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

1 Fluorine forms many compounds that contain covalent bonds.

1 (a) (i) State the meaning of the term *covalent bond*.

.....

.....

(1 mark)

1 (a) (ii) Write an equation to show the formation of one molecule of ClF_3 from chlorine and fluorine molecules.

.....

(1 mark)

1 (b) Draw the shape of a dichlorodifluoromethane molecule (CCl_2F_2) and the shape of a chlorine trifluoride molecule (ClF_3). Include any lone pairs of electrons that influence the shape.

Shape of CCl_2F_2 Shape of ClF_3

(2 marks)

1 (c) Suggest the strongest type of intermolecular force between CCl_2F_2 molecules.

.....

(1 mark)

1 (d) BF_3 is a covalent molecule that reacts with an F^- ion to form a BF_4^- ion.

1 (d) (i) Name the type of bond formed when a molecule of BF_3 reacts with an F^- ion. Explain how this bond is formed.

Type of bond .....

Explanation .....

.....

.....

.....

(3 marks)

(Extra space) .....

.....

1 (d) (ii) State the bond angle in the BF_4^- ion.

.....

(1 mark)

1 (e) An ultrasound imaging agent has the formula C_4F_{10}
It can be made by the reaction of butane and fluorine as shown in the following equation.

$$C_4H_{10} + 10F_2 \longrightarrow C_4F_{10} + 10HF$$

Calculate the percentage atom economy for the formation of C_4F_{10} in this reaction. Give your answer to three significant figures.

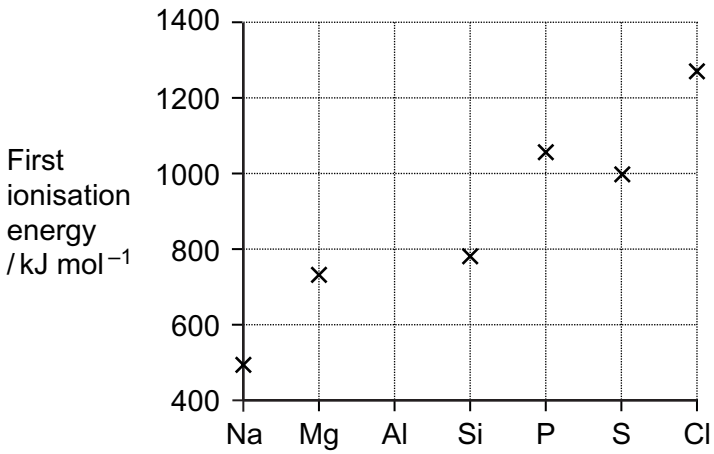
.....

.....

(2 marks)

11

2 The following diagram shows the first ionisation energies of some Period 3 elements.



2 (a) Draw a cross on the diagram to show the first ionisation energy of aluminium.

(1 mark)

2 (b) Write an equation to show the process that occurs when the first ionisation energy of aluminium is measured.

.....

(2 marks)

2 (c) State which of the first, second or third ionisations of aluminium would produce an ion with the electron configuration $1s^2\ 2s^2\ 2p^6\ 3s^1$

.....

(1 mark)

2 (d) Explain why the value of the first ionisation energy of sulfur is less than the value of the first ionisation energy of phosphorus.

.....

.....

.....

.....

(2 marks)

(Extra space) .....

.....

2 (e) Identify the element in Period 2 that has the highest first ionisation energy and give its electron configuration.

Element .....

Electron configuration .....

(2 marks)

2 (f) State the trend in first ionisation energies in Group 2 from beryllium to barium. Explain your answer in terms of a suitable model of atomic structure.

Trend.....

Explanation .....

.....

.....

.....

(3 marks)

(Extra space) .....

.....

11

Turn over for the next question

3 In this question give all your answers to three significant figures.

Magnesium nitrate decomposes on heating to form magnesium oxide, nitrogen dioxide and oxygen as shown in the following equation.

$$2Mg(NO_3)_2(s) \longrightarrow 2MgO(s) + 4NO_2(g) + O_2(g)$$

3 (a) Thermal decomposition of a sample of magnesium nitrate produced 0.741 g of magnesium oxide.

3 (a) (i) Calculate the amount, in moles, of MgO in 0.741 g of magnesium oxide.

.....

.....

(2 marks)

3 (a) (ii) Calculate the total amount, in moles, of gas produced from this sample of magnesium nitrate.

.....

.....

(1 mark)

3 (b) In another experiment, a different sample of magnesium nitrate decomposed to produce 0.402 mol of gas. Calculate the volume, in dm^3, that this gas would occupy at 333 K and 1.00×10^5 Pa.
(The gas constant $R = 8.31\ J\ K^{-1}\ mol^{-1}$)

.....

.....

.....

.....

(3 marks)

(Extra space) .....

.....

.....

3 (c) A 0.0152 mol sample of magnesium oxide, produced from the decomposition of magnesium nitrate, was reacted with hydrochloric acid.

$$MgO + 2HCl \longrightarrow MgCl_2 + H_2O$$

3 (c) (i) Calculate the amount, in moles, of HCl needed to react completely with the 0.0152 mol sample of magnesium oxide.

.....

(1 mark)

3 (c) (ii) This 0.0152 mol sample of magnesium oxide required 32.4 cm^3 of hydrochloric acid for complete reaction. Use this information and your answer to part **(c) (i)** to calculate the concentration, in mol dm^{-3}, of the hydrochloric acid.

.....

.....

.....

(1 mark)

8

Turn over for the next question

4 There are several oxides of nitrogen.

4 (a) An oxide of nitrogen contains 25.9% by mass of nitrogen. Determine the empirical formula of this oxide.

.....

.....

.....

.....

(3 marks)

(Extra space) .....

.....

.....

4 (b) Give **one** reason why the oxide NO is a pollutant gas.

.....

.....

(1 mark)

4 (c) The oxide NO reacts with oxygen to form nitrogen dioxide. Write an equation for this reaction.

.....

(1 mark)

4 (d) Explain how NO is produced in the engine of a motor vehicle.

.....

.....

.....

(2 marks)

4 (e) Write an equation to show how NO is removed from the exhaust gases in motor vehicles using a catalytic converter.

.....

(1 mark)

8

5 The alkane butane is used as a fuel.

5 (a) (i) Write an equation for the complete combustion of butane.

.....

(1 mark)

5 (a) (ii) State a condition which may cause carbon to be formed as a product in the combustion of butane.

.....

(1 mark)

5 (b) Butane obtained from crude oil may contain trace amounts of an impurity.
When this impurity burns it produces a toxic gas that can be removed by reacting it with calcium oxide coated on a mesh.

5 (b) (i) Suggest the identity of the toxic gas.

.....

(1 mark)

5 (b) (ii) Suggest why calcium oxide reacts with the toxic gas.

.....

(1 mark)

5 (b) (iii) Suggest why the calcium oxide is coated on a mesh.

.....

(1 mark)

5

Turn over for the next question

6 Pent-1-ene is a member of the alkene homologous series.

6 (a) Pent-1-ene can be separated from other alkenes.

State the physical property of alkenes that allows them to be separated from a mixture by fractional distillation.

.....

(1 mark)

6 (b) (i) State the meaning of the term *structural isomerism*.

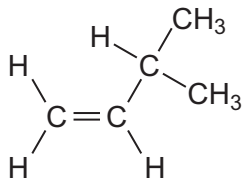
.....

.....

.....

(2 marks)

6 (b) (ii) Name the branched chain isomer of pent-1-ene shown below.



.....

(1 mark)

6 (b) (iii) Draw the structure of a functional group isomer of pent-1-ene.

(1 mark)

6 (c) The cracking of one molecule of compound **X** produces pent-1-ene, ethene and butane in a 1:2:1 mol ratio.
Deduce the molecular formula of **X** and state a use for the ethene formed.

Molecular formula of **X** .....

.....

Use of ethene .....

(2 marks)

7

Turn over for the next question

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

7 Iodine and graphite are both solids. When iodine is heated gently a purple vapour is seen. Graphite will not melt until the temperature reaches 4000 K. Graphite conducts electricity but iodine is a very poor conductor of electricity.

7 (a) State the type of crystal structure for each of iodine and graphite.

.....

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.....

(2 marks)

7 (b) Describe the structure of and bonding in graphite and explain why the melting point of graphite is very high.

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(4 marks)

(Extra space) .....

.....

.....

.....

7 (c) Explain why iodine vaporises when heated gently.

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(2 marks)

7 (d) State why iodine is a very poor conductor of electricity.

.....

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(1 mark)

9

Turn over for the next question

8 (a) Define the term *mass number* of an atom.

The mass number of an isotope of nitrogen is 15. Deduce the number of each of the fundamental particles in an atom of ^{15}N

.....

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(3 marks)

(Extra space) .....

.....

.....

8 (b) Define the term *relative atomic mass*.

An organic fertiliser was analysed using a mass spectrometer. The spectrum showed that the nitrogen in the fertiliser was made up of 95.12% ^{14}N and 4.88% ^{15}N

Calculate the relative atomic mass of the nitrogen found in this organic fertiliser. Give your answer to two decimal places.

.....

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(4 marks)

(Extra space) .....

.....

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.....

8 (c) In a mass spectrometer, under the same conditions, $^{14}N^+$ and $^{15}N^+$ ions follow different paths. State the property of these ions that causes them to follow different paths.

State **one** change in the operation of the mass spectrometer that will change the path of an ion.

.....

.....

.....

.....

(2 marks)

Question 8 continues on the next page

8 (d) Organic fertilisers contain a higher proportion of ^{15}N atoms than are found in synthetic fertilisers.

State and explain whether or not you would expect the chemical reactions of the nitrogen compounds in the synthetic fertiliser to be different from those in the organic fertiliser. Assume that the nitrogen compounds in each fertiliser are the same.

.....

.....

.....

.....

