1)

(a) The methanol produced by this synthesis has been described as a carbon-neutral fuel.

(a) (i) State the meaning of the term *carbon-neutral*.

.....

(1 mark)

(a) (ii) Write an equation for the complete combustion of methanol.

.....

(1 mark)

(a) (iii) The equation for the synthesis of methanol is shown below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Use this equation and your answer to part **(d) (ii)** to deduce an equation to represent the overall chemical change that occurs when methanol behaves as a carbon-neutral fuel.

Equation .....

(1 mark)

(b) A student carried out an experiment to determine the enthalpy change when a sample of methanol was burned.

The student found that the temperature of 140 g of water increased by 7.5 °C when 0.011 mol of methanol was burned in air and the heat produced was used to warm the water.

Use the student's results to calculate a value, in $kJ\,mol^{-1}$, for the enthalpy change when one mole of methanol was burned.
(The specific heat capacity of water is $4.18\,J\,K^{-1}\,g^{-1}$).

.....

(3 marks)

2)

The manufacture of food grade phosphoric acid for use in cola drinks begins with the production of pure white phosphorus from the mineral fluoroapatite, $Ca_5F(PO_4)_3$

(a) Complete the following equation for the manufacture of phosphorus.

.....$Ca_5F(PO_4)_3$ + $9SiO_2$ + ...C ⟶ $9CaSiO_3$ + CaF_2 + ...CO + ...P

(1 mark)

(b) As the phosphorus cools, it forms white phosphorus, P_4

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

P_4 .....

H_3PO_4 .....

(2 marks)

(c) Fertiliser grade phosphoric acid is manufactured from sulfuric acid and calcium phosphate.
Use the following precise relative atomic mass data to show how mass spectrometry can be used to distinguish between pure sulfuric acid (H_2SO_4) and pure phosphoric acid (H_3PO_4) which both have M_r = 98 to two significant figures.

Atom	Precise relative atomic mass
^{1}H	1.00794
^{16}O	15.99491
^{31}P	30.97376
^{32}S	32.06550

.....

(1 mark)

(d) Concentrated phosphoric acid is used as a catalyst in the hydration of propene to form the alcohol $CH_3CH(OH)CH_3$ as the main organic product.
The industrial name for this alcohol is isopropyl alcohol.

(d) (i) State the meaning of the term *catalyst*.

.....

(1 mark)

(d) (ii) State the meaning of the term *hydration*.

.....

(1 mark)

(d) (iii) Write an equation for the hydration of propene to form isopropyl alcohol.
Give the IUPAC name for isopropyl alcohol.

Equation .....

IUPAC name .....

(2 marks)

.....

3)

There are many uses for compounds of barium.

(a) (i) Write an equation for the reaction of barium with water.

.....

(1 mark)

(a) (ii) State the trend in reactivity with water of the Group 2 metals from Mg to Ba

.....

(1 mark)

(b) Give the formula of the **least** soluble hydroxide of the Group 2 metals from Mg to Ba

.....

(1 mark)

(c) State how barium sulfate is used in medicine.
Explain why this use is possible, given that solutions containing barium ions are poisonous.

Use .....

.....

Explanation .....

.....

(2 marks)

4)

Chloromethanes, such as dichloromethane and trichloromethane, are produced in industry as they have many uses.
Trichloromethane has been used in the manufacture of the refrigerant chlorodifluoromethane.

(a) Chlorine can react with dichloromethane (CH_2Cl_2) to form trichloromethane ($CHCl_3$).

(a) (i) Write an equation for each of the following steps in the mechanism for this reaction.

Initiation step

.....

First propagation step

.....

Second propagation step

.....

(3 marks)

(a) (ii) Give **one** essential condition for this reaction and name the type of mechanism.

Essential condition .....

Type of mechanism .....

