the peaks with wavenumbers above 1500 cm^{-1} .

.....

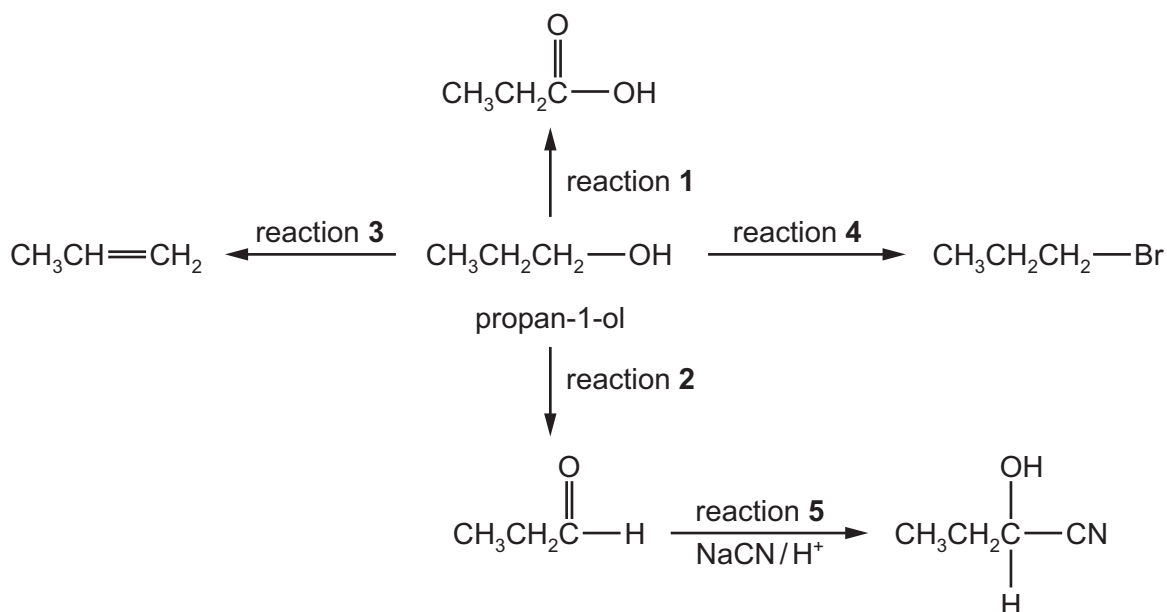
.....

.....

..... [3]

[Total: 9]

- 5 A reaction sequence based on propan-1-ol is shown.



- (a) Reactions 1 and 2 can both be carried out using the same reagents.

- (i) Identify suitable reagents for reactions 1 and 2.

.....
 [1]

- (ii) State and explain how the reaction should be carried out to ensure that reaction 2 rather than reaction 1 occurs.

.....

 [2]

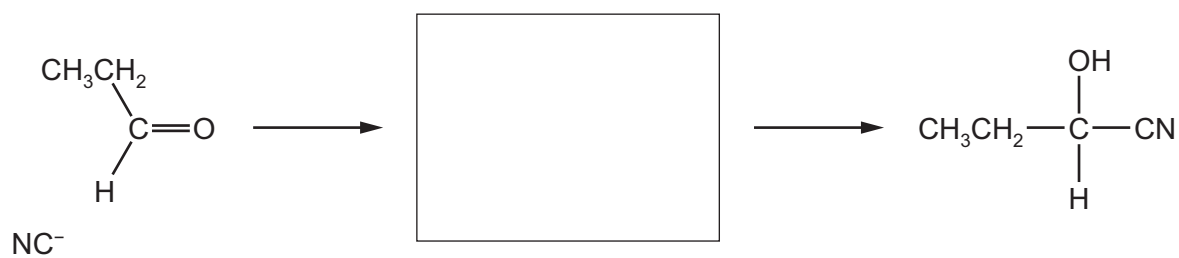
- (b) Identify the necessary reagents and conditions for each of reactions 3 and 4.

reaction 3

 reaction 4

[2]

- (c) (i) Complete the reaction mechanism for reaction 5. Include all relevant lone pairs, curly arrows, charges and partial charges.



[4]

The product of reaction **5** exhibits stereoisomerism.