(2 marks)

11

END OF QUESTIONS

GCE Chemistry Data Sheet

Table 1

Infrared absorption data

Bond	Wavenumber /cm^{-1}
N—H (amines)	3300 – 3500
O—H (alcohols)	3230 – 3550
C—H	2850 – 3300
O—H (acids)	2500 – 3000
C≡N	2220 – 2260
C=O	1680 – 1750
C=C	1620 – 1680
C—O	1000 – 1300
C—C	750 – 1100

Table 2

^{1}H n.m.r. chemical shift data

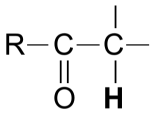
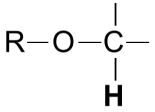
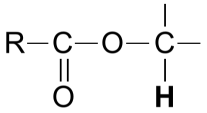
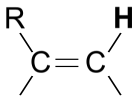
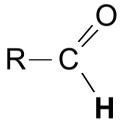
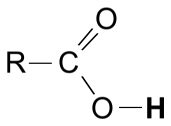
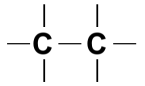
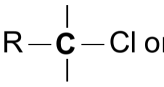
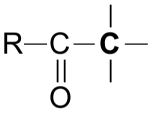
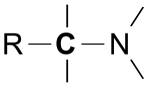
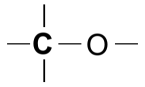
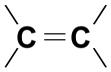
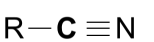
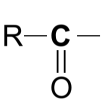
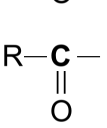
Type of proton	δ/ppm
ROH	0.5 – 5.0
RCH$_3$	0.7 – 1.2
RNH$_2$	1.0 – 4.5
R$_2$CH$_2$	1.2 – 1.4
R$_3$CH	1.4 – 1.6
	2.1 – 2.6
	3.1 – 3.9
RCH$_2$Cl or Br	3.1 – 4.2
	3.7 – 4.1
	4.5 – 6.0
	9.0 – 10.0
	10.0 – 12.0

Table 3

^{13}C n.m.r. chemical shift data

Type of carbon	δ/ppm
	5 – 40
	10 – 70
	20 – 50
	25 – 60
 alcohols, ethers or esters	50 – 90
	90 – 150
	110 – 125
	110 – 160
 esters or acids	160 – 185
 aldehydes or ketones	190 – 220

The Periodic Table of the Elements

1	2											3	4	5	6	7	0
																	(18)
							1.0 **H** hydrogen 1										4.0 **He** helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 **Li** lithium 3	9.0 **Be** beryllium 4		relative atomic mass **symbol** name atomic (proton) number									10.8 **B** boron 5	12.0 **C** carbon 6	14.0 **N** nitrogen 7	16.0 **O** oxygen 8	19.0 **F** fluorine 9	20.2 **Ne** neon 10
23.0 **Na** sodium 11	24.3 **Mg** magnesium 12	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	27.0 **Al** aluminium 13	28.1 **Si** silicon 14	31.0 **P** phosphorus 15	32.1 **S** sulfur 16	35.5 **Cl** chlorine 17	39.9 **Ar** argon 18
39.1 **K** potassium 19	40.1 **Ca** calcium 20	45.0 **Sc** scandium 21	47.9 **Ti** titanium 22	50.9 **V** vanadium 23	52.0 **Cr** chromium 24	54.9 **Mn** manganese 25	55.8 **Fe** iron 26	58.9 **Co** cobalt 27	58.7 **Ni** nickel 28	63.5 **Cu** copper 29	65.4 **Zn** zinc 30	69.7 **Ga** gallium 31	72.6 **Ge** germanium 32	74.9 **As** arsenic 33	79.0 **Se** selenium 34	79.9 **Br** bromine 35	83.8 **Kr** krypton 36
85.5 **Rb** rubidium 37	87.6 **Sr** strontium 38	88.9 **Y** yttrium 39	91.2 **Zr** zirconium 40	92.9 **Nb** niobium 41	96.0 **Mo** molybdenum 42	[98] **Tc** technetium 43	101.1 **Ru** ruthenium 44	102.9 **Rh** rhodium 45	106.4 **Pd** palladium 46	107.9 **Ag** silver 47	112.4 **Cd** cadmium 48	114.8 **In** indium 49	118.7 **Sn** tin 50	121.8 **Sb** antimony 51	127.6 **Te** tellurium 52	126.9 **I** iodine 53	131.3 **Xe** xenon 54
132.9 **Cs** caesium 55	137.3 **Ba** barium 56	138.9 **La** * lanthanum 57	178.5 **Hf** hafnium 72	180.9 **Ta** tantalum 73	183.8 **W** tungsten 74	186.2 **Re** rhenium 75	190.2 **Os** osmium 76	192.2 **Ir** iridium 77	195.1 **Pt** platinum 78	197.0 **Au** gold 79	200.6 **Hg** mercury 80	204.4 **Tl** thallium 81	207.2 **Pb** lead 82	209.0 **Bi** bismuth 83	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
[223] **Fr** francium 87	[226] **Ra** radium 88	[227] **Ac** † actinium 89	[267] **Rf** rutherfordium 104	[268] **Db** dubnium 105	[271] **Sg** seaborgium 106	[272] **Bh** bohrium 107	[270] **Hs** hassium 108	[276] **Mt** meitnerium 109	[281] **Ds** darmstadtium 110	[280] **Rg** roentgenium 111	Elements with atomic numbers 112-116 have been reported but not fully authenticated						

140.1 **Ce** cerium 58	140.9 **Pr** praseodymium 59	144.2 **Nd** neodymium 60	[145] **Pm** promethium 61	150.4 **Sm** samarium 62	152.0 **Eu** europium 63	157.3 **Gd** gadolinium 64	158.9 **Tb** terbium 65	162.5 **Dy** dysprosium 66	164.9 **Ho** holmium 67	167.3 **Er** erbium 68	168.9 **Tm** thulium 69	173.1 **Yb** ytterbium 70	175.0 **Lu** lutetium 71
232.0 **Th** thorium 90	231.0 **Pa** protactinium 91	238.0 **U** uranium 92	[237] **Np** neptunium 93	[244] **Pu** plutonium 94	[243] **Am** americium 95	[247] **Cm** curium 96	[247] **Bk** berkelium 97	[251] **Cf** californium 98	[252] **Es** einsteinium 99	[257] **Fm** fermium 100	[258] **Md** mendelevium 101	[259] **No** nobelium 102	[262] **Lr** lawrencium 103

* **58 – 71** Lanthanides

† **90 – 103** Actinides

1

Answer **all** the questions.

1 The Group 2 element magnesium was first isolated by Sir Humphry Davy in 1808.

(a) Magnesium has three stable isotopes, which are ^{24}Mg, ^{25}Mg and ^{26}Mg.

(i) Complete the table below to show the atomic structures of ^{24}Mg and ^{25}Mg.

	protons	**neutrons**	**electrons**
^{24}Mg			
^{25}Mg			

[2]

(ii) A sample of magnesium contained ^{24}Mg: 78.60%; ^{25}Mg: 10.11%; ^{26}Mg: 11.29%.

Calculate the relative atomic mass of this sample of Mg.

Give your answer to **four** significant figures.

answer = ... **[2]**

(iii) Define the term *relative atomic mass*.

.....

.....

.....

.....

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

(b) The reaction between magnesium and sulfuric acid is a redox reaction.

$$Mg(s) + H_2SO_4(aq) \longrightarrow MgSO_4(aq) + H_2(g)$$

(i) Use oxidation numbers to identify which element has been oxidised.

Explain your answer.

element oxidised .....

explanation .....

.....

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

(ii) Describe what you would **see** when magnesium reacts with an excess of sulfuric acid.

.....

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

(c) Epsom salts can be used as bath salts to help relieve aches and pains.

Epsom salts are crystals of hydrated magnesium sulfate, $MgSO_4 \bullet \boldsymbol{x}H_2O$.

A sample of Epsom salts was heated to remove the water. 1.57 g of water was removed leaving behind 1.51 g of anhydrous $MgSO_4$.

(i) Calculate the amount, in mol, of anhydrous $MgSO_4$ formed.

amount = ... mol **[2]**

(ii) Calculate the amount, in mol, of H_2O removed.

amount = ... mol **[1]**

(iii) Calculate the value of $\boldsymbol{x}$ in $MgSO_4 \bullet \boldsymbol{x}H_2O$.

$\boldsymbol{x}$ = ... **[1]**

[Total: 15]

2 This question compares the bonding, structure and properties of sodium and sodium oxide.

(a) Sodium, Na, is a metallic element.

Explain, with the aid of a labelled diagram, what is meant by the term *metallic bonding*.

.....

.....

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

(b) Sodium reacts with oxygen to form sodium oxide, Na_2O, which is an ionic compound.

(i) Write the equation for the reaction of sodium with oxygen to form sodium oxide.

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

(ii) State what is meant by the term *ionic bond*.

.....

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

(iii) Draw a '*dot-and-cross*' diagram to show the bonding in Na_2O.

Show **outer** electrons only.

[2]

(c) Compare and explain the electrical conductivities of sodium and sodium oxide in the solid and liquid states.

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..... **[5]**

[Total: 12]

3 Calcium carbonate, $CaCO_3$, reacts with hydrochloric acid as shown in the equation below.

$$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

(a) 7.50×10^{-3} mol $CaCO_3$ reacts with 0.200 mol dm^{-3} HCl.

(i) Calculate the volume, in cm^3, of 0.200 mol dm^{-3} HCl required to react with 7.50×10^{-3} mol $CaCO_3$.

answer = ... cm^3 **[2]**

(ii) Calculate the volume, in cm^3, of CO_2 formed at room temperature and pressure.

answer = ... cm^3 **[1]**

(b) When heated strongly, $CaCO_3$ decomposes.

Write an equation, including state symbols, for the thermal decomposition of $CaCO_3$.

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

(c) Calcium oxide reacts with water and with nitric acid.