(2 marks)

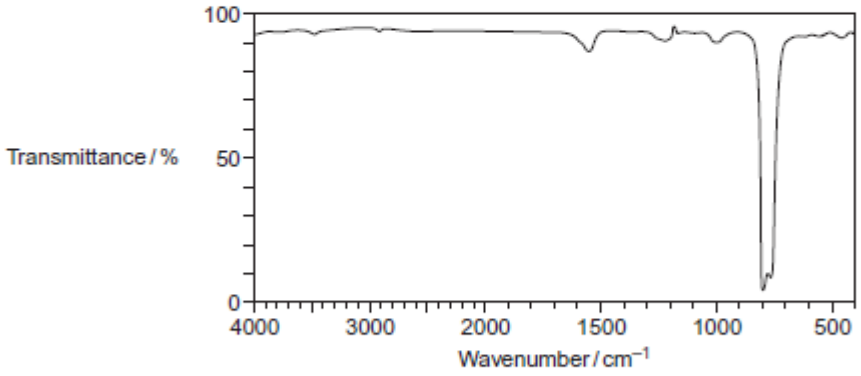
(b) An organic product, **X**, with M_r = 154.0 is obtained when chlorine reacts with trichloromethane.

(b) (i) Write an equation for the overall reaction of chlorine with trichloromethane to form **X**, by the same mechanism as that outlined in part **(a) (i)**.

.....

(1 mark)

(b) (ii) The following infrared spectrum was obtained for a sample of **X** produced in this reaction.



Use this infrared spectrum to explain why it is possible to deduce that this sample of **X** contains no trichloromethane.
You may find it helpful to refer to **Table 1** on the Data Sheet.

.....

(2 marks)

(c) Explain, with the aid of equations and the intermediates that form in the ozone layer, why the European Union has banned the use of chlorodifluoromethane ($CHClF_2$) as a refrigerant.

.....

(4 marks)

(d) The compound 2,3,3,3-tetrafluoropropene is the refrigerant used in all new car air conditioners.

(d) (i) Draw the displayed formula for 2,3,3,3-tetrafluoropropene. *(1 mark)*

(d) (ii) Give **one** reason why 2,3,3,3-tetrafluoropropene is a more **environmentally** acceptable refrigerant than chlorodifluoromethane.

(1 mark)

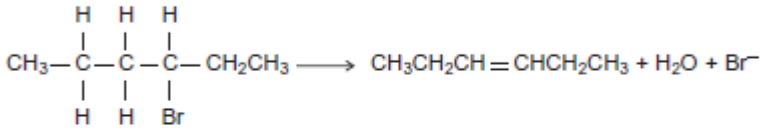
.....

5)

Alkenes are useful intermediates in the synthesis of organic compounds.

(a) (i) Complete the elimination mechanism by drawing appropriate curly arrows.

$H\bar{O}$**:**



3-bromohexane hex-3-ene

(3 marks)

(a) (ii) Draw structures for the E and Z stereoisomers of hex-3-ene.

E isomer of hex-3-ene Z isomer of hex-3-ene

(2 marks)

(a) (iii) State the meaning of the term *stereoisomers*.

.....

(2 marks)

(b) The equation for the first reaction in the conversion of hex-3-ene into hexan-3-ol is shown below.

$CH_3CH_2CH{=}CHCH_2CH_3 + H_2SO_4 \longrightarrow CH_3CH_2CH_2CH(OSO_2OH)CH_2CH_3$

Outline a mechanism for this reaction.

(4 marks)

6)

The reaction of butane-1,4-diol with butanedioic acid produces the polymer PBS used in biodegradable packaging and disposable cutlery.
Butanedioic acid is produced by two different processes.

Process 1

- Aqueous sodium hydroxide reacts with 1,4-dibromobutane to make butane-1,4-diol.
- Butane-1,4-diol is oxidised to butanedioic acid.

Process 2

- Glucose reacts with carbon dioxide in the presence of microorganisms to produce butanedioic acid directly.
- The carbon dioxide used in this process is obtained from a local factory that produces bioethanol.

