1 Oxygen and ozone (O_3) both occur as gases in the upper atmosphere.
Chlorine atoms catalyse the decomposition of ozone and contribute to the formation of a hole in the ozone layer.
These chlorine atoms are formed from chlorofluorocarbons (CFCs) such as CF_3Cl

1 (a) (i) Give the IUPAC name of CF_3Cl

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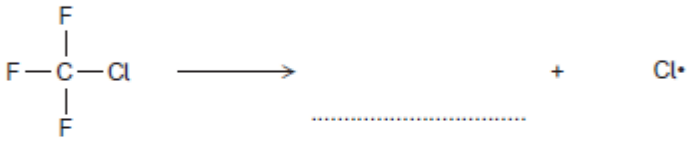
(1 mark)

1 (a) (ii) Complete the following equation that shows the formation of a chlorine atom from a molecule of CF_3Cl



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(1 mark)

1 (a) (iii) State what the • represents in Cl•

.....

(1 mark)

1 (b) Write two equations that show how chlorine atoms catalyse the decomposition of ozone into oxygen.

Equation 1 .....

Equation 2 .....

(2 marks)

1 (c) An equilibrium is established between oxygen and ozone molecules as shown below.

$$3O_2(g) \rightleftharpoons 2O_3(g) \qquad \Delta H = +284\ kJ\ mol^{-1}$$

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

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(1 mark)

(Extra space) .....

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1 (c) (ii) Use Le Chatelier's principle to explain how an increase in temperature causes an increase in the equilibrium yield of ozone.

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(2 marks)

(Extra space) .....

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1 (d) Chemists supported the legislation to ban the use of CFCs. Modern refrigerators use pentane rather than CFCs as refrigerants.
With reference to its formula, state why pentane is a more environmentally acceptable refrigerant.

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(1 mark)

(Extra space) .....

2 The following pairs of compounds can be distinguished by observing what happens in test-tube reactions.
For each pair, give a suitable aqueous reagent that could be added separately to each compound.
Describe what you would observe in each case.

(a) NaF(aq) and NaCl(aq)

Reagent .....

Observation with NaF(aq) .....

Observation with NaCl(aq) .....

(3 marks)

(b) $BaCl_2(aq)$ and $MgCl_2(aq)$

Reagent .....

Observation with $BaCl_2(aq)$.....

Observation with $MgCl_2(aq)$ .....

(3 marks)

(c) AgCl(s) and AgI(s)

Reagent .....

Observation with AgCl(s) .....

Observation with AgI(s) .....

(3 marks)

(d) Butan-2-ol(l) and 2-methylpropan-2-ol(l)

Reagent .....

Observation with butan-2-ol(l) .....

Observation with 2-methylpropan-2-ol(l) .....

(3 marks)

3 Sea water contains large amounts of dissolved magnesium compounds.
Approximately 1 kg of magnesium can be extracted from 1000 dm^3 of sea water.

(a) The first step in the extraction process is to react the magnesium ions in sea water with hydroxide ions to produce a precipitate of magnesium hydroxide.
Write the **simplest ionic** equation for this reaction.

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(1 mark)

(b) The second step in the extraction process is to react magnesium hydroxide with hydrochloric acid to give magnesium chloride. Write an equation for this reaction.

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(1 mark)

(c) In the final step, molten magnesium chloride is electrolysed to form magnesium and chlorine. This is similar to the method used to extract aluminium.
Deduce an equation for the reaction that occurs at the negative electrode in the electrolysis of magnesium chloride.

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(1 mark)

(d) Magnesium is used in the extraction of titanium.

(d) (i) Write an equation for the conversion of titanium(IV) oxide into titanium(IV) chloride.

.....

(2 marks)

(d) (ii) Write an equation for the extraction of titanium from titanium(IV) chloride using magnesium.

.....

(1 mark)

(d) (iii) State the role of magnesium in this extraction.

.....

(1 mark)

(e) Use your knowledge of the reactions of Group 2 metals with water to explain why water should **not** be used to put out a fire in which magnesium metal is burning.

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(2 marks)

(Extra space) .....