State the formula of the calcium compound formed when:

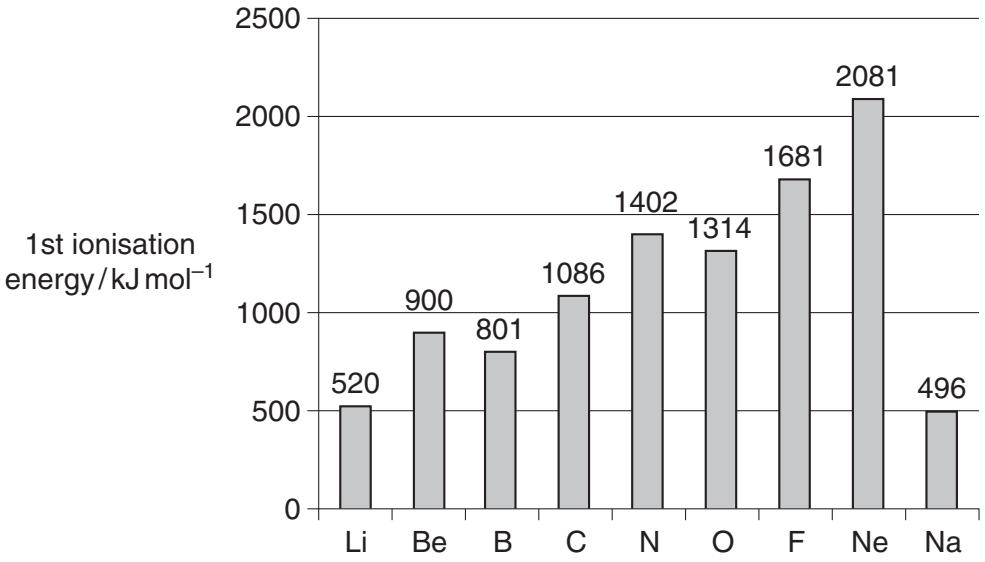
(i) calcium oxide reacts with water, ... **[1]**

(ii) calcium oxide reacts with nitric acid. ..... **[1]**

[Total: 7]

4 Ionisation energies have been used to develop the model of the atom.

The first ionisation energies of the elements Li to Na are shown in the figure below.



(a) Define the term *first ionisation energy*.

.....

.....

.....

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

(b) **(i)** Explain why the first ionisation energies show a general increase from Li to Ne.

.....

.....

.....

.....

.....

.....

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

(ii) Explain the difference between the first ionisation energies of Li and Na.

In your answer, you should use appropriate technical terms, spelt correctly.

.....

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.....

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

(c) The first ionisation energy of oxygen is 1314 kJ mol^{-1} and the second ionisation energy of oxygen is 3388 kJ mol^{-1}.

(i) Write an equation to represent the **second** ionisation energy of oxygen.

Include state symbols.

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

(ii) Suggest why the second ionisation energy of oxygen has a greater value than the first ionisation energy of oxygen.

.....

.....

.....

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

[Total: 11]

5 The Periodic Table is a table of elements arranged in order of atomic number. The elements are classified into blocks.

(a) (i) State what is meant by the term *atomic number*.

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

(ii) Complete the full electron configuration for a titanium atom.

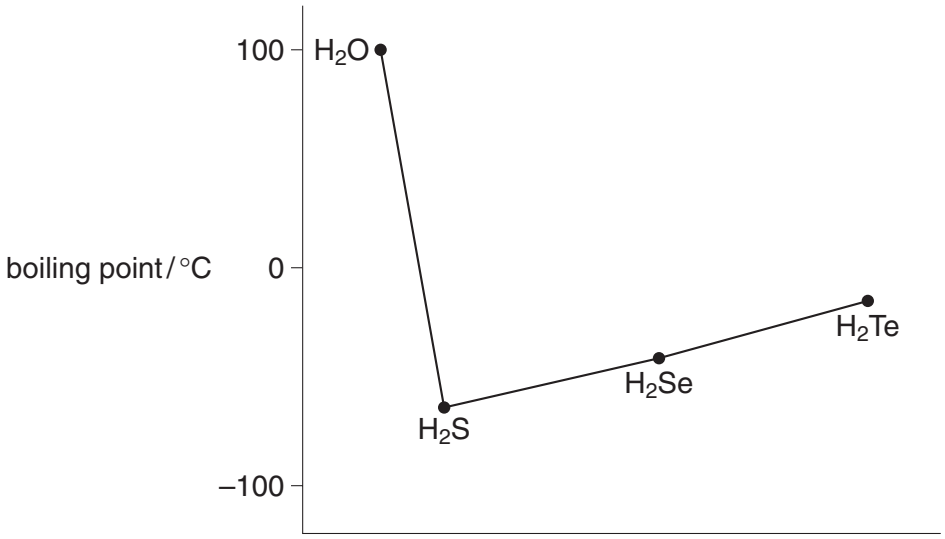
$1s^2$ ..... **[1]**

(iii) Identify the **seventh** element in the **fourth** period.

State which block this element is in.

element ..... block ..... **[1]**

(b) The figure below shows the boiling points of four hydrides of Group 6 elements.



(i) Explain, with the aid of a diagram, the intermolecular forces in H_2O that lead to the relatively high boiling point of H_2O.

.....

.....

.....

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

(ii) Suggest why H_2S has a much lower boiling point than H_2O.

.....

.....

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

(c) The boiling points of some Group 7 elements are shown below.

Group 7 element	boiling point / °C
chlorine	–35
bromine	59
iodine	184

Explain why the halogens show this trend in boiling points.

In your answer, you should use appropriate technical terms, spelt correctly.

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

TURN OVER FOR QUESTION 5(d)

(d) During the extraction of bromine industrially, chlorine is bubbled through a solution of bromide ions. A student thought this principle would also work for extracting iodine and carried out the experiment below.

Stage 1 The student bubbled some chlorine through an aqueous solution of potassium iodide.

Stage 2 The student added an organic solvent and shook the mixture.

(i) What would the student see at **stage 1**?

.....

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

(ii) Name the products and write an ionic equation for the reaction in **stage 1**.

names of products: .....

ionic equation: ..... **[2]**

(iii) Why does the reaction in **stage 1** occur?

.....

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

(iv) What would the student see at **stage 2**?

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

[Total: 15]

END OF QUESTION PAPER

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

1 Hydrogen gas is used in the chemical industry.

1 (a) Tungsten is extracted by passing hydrogen over heated tungsten oxide (WO_3).

1 (a) (i) State the role of the hydrogen in this reaction.

.....

(1 mark)

1 (a) (ii) Write an equation for this reaction.

.....

(1 mark)

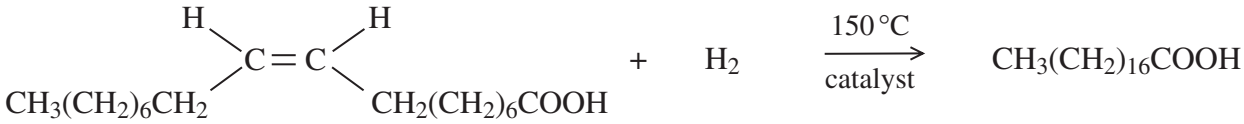
1 (a) (iii) State **one** risk of using hydrogen gas in metal extractions.

.....

.....

(1 mark)

1 (b) Hydrogen is used to convert oleic acid into stearic acid as shown by the following equation.



oleic acid stearic acid

1 (b) (i) Use your knowledge of the chemistry of alkenes to deduce the type of reaction that has occurred in this conversion.

.....

(1 mark)

1 (b) (ii) State the type of stereoisomerism shown by oleic acid.

.....

(1 mark)

1 (c) Hydrogen reacts with nitrogen in the Haber Process. The equation for the equilibrium that is established is shown below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

1 (c) (i) State Le Chatelier's principle.

.....

.....

(1 mark)

1 (c) (ii) Use Le Chatelier's principle to explain why an increase in the total pressure of this equilibrium results in an increase in the equilibrium yield of ammonia.

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(2 marks)

1 (d) Hydrogen reacts with oxygen in an exothermic reaction as shown by the following equation.

$$H_2(g) + \tfrac{1}{2}O_2(g) \longrightarrow H_2O(g) \qquad \Delta H = -242\,\text{kJ mol}^{-1}$$

Use the information in the equation and the data in the following table to calculate a value for the bond enthalpy of the H–H bond.

	O–H	O=O
Mean bond enthalpy / kJ mol^{-1}	+463	+496

.....

.....

.....

.....

(3 marks)

(Extra space) .....

.....

11

2 Hess's Law is used to calculate the enthalpy change in reactions for which it is difficult to determine a value experimentally.

2 (a) State the meaning of the term *enthalpy change*.

.....

(1 mark)

2 (b) State Hess's Law.

.....

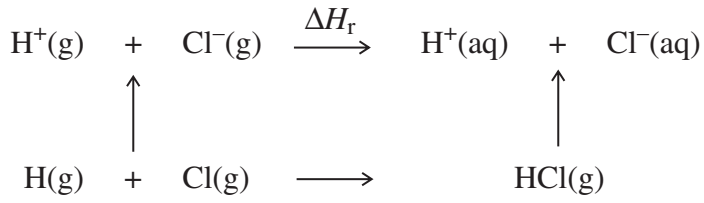
.....

.....

(1 mark)

2 (c) Consider the following table of data and the scheme of reactions.

Reaction	Enthalpy change / kJ mol^{-1}
$HCl(g) \longrightarrow H^+(aq) + Cl^-(aq)$	–75
$H(g) + Cl(g) \longrightarrow HCl(g)$	–432
$H(g) + Cl(g) \longrightarrow H^+(g) + Cl^-(g)$	+963



Use the data in the table, the scheme of reactions and Hess's Law to calculate a value for ΔH_r

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(3 marks)

5

3 For each of the following reactions, select from the list below, the **formula** of a sodium halide that would react as described.

NaF NaCl NaBr NaI

Each **formula** may be selected once, more than once or not at all.

3 (a) This sodium halide is a white solid that reacts with concentrated sulfuric acid to give a brown gas.

Formula of sodium halide .....

(1 mark)

3 (b) When a solution of this sodium halide is mixed with silver nitrate solution, no precipitate is formed.

Formula of sodium halide .....

(1 mark)

3 (c) When this solid sodium halide reacts with concentrated sulfuric acid, the reaction mixture remains white and steamy fumes are given off.

Formula of sodium halide .....

(1 mark)

3 (d) A colourless aqueous solution of this sodium halide reacts with orange bromine water to give a dark brown solution.

Formula of sodium halide .....

(1 mark)

4

Turn over for the next question

4 Group 2 metals and their compounds are used commercially in a variety of processes and applications.

4 (a) State a use of magnesium hydroxide in medicine.

.....

(1 mark)

4 (b) Calcium carbonate is an insoluble solid that can be used in a reaction to lower the acidity of the water in a lake.

Explain why the rate of this reaction decreases when the temperature of the water in the lake falls.

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(3 marks)

(Extra space) .....

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4 (c) Strontium metal is used in the manufacture of alloys.