- (ii) Draw the two stereoisomers in the conventional way.



[2]

- (iii) Suggest why a mixture of the two stereoisomers is formed by reaction 5.

..... [2]

[Total: 13]

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* 3 2 8 0 2 9 6 2 8 3 *



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1 An experiment was carried out to determine the percentage of iron in a sample of iron wire.

(a) A 3.35 g piece of the wire was reacted with dilute sulfuric acid, in the absence of air, so that all of the iron atoms were converted to iron(II) ions. The resulting solution was made up to 250 cm³.

(i) Write a balanced equation for the reaction between the iron in the wire and the sulfuric acid.

..... [1]

A 25.0 cm³ sample of this solution was acidified and titrated with 0.0250 mol dm⁻³ potassium dichromate(VI). 32.0 cm³ of the potassium dichromate(VI) solution was required for complete reaction with the iron(II) ions in the sample.

The relevant half-equations are shown.



(ii) Use the half-equations to write an equation for the reaction between the iron(II) ions and the acidified dichromate(VI) ions.

..... [1]

(iii) Calculate the amount, in moles, of dichromate(VI) ions used in the titration.

amount = ... mol [1]

(iv) Calculate the amount, in moles, of iron(II) ions in the 25.0 cm³ sample of solution.

amount = ... mol [1]

(v) Calculate the amount, in moles, of iron in the 3.35 g piece of wire.

amount = ... mol [1]

(vi) Calculate the mass of iron in the 3.35 g piece of wire.

mass = ... g [1]

(vii) Calculate the percentage of iron in the iron wire.

percentage = ... % [1]

(b) Some electronegativity values are shown.

element	electronegativity
aluminium	1.5
chlorine	3.0
iron	1.8

(i) Use the data to suggest the nature of the bonding in iron(III) chloride. Explain your answer.

.....

 [2]

(ii) Suggest an equation for the reaction between iron(III) chloride and water.

..... [1]

[Total: 10]

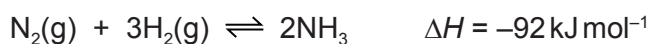
- 2 Ammonium nitrate is an important fertiliser made by the acid-base reaction between ammonia and nitric acid.

(a) Write an equation for the production of ammonium nitrate from ammonia and nitric acid.

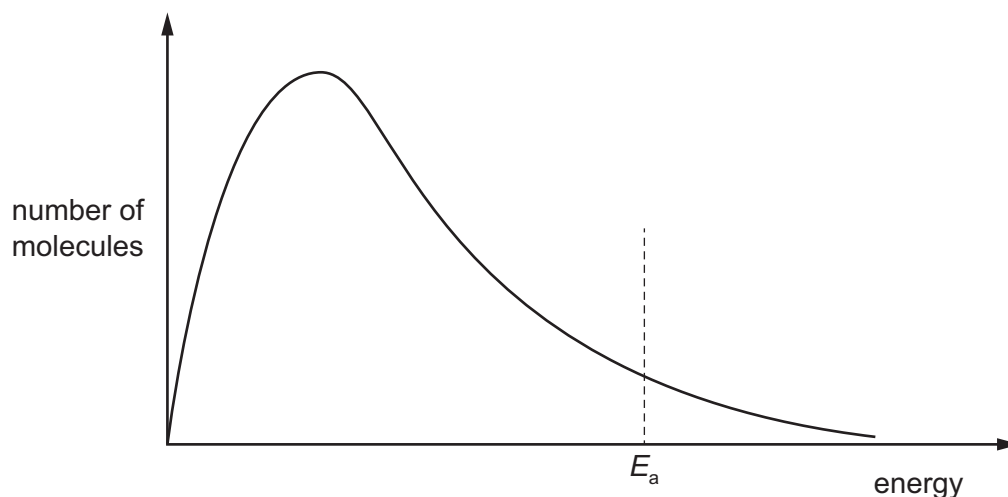
..... [1]

The ammonia for this reaction is produced by the Haber process and the nitric acid is produced by oxidation of ammonia.

- (b) The Haber process involves a reaction between nitrogen and hydrogen at a temperature of 450 °C and a pressure of 20 000 kPa. At a higher reaction temperature, the rate of production of ammonia would be greater.