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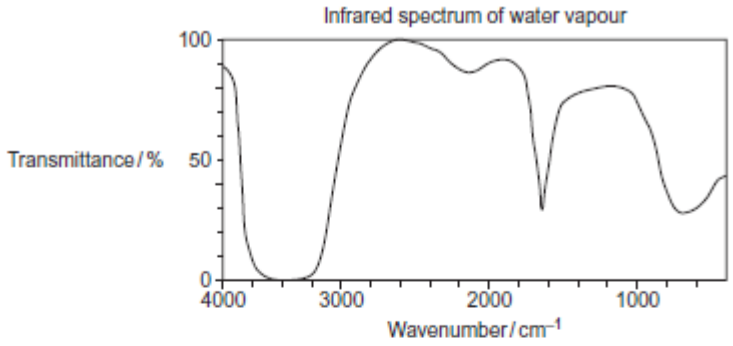
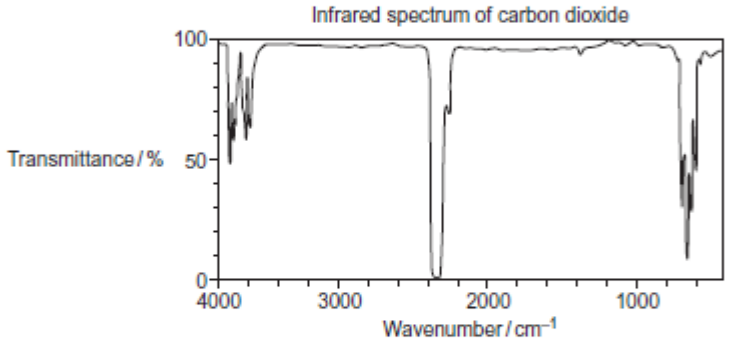
4(a) A student used the infrared spectra of water vapour and of carbon dioxide to try to find a link between infrared radiation and global warming.





(a) (i) Use information from the infrared spectra to deduce **one** reason why the student concluded that water vapour is a more effective greenhouse gas than carbon dioxide.

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(1 mark)

(a) (ii) Use your knowledge of the bonds in CO_2 to state why the infrared spectrum of carbon dioxide is **not** as might be predicted from the data provided in **Table 1** on the Data Sheet.

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(2 marks)

(b) The initiatives to decrease the carbon dioxide in the atmosphere include the use of carbon-neutral fuels and the development of carbon capture.
The mineral serpentine, $Mg_3Si_2O_5(OH)_4$, has been proposed as a solid for the capture of carbon dioxide gas.

(b) (i) Give the meaning of the term *carbon-neutral*, as applied to a fuel.

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(1 mark)

(Extra space) .....

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(b) (ii) Balance the following equation for the reaction of serpentine with carbon dioxide.

$Mg_3Si_2O_5(OH)_4$ + ...CO_2 ⟶ .....$MgCO_3$ + ...SiO_2 + ...H_2O

(1 mark)

5(a) The reaction of bromine with propane is similar to that of chlorine with methane.
Three steps in the mechanism for the bromination of propane to form 1-bromopropane are shown below.

Step **1** $Br_2 \longrightarrow 2Br\bullet$

Step **2** $Br\bullet + CH_3CH_2CH_3 \longrightarrow CH_3CH_2CH_2\bullet + HBr$

Step **3** $CH_3CH_2CH_2\bullet + Br_2 \longrightarrow CH_3CH_2CH_2Br + Br\bullet$

(a) (i) Name the type of mechanism in this reaction.

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(1 mark)

(a) (ii) Give an essential condition for Step **1** to occur.

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(1 mark)

(a) (iii) Name the type of step illustrated by Steps **2** and **3**.

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(1 mark)

(a) (iv) In this mechanism, a different type of step occurs in which free radicals combine.
Name this type of step.
Write an equation to show how hexane could be formed from two free radicals in the mechanism of this reaction.

Type of step .....

Equation .....

(2 marks)

(a) (v) Write an overall equation for the reaction between bromine and propane by the same mechanism to produce octabromopropane (C_3Br_8).

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(1 mark)

5 (b) Bromine reacts with alkenes, even though bromine is a non-polar molecule.

(b) (i) Explain why bromine molecules react with the double bonds in alkenes.

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(2 marks)

(Extra space) .....

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(b) (ii) Name the type of mechanism involved in this reaction.

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(1 mark)

(b) (iii) Draw the structure of the compound with M_r = 387.6 formed when penta-1,4-diene ($H_2C{=}CHCH_2CH{=}CH_2$) reacts with an excess of bromine.

(1 mark)

(c) Two products are formed when propene reacts with hydrogen bromide.
Draw the structure of the intermediate that leads to the formation of the major product in the reaction of propene with hydrogen bromide.
Give the name of this type of intermediate.

Structure of intermediate

Type of intermediate .....

(2 marks)

6 A student read the following passage on the Internet.

> Haloalkanes contain a polar covalent bond. The carbon atom of the polar covalent bond can be attacked by nucleophiles. Nucleophilic attack enables haloalkanes to undergo substitution reactions.
> A nucleophilic substitution reaction occurs when a haloalkane undergoes hydrolysis; the rate of hydrolysis of the haloalkane is influenced by the carbon–halogen bond enthalpy.

(a) Explain the meaning of each of the following terms in the information given above.

(a) (i) *nucleophile*

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(1 mark)

(a) (ii) *substitution,* as applied to nucleophilic substitution in a haloalkane

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(1 mark)

(a) (iii) *hydrolysis*

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(1 mark)

(a) (iv) *bond enthalpy,* as applied to a carbon–halogen bond.

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(1 mark)

(b) Outline a mechanism for the nucleophilic substitution reaction in which 2-bromopropane ($CH_3CHBrCH_3$) reacts with potassium hydroxide to form propan-2-ol.