4 (c) (i) Explain why strontium has a higher melting point than barium.

.....

.....

.....

.....

(2 marks)

(Extra space) .....

.....

4 (c) (ii) Write an equation for the reaction of strontium with water.

.....

(1 mark)

4 (d) Magnesium can be used in the extraction of titanium.

4 (d) (i) Write an equation for the reaction of magnesium with titanium(IV) chloride.

.....

(1 mark)

4 (d) (ii) The excess of magnesium used in this extraction can be removed by reacting it with dilute sulfuric acid to form magnesium sulfate.

Use your knowledge of Group 2 sulfates to explain why the magnesium sulfate formed is easy to separate from the titanium.

.....

.....

.....

(1 mark)

9

Turn over for the next question

5 Nitric acid is manufactured from ammonia in a process that involves several stages.

5 (a) In the first stage, ammonia is converted into nitrogen monoxide and the following equilibrium is established.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H = -905\,kJ\,mol^{-1}$$

The catalyst for this equilibrium reaction is a platinum–rhodium alloy in the form of a gauze. This catalyst gauze is heated initially but then remains hot during the reaction.

5 (a) (i) In terms of redox, state what happens to the ammonia in the forward reaction.

.....

(1 mark)

5 (a) (ii) Suggest a reason why the catalyst must be hot.

.....

(1 mark)

5 (a) (iii) Suggest a reason why the catalyst remains hot during the reaction.

.....

(1 mark)

5 (a) (iv) State how a catalyst increases the rate of a reaction.

.....

.....

.....

.....

(2 marks)

5 (b) In the second stage, nitrogen monoxide is converted into nitrogen dioxide. The equation for the equilibrium that is established is shown below.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H = -113\,kJ\,mol^{-1}$$

Explain why the equilibrium mixture is cooled during this stage of the process.

.....

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(2 marks)

5 (c) In the final stage, nitrogen dioxide reacts with water as shown by the following equation.

$$2NO_2(g) + H_2O(l) \longrightarrow H^+(aq) + NO_3^-(aq) + HNO_2(aq)$$

Give the oxidation state of nitrogen in each of the following.

NO_2 .....

NO_3^- .....

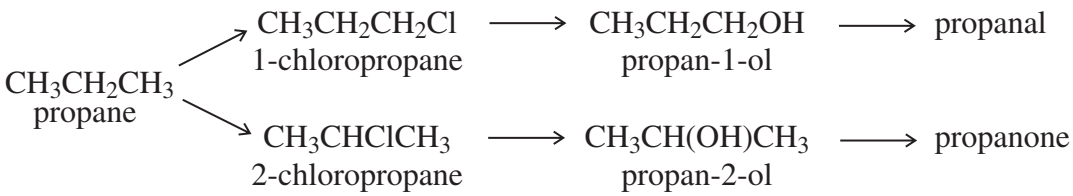
HNO_2 .....

(3 marks)

10

Turn over for the next question

6 Consider the following scheme of reactions.



6 (a) State the type of structural isomerism shown by propanal and propanone.

.....

(1 mark)

6 (b) A chemical test can be used to distinguish between separate samples of propanal and propanone.

Identify a suitable reagent for the test.
State what you would observe with propanal and with propanone.

Test reagent .....

Observation with propanal .....

Observation with propanone .....

(3 marks)

6 (c) State the structural feature of propanal and propanone which can be identified from their infrared spectra by absorptions at approximately $1720\,cm^{-1}$.
You may find it helpful to refer to **Table 1** on the Data Sheet.

.....

(1 mark)

6 (d) The reaction of chlorine with propane is similar to the reaction of chlorine with methane.

6 (d) (i) Name the type of mechanism in the reaction of chlorine with methane.

.....

(1 mark)

6 (d) (ii) Write an equation for each of the following steps in the mechanism for the reaction of chlorine with propane to form l-chloropropane ($CH_3CH_2CH_2Cl$).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

A termination step to form a molecule with the empirical formula C_3H_7

.....

(4 marks)

6 (e) High resolution mass spectrometry of a sample of propane indicated that it was contaminated with traces of carbon dioxide.

Use the data in the table to show how precise M_r values can be used to prove that the sample contains both of these gases.

Atom	Precise relative atomic mass
^{12}C	12.00000
^{1}H	1.00794
^{16}O	15.99491

.....

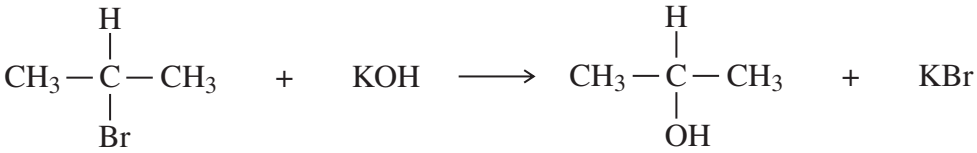
.....

.....

(2 marks)

12

7 (a) Consider the following reaction.



7 (a) (i) Name and outline a mechanism for this reaction.

Name of mechanism .....

Mechanism

(3 marks)

7 (a) (ii) Name the haloalkane in this reaction.

.....

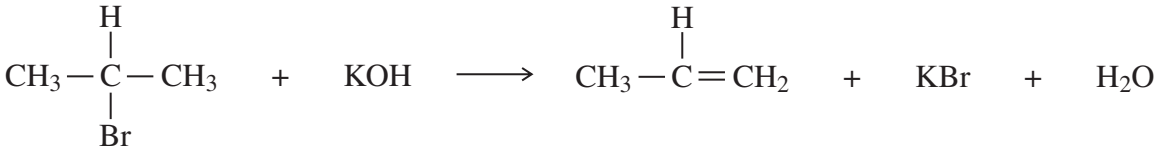
(1 mark)

7 (a) (iii) Identify the characteristic of the haloalkane molecule that enables it to undergo this type of reaction.

.....

(1 mark)

7 (b) An alternative reaction can occur between this haloalkane and potassium hydroxide as shown by the following equation.



Name and outline a mechanism for this reaction.

Name of mechanism .....

Mechanism

(4 marks)

7 (c) Give **one** condition needed to favour the reaction shown in part (b) rather than that shown in part (a).

.....

(1 mark)

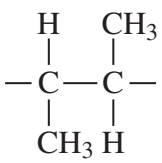
7 (d) Alkenes can be polymerised to produce poly(alkenes).

7 (d) (i) State the type of polymerisation that alkenes undergo.

.....

(1 mark)

7 (d) (ii) Name the alkene that gives a polymer with the repeating unit shown below.



Name of alkene .....

(1 mark)

12

8 Copper is extracted from the ore chalcopyrite ($CuFeS_2$) in a three-stage process.

8 (a) In the first stage of this extraction, the chalcopyrite is heated with silicon dioxide and oxygen.

8 (a) (i) Balance the following equation for this first stage in which copper(I) sulfide is formed.

……$CuFeS_2$ + ……SiO_2 + ……O_2 ⟶ Cu_2S + ……$FeSiO_3$ + ……SO_2

(1 mark)

8 (a) (ii) Give **one** environmental reason why the SO_2 gas formed in this reaction is not allowed to escape into the atmosphere.

.....

.....

(1 mark)

8 (a) (iii) State **one** use for the sulfur dioxide formed in this reaction.

.....

.....

(1 mark)

8 (b) In the second stage of this extraction, the copper(I) sulfide is converted into copper(II) oxide. This occurs by roasting the sulfide with oxygen at high temperature. Write an equation for this reaction.

.....

(1 mark)

8 (c) In the third stage of this extraction, copper(II) oxide is reduced to copper by its reaction with carbon. Write an equation for this reaction.

.....

(1 mark)

8 (d) Scrap iron can be used to extract copper from dilute aqueous solutions containing copper(II) ions.

8 (d) (i) Explain why this is a low-cost method of extracting copper.

.....

.....

(1 mark)

8 (d) (ii) Write the **simplest ionic** equation for the reaction of iron with copper(II) ions in aqueous solution.

.....

(1 mark)

7

Turn over for the next question

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

9 There are **four** isomeric alcohols with the molecular formula $C_4H_{10}O$

9 (a) Two of these are butan-l-ol ($CH_3CH_2CH_2CH_2OH$) and butan-2-ol.
The other two isomers are alcohol **X** and alcohol **Y**.

Draw the displayed formula for butan-2-ol.

Alcohol **X** does not react with acidified potassium dichromate(VI) solution.
Give the structure of alcohol **X**.

Name the fourth isomer, alcohol **Y**.

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(3 marks)

(Extra space) .....

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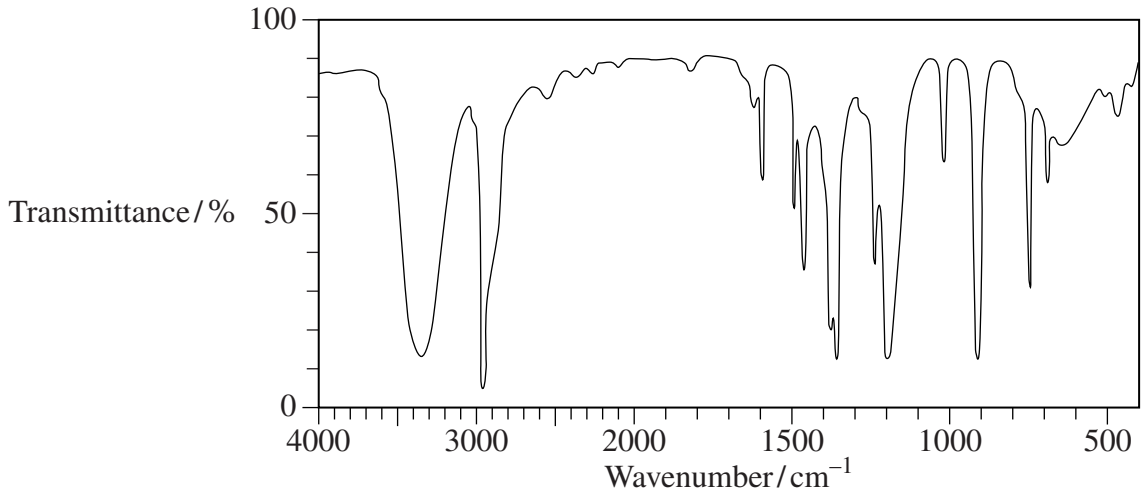
9 (b) The infrared spectrum of one of these isomeric alcohols is given below.