(a) Deduce **one** safety reason and **one** environmental reason why **Process 2** is preferred to **Process 1**.

.....

(2 marks)

(b) (i) Name and outline a mechanism for the following reaction that occurs in **Process 1**.

$BrCH_2CH_2CH_2CH_2Br + NaOH \longrightarrow BrCH_2CH_2CH_2CH_2OH + NaBr$

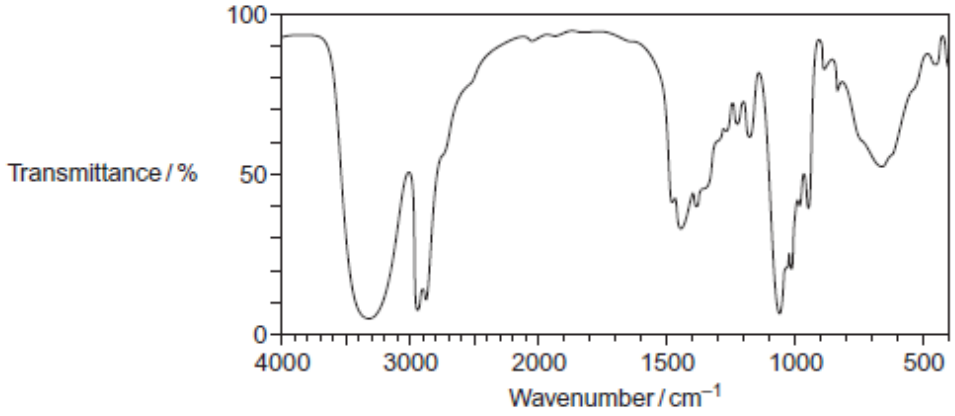
.....

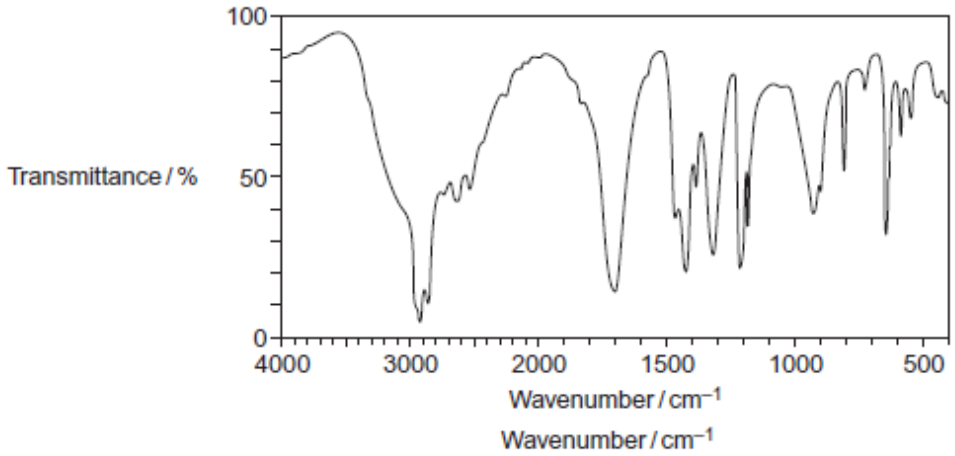
(3 marks)