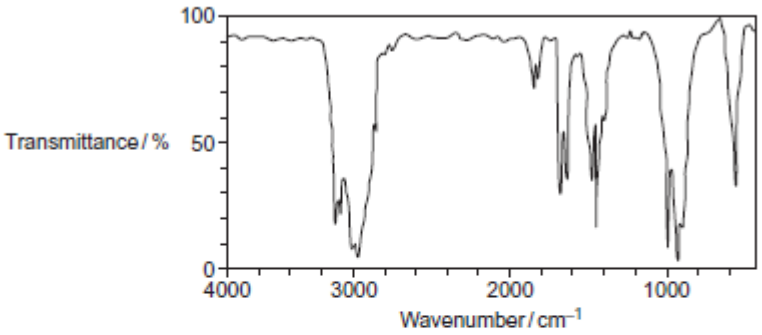
(2 marks)

(c) Haloalkanes also undergo elimination reactions to produce alkenes.

(c) (i) Outline a mechanism for the elimination reaction in which 2-bromopropane reacts with potassium hydroxide to form propene.

(3 marks)

(c) (ii) A student obtained the following infrared spectrum for the product from this elimination reaction.



Use information from the infrared spectrum to state and explain how the student deduced that the product was an alkene.
You may find it helpful to refer to **Table 1** on the Data Sheet.

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(2 marks)

(Extra space) .....

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7 A student devised an experiment to investigate the enthalpies of combustion of some alcohols. The student chose the following series of primary alcohols.

Name	Formula
Methanol	CH_3OH
Ethanol	CH_3CH_2OH
Propan-1-ol	$CH_3CH_2CH_2OH$
Butan-1-ol	$CH_3CH_2CH_2CH_2OH$
Pentan-1-ol	$CH_3CH_2CH_2CH_2CH_2OH$
Alcohol **X**	$CH_3CH_2CH_2CH_2CH_2CH_2OH$
Heptan-1-ol	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2OH$

(a) (i) Name alcohol **X**.

.....

(1 mark)

(a) (ii) State the general name of the type of series shown by these primary alcohols.

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(1 mark)

(a) (iii) Draw the displayed formula of the position isomer of butan-1-ol.

(1 mark)

(a) (iv) Using [O] to represent the oxidising agent, write an equation for the oxidation of butan-1-ol to form an aldehyde.

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(1 mark)

(a) (v) Draw the displayed formula of a functional group isomer of this aldehyde.

(1 mark)

(b) The student carried out a laboratory experiment to determine the enthalpy change when a sample of butan-1-ol was burned.
The student found that the temperature of 175 g of water increased by 8.0 ^{0}C when 5.00×10^{-3} mol of pure butan-1-ol 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 butan-1-ol is burned.
(The specific heat capacity of water is 4.18 J K^{-1} g^{-1})

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(3 marks)

(c) (i) Give the meaning of the term *standard enthalpy of combustion*.

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(3 marks)

(Extra space) .....

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(c) (ii) Use the standard enthalpy of formation data from the table and the equation for the combustion of butan-1-ol to calculate a value for the standard enthalpy of combustion of butan-1-ol.

	$CH_3CH_2CH_2CH_2OH(l)$	$O_2(g)$	$CO_2(g)$	$H_2O(l)$
$\Delta H_f^{\ominus}$/kJ mol^{-1}	– 327	0	– 394	– 286

$$CH_3CH_2CH_2CH_2OH(l) + 6O_2(g) \longrightarrow 4CO_2(g) + 5H_2O(l)$$

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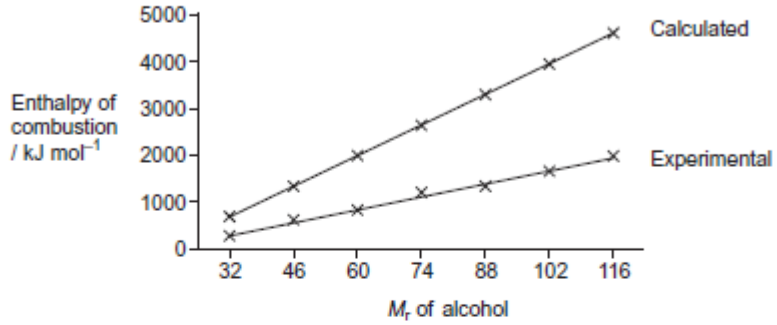
(3 marks)

(Extra space) .....

(d) The student repeated the experiment described in part **9 (b)** and obtained an experimental value for the enthalpy of combustion for each alcohol in this series. These experimental values were then compared with calculated values from standard enthalpies of formation, as shown in the graph below.

Enthalpies of combustion values for a series of primary alcohols



(d) (i) In terms of bonds broken and bonds formed, explain why the calculated values of enthalpies of combustion of these alcohols, when plotted against M_r, follow a straight line.

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(2 marks)

(Extra space) .....

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(d) (ii) Give **two** reasons why the experimental values obtained by the student are lower than the calculated values using the enthalpy of formation data.

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(2 marks)