Identify **one** feature of the infrared spectrum which supports the fact that this is an alcohol. You may find it helpful to refer to **Table 1** on the Data Sheet.

Explain how infrared spectroscopy can be used to identify this isomeric alcohol.

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(3 marks)

(Extra space) .....

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.....

Question 9 continues on the next page

9 (c) British scientists have used bacteria to ferment glucose and produce the biofuel butan-l-ol.

Write an equation for the fermentation of glucose ($C_6H_{12}O_6$) to form butan-l-ol, carbon dioxide and water only.

State **one** condition necessary to ensure the complete combustion of a fuel in air.

Write an equation for the complete combustion of butan-l-ol and state why it can be described as a *biofuel*.

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(4 marks)

(Extra space) .....

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.....

9 (d) Butan-l-ol reacts with acidified potassium dichromate(VI) solution to produce two organic compounds.

State the class of alcohols to which butan-l-ol belongs.

Draw the displayed formula for **both** of the organic products.

State the type of reaction that occurs and the change in colour of the potassium dichromate(VI) solution.

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(5 marks)

(Extra space) .....

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15

Turn over for the next question

10 (a) When chlorine gas dissolves in cold water, a pale green solution is formed. In this solution, the following equilibrium is established.

$$Cl_2(g) + H_2O(l) \rightleftharpoons H^+(aq) + Cl^-(aq) + HClO(aq)$$

Give the formula of the species responsible for the pale green colour in the solution of chlorine in water.

Use Le Chatelier's principle to explain why the green colour disappears when sodium hydroxide solution is added to this solution.

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.....

(3 marks)

(Extra space) .....

.....

.....

10 (b) Consider the following reaction in which iodide ions behave as reducing agents.

$$Cl_2(aq) + 2I^-(aq) \longrightarrow I_2(aq) + 2Cl^-(aq)$$

In terms of electrons, state the meaning of the term *reducing agent*.

Deduce the half-equation for the conversion of chlorine into chloride ions.

Explain why iodide ions are stronger reducing agents than chloride ions.

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(4 marks)

(Extra space) .....

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Question 10 continues on the next page

10 (c) When chlorine reacts with water in bright sunlight, only two products are formed. One of these products is a colourless, odourless gas and the other is an acidic solution that reacts with silver nitrate solution to give a white precipitate.

Write an equation for the reaction of chlorine with water in bright sunlight.

Name the white precipitate and state what you would observe when an excess of aqueous ammonia is added to it.

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(3 marks)

(Extra space) .....

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.....

10 (d) The reaction of chlorine with ethene is similar to that of bromine with ethene.

Name and outline a mechanism for the reaction of chlorine with ethene to form 1,2-dichloroethane, as shown by the following equation.

$$H_2C{=}CH_2 + Cl_2 \longrightarrow ClCH_2CH_2Cl$$

(5 marks)

15

END OF QUESTIONS

GCE Chemistry Data Sheet

Table 1
Infrared absorption data

Bond	Wavenumber /cm^{-1}
N—H (amines)	3300 – 3500
O—H (alcohols)	3230 – 3550
C—H	2850 – 3300
O—H (acids)	2500 – 3000
C≡N	2220 – 2260
C=O	1680 – 1750
C=C	1620 – 1680
C—O	1000 – 1300
C—C	750 – 1100

Table 2
^{1}H n.m.r. chemical shift data

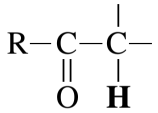
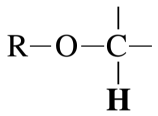
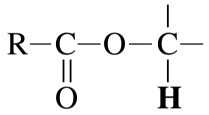
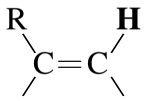
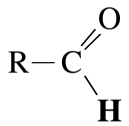
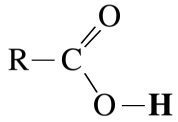
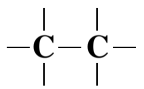
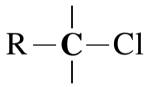
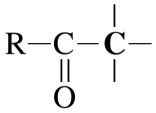
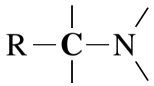
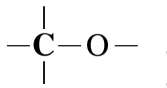
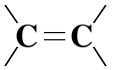
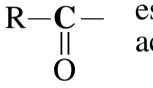
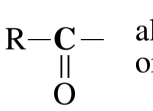
Type of proton	δ/ppm
ROH	0.5 – 5.0
RCH$_3$	0.7 – 1.2
RNH$_2$	1.0 – 4.5
R$_2$CH$_2$	1.2 – 1.4
R$_3$CH	1.4 – 1.6
	2.1 – 2.6
	3.1 – 3.9
RCH$_2$Cl or Br	3.1 – 4.2
	3.7 – 4.1
	4.5 – 6.0
	9.0 – 10.0
	10.0 – 12.0

Table 3
^{13}C n.m.r. chemical shift data

Type of carbon	δ/ppm
	5 – 40
 Cl or Br	10 – 70
	20 – 50
	25 – 60
 alcohols, ethers or esters	50 – 90
	90 – 150
	110 – 125
	110 – 160
 esters or acids	160 – 185
 aldehydes or ketones	190 – 220

The Periodic Table of the Elements

1	2											3	4	5	6	7	0 (18)
							1.0 H hydrogen 1										4.0 He helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4		relative atomic mass **symbol** name atomic (proton) number									10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10
23.0 Na sodium 11	24.3 Mg magnesium 12	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18
39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.6 Ge germanium 32	74.9 As arsenic 33	79.0 Se selenium 34	79.9 Br bromine 35	83.8 Kr krypton 36
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	96.0 Mo molybdenum 42	[98] Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	106.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	126.9 I iodine 53	131.3 Xe xenon 54
132.9 Cs caesium 55	137.3 Ba barium 56	138.9 La * lanthanum 57	178.5 Hf hafnium 72	180.9 Ta tantalum 73	183.8 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.1 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	209.0 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86
[223] Fr francium 87	[226] Ra radium 88	[227] Ac † actinium 89	[267] Rf rutherfordium 104	[268] Db dubnium 105	[271] Sg seaborgium 106	[272] Bh bohrium 107	[270] Hs hassium 108	[276] Mt meitnerium 109	[281] Ds darmstadtium 110	[280] Rg roentgenium 111	Elements with atomic numbers 112-116 have been reported but not fully authenticated						

140.1 Ce cerium 58	140.9 Pr praseodymium 59	144.2 Nd neodymium 60	[145] Pm promethium 61	150.4 Sm samarium 62	152.0 Eu europium 63	157.3 Gd gadolinium 64	158.9 Tb terbium 65	162.5 Dy dysprosium 66	164.9 Ho holmium 67	167.3 Er erbium 68	168.9 Tm thulium 69	173.1 Yb ytterbium 70	175.0 Lu lutetium 71
232.0 Th thorium 90	231.0 Pa protactinium 91	238.0 U uranium 92	[237] Np neptunium 93	[244] Pu plutonium 94	[243] Am americium 95	[247] Cm curium 96	[247] Bk berkelium 97	[251] Cf californium 98	[252] Es einsteinium 99	[257] Fm fermium 100	[258] Md mendelevium 101	[259] No nobelium 102	[262] Lr lawrencium 103

* **58 – 71** Lanthanides

† **90 – 103** Actinides

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

1 A mixture was prepared using 1.00 mol of propanoic acid, 2.00 mol of ethanol and 5.00 mol of water. At a given temperature, the mixture was left to reach equilibrium according to the following equation.

$$CH_3CH_2COOH + CH_3CH_2OH \rightleftharpoons CH_3CH_2COOCH_2CH_3 + H_2O \qquad \Delta H^{\ominus} = -22\,kJ\,mol^{-1}$$

The equilibrium mixture contained 0.54 mol of the ester ethyl propanoate.

1 (a) (i) Calculate the amounts, in moles, of propanoic acid, of ethanol and of water in this equilibrium mixture.

Moles of propanoic acid .....

Moles of ethanol .....

Moles of water .....

(3 marks)

1 (a) (ii) Write an expression for the equilibrium constant, K_c, for this equilibrium.

.....

.....

(1 mark)

1 (a) (iii) Calculate a value for K_c for this equilibrium at this temperature. Explain why this K_c value has no units.

Calculation .....

.....

.....

.....

Explanation .....

.....

(3 marks)

(Extra space) .....

.....

1 (b) For this equilibrium, predict the effect of an increase in temperature on each of the following.

1 (b) (i) the amount, in moles, of ester at equilibrium

.....

(1 mark)

1 (b) (ii) the time taken to reach equilibrium

.....

(1 mark)

1 (b) (iii) the value of K_c

.....

(1 mark)

10

Turn over for the next question

2 In this question, give all values of pH to 2 decimal places.

2 (a) (i) Write an expression for the term pH.

.....

(1 mark)

2 (a) (ii) Calculate the concentration, in mol dm^{-3}, of an aqueous solution of sulfuric acid that has a pH of 0.25

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.....

(2 marks)

2 (b) A student carried out a titration by adding an aqueous solution of sodium hydroxide from a burette to an aqueous solution of ethanoic acid. The end-point was reached when 22.60 cm^3 of the sodium hydroxide solution had been added to 25.00 cm^3 of 0.410 mol dm^{-3} ethanoic acid.

2 (b) (i) Write an equation for the reaction between sodium hydroxide and ethanoic acid.

.....

(1 mark)

2 (b) (ii) Calculate the concentration, in mol dm^{-3}, of the sodium hydroxide solution used.

.....

.....

.....

.....

(2 marks)

2 (b) (iii) A list of indicators is shown below.

Indicator	pH range
thymol blue	1.2–2.8
bromophenol blue	3.0–4.6
litmus	5.0–8.0
cresol purple	7.6–9.2

Select from the list the most suitable indicator for the end-point of this titration.

.....

(1 mark)

2 (b) (iv) Suggest why the concentration of sodium hydroxide in a solution slowly decreases when left open to air.

.....

.....

(1 mark)

2 (c) At 298 K, the value of the acid dissociation constant, K_a, for ethanoic acid in aqueous solution is 1.74×10^{-5} mol dm^{-3}

2 (c) (i) Write an expression for the acid dissociation constant, K_a, for ethanoic acid.