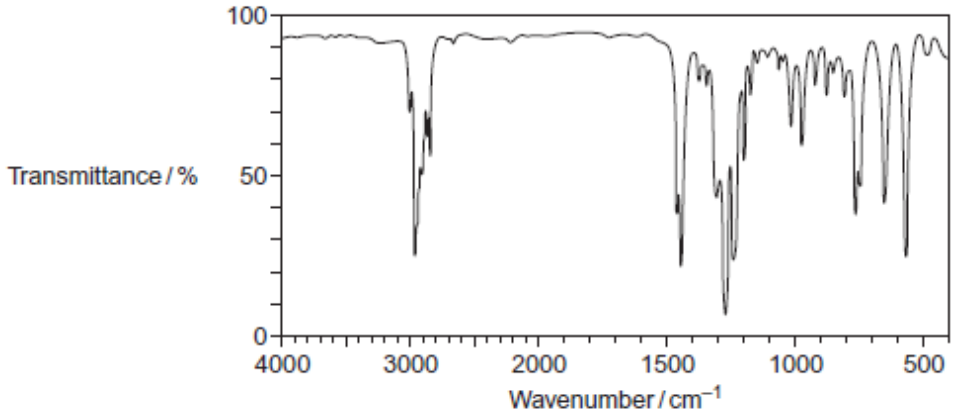
(b) (ii) The infrared spectra shown are those of three compounds.

Compound **A** 1,4-dibromobutane
Compound **B** butane-1,4-diol
Compound **C** butanedioic acid

Identify the compound responsible for each spectrum by writing the correct letter, **A**, **B** or **C**, in the box next to each spectrum.
You may find it helpful to refer to **Table 1** on the Data Sheet.







(3 marks)

(c) In the production of bioethanol, glucose ($C_6H_{12}O_6$) is converted into a dilute aqueous solution of ethanol and carbon dioxide.

Give the name of this process and state **three** essential conditions necessary to produce a good yield of ethanol.

.....

(4 marks)

(d) State the class of alcohols to which the diol butane-1,4-diol belongs.

Identify a suitable reagent or combination of reagents for the conversion of butane-1,4-diol into butanedioic acid ($HOOCCH_2CH_2COOH$).

Write an equation for this oxidation reaction using [O] to represent the oxidising agent.

.....

(3 marks)

7)

A student investigated the chemistry of the halogens and the halide ions.

(a) In the first two tests, the student made the following observations.

Test	Observation
1. Add chlorine water to aqueous potassium iodide solution.	The colourless solution turned a brown colour.
2. Add silver nitrate solution to aqueous potassium chloride solution.	The colourless solution produced a white precipitate.

(a) (i) Identify the species responsible for the brown colour in Test **1**.

Write the **simplest ionic** equation for the reaction that has taken place in Test **1**.

State the type of reaction that has taken place in Test **1**.

.....

(3 marks)

(Extra space) .....

.....

(a) (ii) Name the species responsible for the white precipitate in Test **2**.

Write the **simplest ionic** equation for the reaction that has taken place in Test **2**.

State what would be observed when an excess of dilute ammonia solution is added to the white precipitate obtained in Test **2**.

..... *(3 marks)*

(b) In two further tests, the student made the following observations.

Test	Observation
3. Add concentrated sulfuric acid to solid potassium chloride.	The white solid produced misty white fumes which turned blue litmus paper to red.
4. Add concentrated sulfuric acid to solid potassium iodide.	The white solid turned black. A gas was released that smelled of rotten eggs. A yellow solid was formed.

(b) (i) Write the **simplest ionic** equation for the reaction that has taken place in Test **3**.

Identify the species responsible for the misty white fumes produced in Test **3**.

.....

.....

(2 marks)

(b) (ii) The student had read in a textbook that the equation for one of the reactions in Test **4** is as follows.

$$8H^+ + 8I^- + H_2SO_4 \longrightarrow 4I_2 + H_2S + 4H_2O$$

Write the **two** half-equations for this reaction.

State the role of the sulfuric acid and identify the yellow solid that is also observed in Test **4**.

.....

(b) (iii) The student knew that bromine can be used for killing microorganisms in swimming pool water.
The following equilibrium is established when bromine is added to cold water.

$$Br_2(l) + H_2O(l) \rightleftharpoons HBrO(aq) + H^+(aq) + Br^-(aq)$$

Use Le Chatelier's principle to explain why this equilibrium moves to the right when sodium hydroxide solution is added to a solution containing dissolved bromine.

Deduce why bromine can be used for killing microorganisms in swimming pool water, even though bromine is toxic.

.....

(3 marks)