The Boltzmann distribution curve shows the distribution of energies in a mixture of nitrogen and hydrogen at 450 °C.



- (i) Sketch a second line onto the axes above to show the distribution of energies in the same mixture of gases at a higher temperature. [2]
- (ii) With reference to the two curves, explain why the rate of production of ammonia would be greater at a higher temperature.

..... [2]

.....

.....

- (iii) Add a suitable label to the horizontal axis above and use it to explain why a catalyst is used in the Haber process.

..... [2]

.....

.....

- (iv) Explain why a higher temperature is **not** used despite the fact that it would increase the rate of production of ammonia.

.....

 [2]

- (c) The first stage in the production of nitric acid involves the reaction of ammonia with oxygen to form nitrogen monoxide, NO, and water.

Suggest an equation for this reaction and use oxidation numbers to show that it is a redox reaction.

.....

 [3]

- (d) (i) Draw a dot-and-cross diagram of the ammonium ion. Show the outer electrons only. Use the following code for your electrons.
- electrons from nitrogen
 - × electrons from hydrogen

[2]

- (ii) State the shape of an ammonium ion and give the H–N–H bond angle.

shape

bond angle [2]

- (e) State and explain the problems that arise from the overuse of ammonium nitrate fertiliser when the excess is washed into rivers.

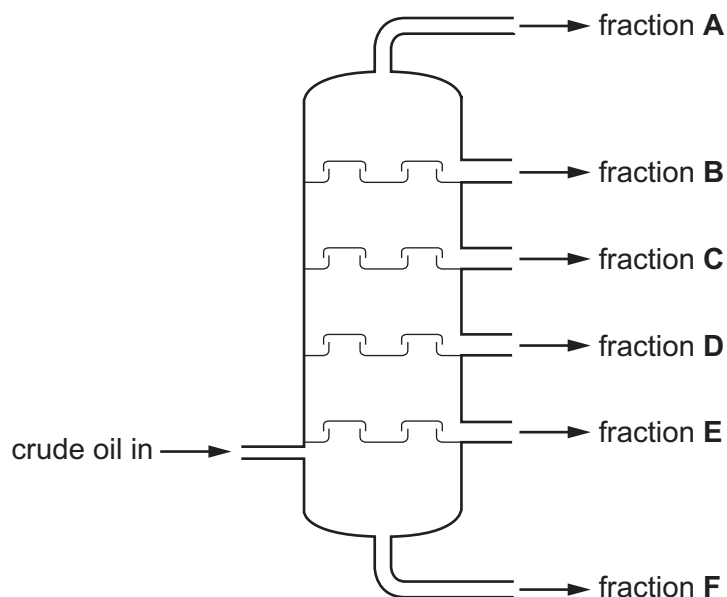
.....

 [3]

[Total: 19]

- 3 Crude oil is a mixture of hydrocarbons and provides many useful chemicals when processed. Two of the stages involved in the processing of crude oil are fractional distillation and cracking.

(a) The diagram is a simplified representation of a fractional distillation column.



- (i) What has to be done to the crude oil before it enters the column?

..... [1]

- (ii) What trend in **structure** is there from fraction **A** to fraction **F**?

.....
 [1]

- (iii) State the trends in **two** properties of the fractions from **A** to **F**.

.....

 [2]

- (b) The naphtha fraction from fractional distillation of crude oil is used as a starting material for cracking.

- (i) Write an equation for the cracking of $C_{12}H_{26}$ to form the products ethene and one other hydrocarbon in a 2 : 1 mole ratio.

..... [1]

- (ii) Suggest a use for each of the products from your equation in (i). Explain what makes each product from (i) suitable for the use you suggest.

use of ethene

.....

explanation

.....

use of other product

.....

explanation

.....

[4]

- (c) Burning hydrocarbons can cause a number of environmental problems.

The products of internal combustion engines can include oxides of nitrogen and oxides of carbon.

Sulfur dioxide is a by-product of burning coal in power stations.

- (i) Explain how and why oxides of nitrogen are produced in internal combustion engines.

.....

.....

..... [2]

- (ii) Write an equation for the reaction between nitrogen monoxide and carbon monoxide in a catalytic converter.