.....

.....

(1 mark)

2 (c) (ii) Calculate the pH of 0.410 mol dm^{-3} ethanoic acid at this temperature.

.....

.....

.....

.....

(3 marks)

(Extra space) .....

.....

Question 2 continues on the next page

2 (c) (iii) Calculate the pH of the buffer solution formed when 10.00 cm^3 of 0.100 mol dm^{-3} potassium hydroxide are added to 25.00 cm^3 of 0.410 mol dm^{-3} ethanoic acid.

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(6 marks)

(Extra space) .....

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18

3 Propanone and iodine react in acidic conditions according to the following equation.

$$CH_3COCH_3 + I_2 \longrightarrow ICH_2COCH_3 + HI$$

A student studied the kinetics of this reaction using hydrochloric acid and a solution containing propanone and iodine. From the results the following rate equation was deduced.

$$\text{rate} = k[CH_3COCH_3][H^+]$$

3 (a) Give the overall order for this reaction.

.....

(1 mark)

3 (b) When the initial concentrations of the reactants were as shown in the table below, the initial rate of reaction was found to be 1.24×10^{-4} mol dm^{-3} s^{-1}.

	initial concentration / mol dm^{-3}
CH_3COCH_3	4.40
I_2	5.00×10^{-3}
H^+	0.820

Use these data to calculate a value for the rate constant, k, for the reaction and give its units.

Calculation .....

.....

.....

.....

Units .....

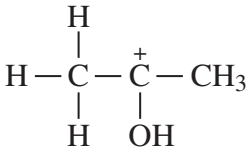
(3 marks)

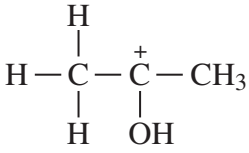
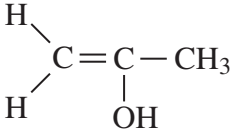
3 (c) Deduce how the initial rate of reaction changes when the concentration of iodine is doubled but the concentrations of propanone and of hydrochloric acid are unchanged.

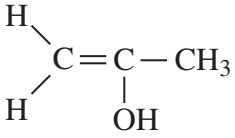
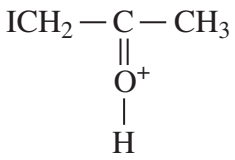
.....

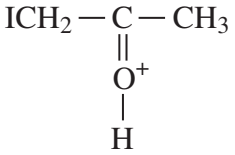
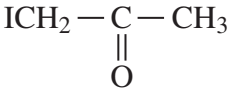
(1 mark)

3 (d) The following mechanism for the overall reaction has been proposed.

Step **1** $CH_3COCH_3 + H^+ \longrightarrow$ 

Step **2**  $\longrightarrow$  $+ H^+$

Step **3**  $+ I_2 \longrightarrow$  $+ I^-$

Step **4**  $\longrightarrow$  $+ H^+$

Use the rate equation to suggest which of the four steps could be the rate-determining step. Explain your answer.

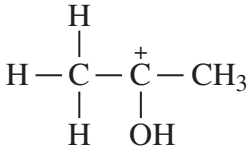
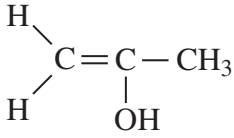
Rate-determining step .....

Explanation .....

.....

(2 marks)

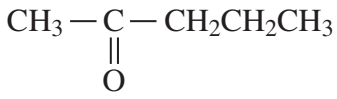
3 (e) Use your understanding of reaction mechanisms to predict a mechanism for Step **2** by adding one or more curly arrows as necessary to the structure of the carbocation below.

Step **2**  $\longrightarrow$  $+ H^+$

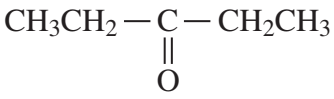
(1 mark)

8

4 Two isomeric ketones are shown below.



Q



R

4 (a) Name and outline a mechanism for the reaction of compound **Q** with HCN and name the product formed.

Name of mechanism .....

Mechanism

Name of product .....

(6 marks)

4 (b) Some students were asked to suggest methods to distinguish between isomers **Q** and **R**.

One student suggested testing the optical activity of the products formed when **Q** and **R** were reacted separately with HCN.

By considering the optical activity of these products formed from **Q** and **R**, explain why this method would **not** distinguish between **Q** and **R**.

.....

.....

.....

.....

.....

(3 marks)

(Extra space) .....

.....

.....

4 (c) Other students suggested using mass spectrometry and the fragmentation patterns of the molecular ions of the two isomers to distinguish between them.

They predicted that only one of the isomers would have a major peak at *m/z* = 57 in its mass spectrum so that this method would distinguish between **Q** and **R**.

4 (c) (i) Identify the isomer that has a major peak at *m/z* = 57 in its mass spectrum.

.....

(1 mark)

4 (c) (ii) Write an equation for the fragmentation of the molecular ion of this isomer to form the species that produces the peak at *m/z* = 57.

.....

(2 marks)

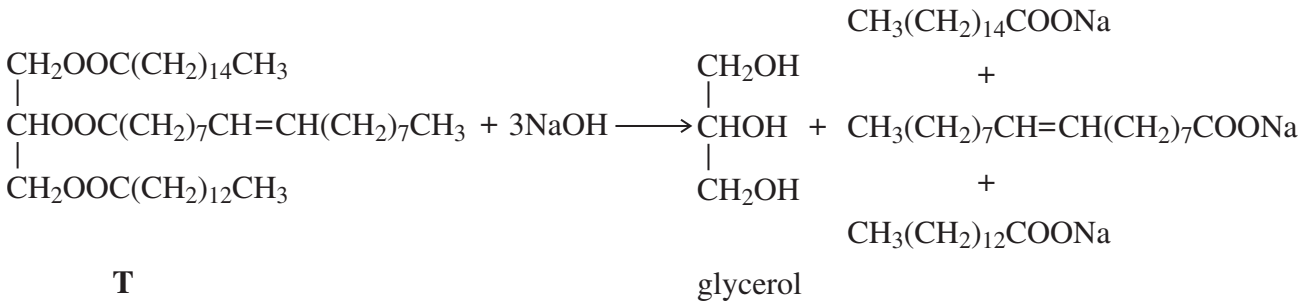
4 (c) (iii) Predict the *m/z* value of a major peak in the mass spectrum of the other isomer.

.....

(1 mark)

13

5 The triester, **T**, shown below is found in palm oil. When **T** is heated with an excess of sodium hydroxide solution, the alcohol glycerol is formed together with a mixture of three other products as shown in the following equation.



T glycerol

5 (a) (i) Give the IUPAC name for glycerol.

.....

(1 mark)

5 (a) (ii) Give a use for the mixture of sodium salts formed in this reaction.

.....

(1 mark)

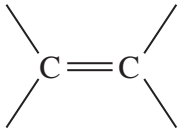
5 (b) When **T** is heated with an excess of methanol, glycerol is formed together with a mixture of methyl esters.

5 (b) (i) Give a use for this mixture of methyl esters.

.....

(1 mark)

5 (b) (ii) One of the methyl esters in the mixture has the IUPAC name methyl (*Z*)-octadec-9-enoate. Draw **two** hydrogen atoms on the diagram below to illustrate the meaning of the letter *Z* in the name of this ester.



(1 mark)

5 (b) (iii) One of the other methyl esters in the mixture has the formula $CH_3(CH_2)_{12}COOCH_3$
Write an equation for the complete combustion of one molecule of this ester.

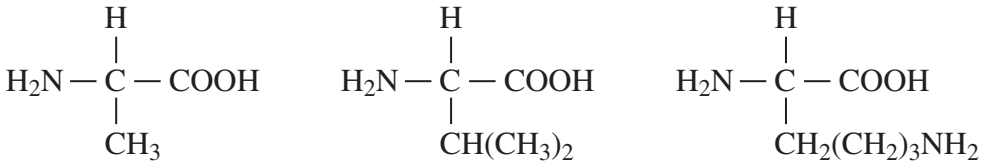
.....

(1 mark)

5

Turn over for the next question

6 The three amino acids shown below were obtained by hydrolysis of a protein.



alanine valine lysine

6 (a) (i) Draw the zwitterion of alanine.

(1 mark)

6 (a) (ii) Draw the species formed when valine is dissolved in an alkaline solution.

(1 mark)

6 (a) (iii) Draw the species formed by lysine at low pH.

(1 mark)

6 (b) Draw the two dipeptides formed by the reaction of alanine with valine.

(2 marks)

6 (c) Name a suitable method by which the mixture of amino acids formed by hydrolysis of the protein can be separated.

.....

(1 mark)

6

Turn over for the next question

7 Organic chemists use a variety of methods to identify unknown compounds. When the molecular formula of a compound is known, spectroscopic and other analytical techniques are used to distinguish between possible structural isomers. Use your knowledge of such techniques to identify the compounds described below.

Use the three tables of spectral data on the Data Sheet where appropriate.

Each part below concerns a different pair of structural isomers.
Draw **one** possible structure for each of the compounds **A** to **J**, described below.

7 (a) Compounds **A** and **B** have the molecular formula C_3H_6O
A has an absorption at 1715 cm^{-1} in its infrared spectrum and has only one peak in its ^1H n.m.r. spectrum.
B has absorptions at 3300 cm^{-1} and at 1645 cm^{-1} in its infrared spectrum and does **not** show *E*–*Z* isomerism.

A **B**

(2 marks)

7 (b) Compounds **C** and **D** have the molecular formula C_5H_{12}
In their ^1H n.m.r. spectra, **C** has three peaks and **D** has only one.

C **D**

(2 marks)

7 (c) Compounds **E** and **F** are both esters with the molecular formula $C_4H_8O_2$
In their ^1H n.m.r. spectra, **E** has a quartet at $\delta = 2.3$ ppm and **F** has a quartet at $\delta = 4.1$ ppm.

E **F**

(2 marks)

7 (d) Compounds **G** and **H** have the molecular formula $C_6H_{12}O$
Each exists as a pair of optical isomers and each has an absorption at about 1700 cm^{-1} in its infrared spectrum. **G** forms a silver mirror with Tollens' reagent but **H** does not.

G **H**

(2 marks)

7 (e) Compounds **I** and **J** have the molecular formula $C_4H_{11}N$ and both are secondary amines. In their ^{13}C n.m.r. spectra, **I** has two peaks and **J** has three.

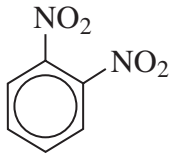
I **J**

(2 marks)

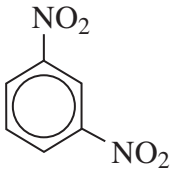
10

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

8 Three isomers of $C_6H_4(NO_2)_2$ are shown below.



W



X

Y

8 (a) (i) Give the number of peaks in the ^{13}C n.m.r. spectrum of each isomer.

.....

.....

.....

(3 marks)

8 (a) (ii) Draw the displayed formula of the compound used as a standard in recording these spectra.

(1 mark)

8 (b) Isomer **X** is prepared from nitrobenzene by reaction with a mixture of concentrated nitric acid and concentrated sulfuric acid.

The two acids react to form an inorganic species that reacts with nitrobenzene to form **X**.

8 (b) (i) Give the formula of this inorganic species formed from the two acids and write an equation to show its formation.

.....

.....

.....

(2 marks)

8 (b) (ii) Name and outline a mechanism for the reaction of this inorganic species with nitrobenzene to form **X**.

(4 marks)

Question 8 continues on the next page

8 (c) Isomer **Y** is used in the production of the polymer Kevlar.

Y is first reduced to the diamine shown below.

8 (c) (i) Identify a suitable reagent or mixture of reagents for the reduction of **Y** to form this diamine. Write an equation for this reaction using [H] to represent the reducing agent.

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(2 marks)

8 (c) (ii) This diamine is then reacted with benzene-l,4-dicarboxylic acid to form Kevlar. Draw the repeating unit of Kevlar.

(2 marks)

8 (c) (iii) Kevlar can be used as the inner lining of bicycle tyres. The rubber used for the outer part of the tyre is made of polymerised alkenes.

State the difference in the biodegradability of Kevlar compared to that of rubber made of polymerised alkenes.

Use your knowledge of the bonding in these polymer molecules to explain this difference.

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(4 marks)

(Extra space) .....

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18

Turn over for the next question

9 (a) Name and outline a mechanism for the reaction of $CH_3CH_2NH_2$ with CH_3CH_2COCl

Name the amide formed.

(6 marks)

9 (b) Haloalkanes such as CH_3Cl are used in organic synthesis.

Outline a three-step synthesis of $CH_3CH_2NH_2$ starting from methane. Your first step should involve the formation of CH_3Cl

In your answer, identify the product of the second step and give the reagents and conditions for each step.

Equations and mechanisms are **not** required.

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(6 marks)

(Extra space) .....

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12

END OF QUESTIONS

GCE Chemistry Data Sheet

Table 1

Infrared absorption data

Bond	Wavenumber /cm^{-1}
N—H (amines)	3300 – 3500
O—H (alcohols)	3230 – 3550
C—H	2850 – 3300
O—H (acids)	2500 – 3000
C≡N	2220 – 2260
C=O	1680 – 1750
C=C	1620 – 1680
C—O	1000 – 1300
C—C	750 – 1100

Table 2

^{1}H n.m.r. chemical shift data

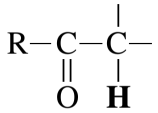
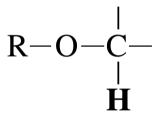
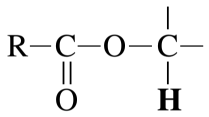
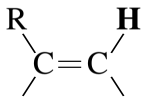
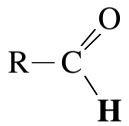
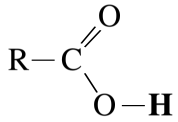
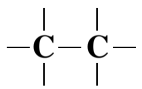
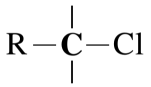
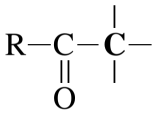
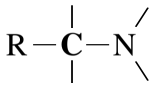
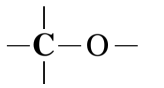
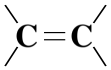
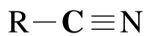
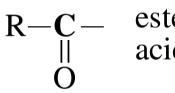
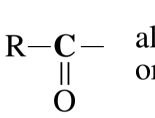
Type of proton	δ/ppm
ROH	0.5 – 5.0
RCH$_3$	0.7 – 1.2
RNH$_2$	1.0 – 4.5
R$_2$CH$_2$	1.2 – 1.4
R$_3$CH	1.4 – 1.6
	2.1 – 2.6
	3.1 – 3.9
RCH$_2$Cl or Br	3.1 – 4.2
	3.7 – 4.1
	4.5 – 6.0
	9.0 – 10.0
	10.0 – 12.0

Table 3

^{13}C n.m.r. chemical shift data

Type of carbon	δ/ppm
	5 – 40
 Cl or Br	10 – 70
	20 – 50
	25 – 60
 alcohols, ethers or esters	50 – 90
	90 – 150
	110 – 125
	110 – 160
 esters or acids	160 – 185
 aldehydes or ketones	190 – 220

The Periodic Table of the Elements

1	2											3	4	5	6	7	0 (18)
							1.0 H hydrogen 1										4.0 He helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4		relative atomic mass **symbol** name atomic (proton) number									10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10
23.0 Na sodium 11	24.3 Mg magnesium 12	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18
39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.6 Ge germanium 32	74.9 As arsenic 33	79.0 Se selenium 34	79.9 Br bromine 35	83.8 Kr krypton 36
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	96.0 Mo molybdenum 42	[98] Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	106.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	126.9 I iodine 53	131.3 Xe xenon 54
132.9 Cs caesium 55	137.3 Ba barium 56	138.9 La * lanthanum 57	178.5 Hf hafnium 72	180.9 Ta tantalum 73	183.8 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.1 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	209.0 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86
[223] Fr francium 87	[226] Ra radium 88	[227] Ac † actinium 89	[267] Rf rutherfordium 104	[268] Db dubnium 105	[271] Sg seaborgium 106	[272] Bh bohrium 107	[270] Hs hassium 108	[276] Mt meitnerium 109	[281] Ds darmstadtium 110	[280] Rg roentgenium 111	Elements with atomic numbers 112-116 have been reported but not fully authenticated						

140.1 Ce cerium 58	140.9 Pr praseodymium 59	144.2 Nd neodymium 60	[145] Pm promethium 61	150.4 Sm samarium 62	152.0 Eu europium 63	157.3 Gd gadolinium 64	158.9 Tb terbium 65	162.5 Dy dysprosium 66	164.9 Ho holmium 67	167.3 Er erbium 68	168.9 Tm thulium 69	173.1 Yb ytterbium 70	175.0 Lu lutetium 71
232.0 Th thorium 90	231.0 Pa protactinium 91	238.0 U uranium 92	[237] Np neptunium 93	[244] Pu plutonium 94	[243] Am americium 95	[247] Cm curium 96	[247] Bk berkelium 97	[251] Cf californium 98	[252] Es einsteinium 99	[257] Fm fermium 100	[258] Md mendelevium 101	[259] No nobelium 102	[262] Lr lawrencium 103

* **58 – 71** Lanthanides

† **90 – 103** Actinides

Answer **all** the questions.

1 A chemist was investigating the reactions of benzene, phenol and cyclohexene with bromine. She found that they all reacted with bromine but under different conditions.

(a) The chemist found that when benzene reacts with bromine, a halogen carrier is required as a catalyst.

Write an equation for this reaction.
You do **not** need to show the halogen carrier in your equation.

[1]

(b) The chemist also found that when phenol or cyclohexene reacts with bromine, a halogen carrier is **not** required.

(i) The chemist observed that bromine decolourises when it reacts with phenol.

What other observation would she have made?

Draw the structure of the organic product formed.

Observation .....

Organic product:

[2]

(ii) Cyclohexene also decolourises bromine.

Name the organic product formed.

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

(iii) Explain the relative resistance to bromination of benzene compared to phenol and compared to cyclohexene.

In your answer, you should use appropriate technical terms, spelt correctly.

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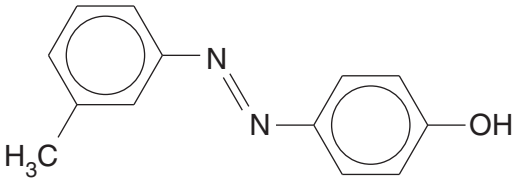
..... **[5]**

(c) Compound **A**, shown below, is being considered as an azo dye by a chemical company. A chemist planned a two-stage synthesis of compound **A** starting from an aromatic amine.



compound A

The aromatic amine is first converted into a diazonium ion.

- Draw the displayed formula of the aromatic amine **and** of the diazonium ion.
- State the reagents and conditions for each stage in the synthesis of compound **A** from an aromatic amine.

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..... **[5]**

[Total: 14]

2 Hydroxyethanal, $HOCH_2CHO$, is sometimes referred to as the 'first sugar' as it is the simplest possible molecule that contains both an aldehyde group and an alcohol group.

A biochemist investigated some redox reactions of hydroxyethanal and found that several different products were produced.

(a) The biochemist reacted hydroxyethanal with Tollens' reagent.

(i) State what the biochemist would see when hydroxyethanal reacts with Tollens' reagent.

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

(ii) Write the structural formula of the organic product formed when hydroxyethanal reacts with Tollens' reagent.

[1]

(b) The biochemist also reacted hydroxyethanal with acidified dichromate by heating under reflux.

Write an equation for this oxidation.

Use **[O]** to represent the oxidising agent.

[2]

(c) The biochemist then reduced hydroxyethanal using aqueous $NaBH_4$.

(i) Write the structural formula of the organic product.

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

(ii) Outline the mechanism for this reduction.

Use curly arrows and show any relevant dipoles.

[4]

[Total: 9]

Turn over

3 α-Amino acids are found in human sweat. A student had read that chromatography could be used to separate and identify the amino acids present in human sweat.

(a) The student used Thin-Layer Chromatography (TLC) to separate the α-amino acids in a sample of human sweat and discovered that three different α-amino acids were present.

(i) Name the process by which TLC separates α-amino acids.

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

(ii) The chromatogram was treated to show the positions of the separated α-amino acids.

Explain how the student could analyse the chromatogram to identify the three α-amino acids that were present.