..... [1]

- (iii) Write equations to show the involvement of nitrogen monoxide in the formation of acid rain from atmospheric sulfur dioxide.

.....

.....

..... [3]

- (iv) Describe two of the problems associated with acid rain.

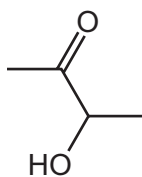
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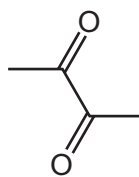
..... [2]

[Total: 17]

- 4 Acetoin, $\text{CH}_3\text{COCH}(\text{OH})\text{CH}_3$, and diacetyl, $\text{CH}_3\text{COCOCH}_3$, are two of the compounds that give butter its characteristic flavour. Their skeletal formulae are shown.



acetoin



diacetyl

- (a) Give the systematic name for acetoin.

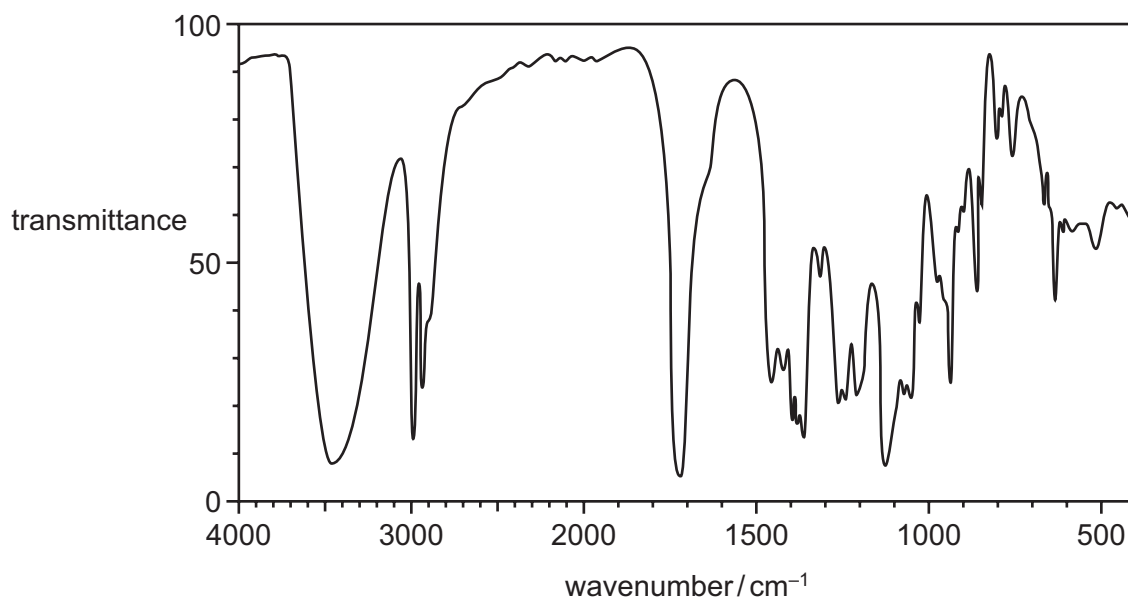
..... [1]

- (b) Identify the reagents and conditions necessary for the conversion of acetoin into diacetyl.

.....

..... [2]

- (c) The infra-red spectrum for acetoin is shown.



- (i) Explain the main features of this spectrum, with reference to the peaks with wavenumbers greater than 1500 cm^{-1} .

.....

.....

.....

.....

..... [3]

- (ii) State and explain how the infra-red spectrum for diacetyl would differ from the infra-red spectrum for acetoin.

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

- (d) If a sample of acetoin is reacted with concentrated sulfuric acid, a single product is formed that does **not** exhibit stereoisomerism.

However, if a sample of acetoin is reacted with HBr, a mixture of a pair of stereoisomers is produced.

- (i) Give the structural formula of the product of the reaction of acetoin with concentrated sulfuric acid.

..... [1]

- (ii) Explain why the product in (i) does **not** exhibit stereoisomerism.

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

- (iii) Explain why the product of reaction of acetoin with HBr **does** exhibit stereoisomerism.

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

- (iv) Draw the two stereoisomers from (iii) using the conventional representation.

.....

[2]

[Total: 14]

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