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

(iii) Several α-amino acids have structures that are very similar.

Suggest why this could cause problems when using TLC to analyse mixtures of α-amino acids.

.....

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

(b) Some of the α-amino acids found in human sweat are shown in the table below.

α-amino acid	**R group**
glycine	H
leucine	$CH_2CH(CH_3)_2$
isoleucine	$CH(CH_3)CH_2CH_3$
alanine	CH_3
valine	$CH(CH_3)_2$
lysine	$(CH_2)_4NH_2$
glutamic acid	$(CH_2)_2COOH$

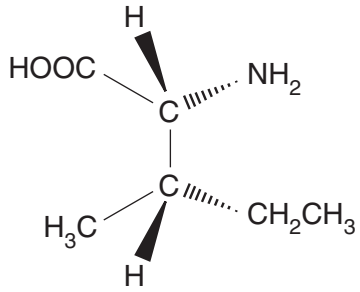
Table 1

(i) State the general formula of an α-amino acid.

[1]

(ii) There are four stereoisomers of isoleucine.

One of the stereoisomers is shown below.



Draw 3D diagrams for the other **three** stereoisomers of isoleucine.

[3]

α-amino acid	R group
glycine	H
leucine	$CH_2CH(CH_3)_2$
isoleucine	$CH(CH_3)CH_2CH_3$
alanine	CH_3
valine	$CH(CH_3)_2$
lysine	$(CH_2)_4NH_2$
glutamic acid	$(CH_2)_2COOH$

Table 1

(c) α-Amino acids form different ions at different pH values. Zwitterions are formed when the pH is equal to the isoelectric point of the α-amino acid.

The isoelectric points of three α-amino acids are given below:

alanine, pH = 6.0 **glutamic acid, pH = 3.2** **lysine, pH = 9.7**

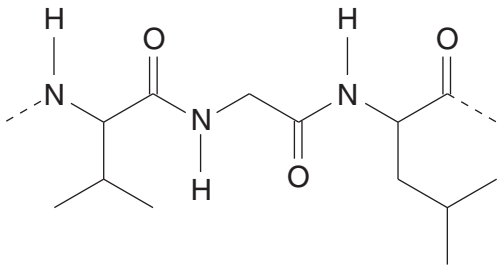
Draw the structures of the ions formed by these α-amino acids at the pH values below. Refer to **Table 1** above.

alanine at pH = 6.0	glutamic acid at pH = 10	lysine at pH = 2.0

[3]

(d) α-Amino acids can react to form polypeptides.

A short section of a polypeptide is shown below.

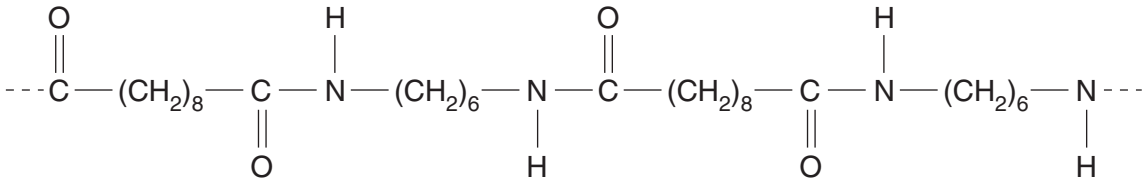


Name the α-amino acid sequence in this section of the polypeptide. Refer to **Table 1**.

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

(e) Synthetic polyamides, such as nylon, contain the same link as polypeptides. Nylon is the general name for a family of polyamides.

A short section of a nylon polymer is shown below.



Draw the structures of **two** monomers that could be used to make this nylon.

[2]

[Total: 14]

4 An industrial chemist discovered five bottles of different chemicals (three esters and two carboxylic acids) that were all labelled $C_5H_{10}O_2$.

The different chemicals had the structural formulae below.

$CH_3CH_2COOCH_2CH_3$ $(CH_3)_3CCOOH$ $CH_3COOCH(CH_3)_2$

$(CH_3)_2CHCH_2COOH$ $(CH_3)_2CHCOOCH_3$

(a) The chemist used both infrared and ^{13}C NMR spectroscopy to identify the two carboxylic acids and to distinguish between them.

How do both types of spectra allow the carboxylic acids to be identified and distinguished?

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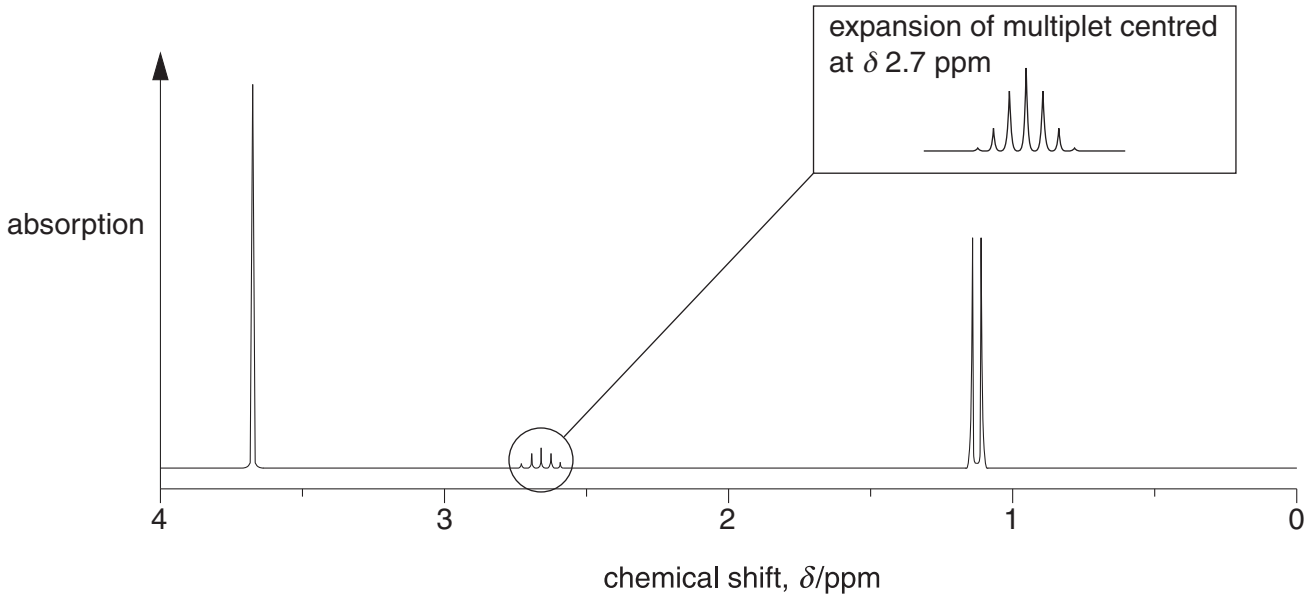
..... **[3]**

(b) The chemist analysed one of the esters by ^1H NMR spectroscopy. The spectrum is shown below.



Analyse the splitting patterns and the chemical shift values to identify the ester.

Give your reasoning.

In your answer, you should use appropriate technical terms, spelt correctly.

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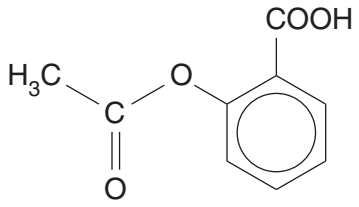
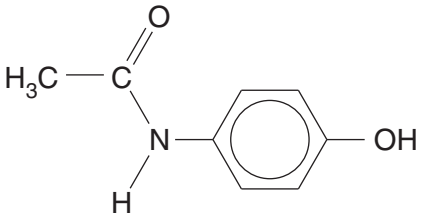
..... **[6]**

[Total: 9]

5 Aspirin and paracetamol are commonly available painkillers.



aspirin



paracetamol

Aspirin and paracetamol can be prepared using ethanoic anhydride, $(CH_3CO)_2O$.

Some examples of the reactions of ethanoic anhydride are shown below.

reaction 1 $(CH_3CO)_2O + CH_3OH \rightarrow CH_3COOCH_3 + CH_3COOH$

reaction 2 $(CH_3CO)_2O + CH_3NH_2 \rightarrow CH_3CONHCH_3 + CH_3COOH$

reaction 3 $(CH_3CO)_2O + C_6H_5OH \rightarrow CH_3COOC_6H_5 + CH_3COOH$

(a) Draw the structure of a compound that could react with ethanoic anhydride to form aspirin.

[1]

(b) Ethanoic anhydride can react with 4-aminophenol to produce paracetamol.

(i) Write an equation, showing structural formulae, for this formation of paracetamol.

[2]

(ii) An impurity with molecular formula $C_{10}H_{11}NO_3$ is also formed.

Draw the structure of this impurity.

[1]

(iii) Explain why it is necessary for pharmaceutical companies to ensure that drugs and medicines are pure.

.....

.....

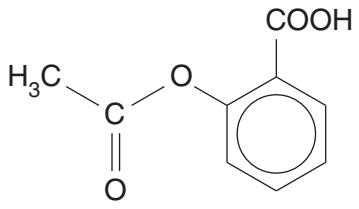
..... **[1]**

(c) Name the functional groups in aspirin and in paracetamol.

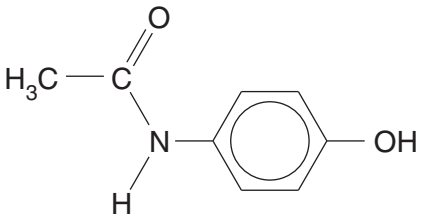
aspirin .....

paracetamol ..... **[2]**

(d) A student carried out some reactions with samples of aspirin and paracetamol in the laboratory. Their structures are repeated below.



aspirin



paracetamol

The student tried to react each of the reagents **A**, **B** and **C** with aspirin and paracetamol.

- Reagent **A** reacted with aspirin **and** with paracetamol.
- Reagent **B** reacted **only** with aspirin.
- Reagent **C** reacted **only** with paracetamol.

Suggest possible identities of reagents **A**, **B** and **C** and the organic products that would be formed.

(i) Reagent **A**: .....

Organic product with aspirin:

Organic product with paracetamol:

[3]

(ii) Reagent **B**: .....

Organic product with aspirin:

[2]

(iii) Reagent **C**: .....

Organic product with paracetamol:

[2]

[Total: 14]

END OF QUESTION PAPER