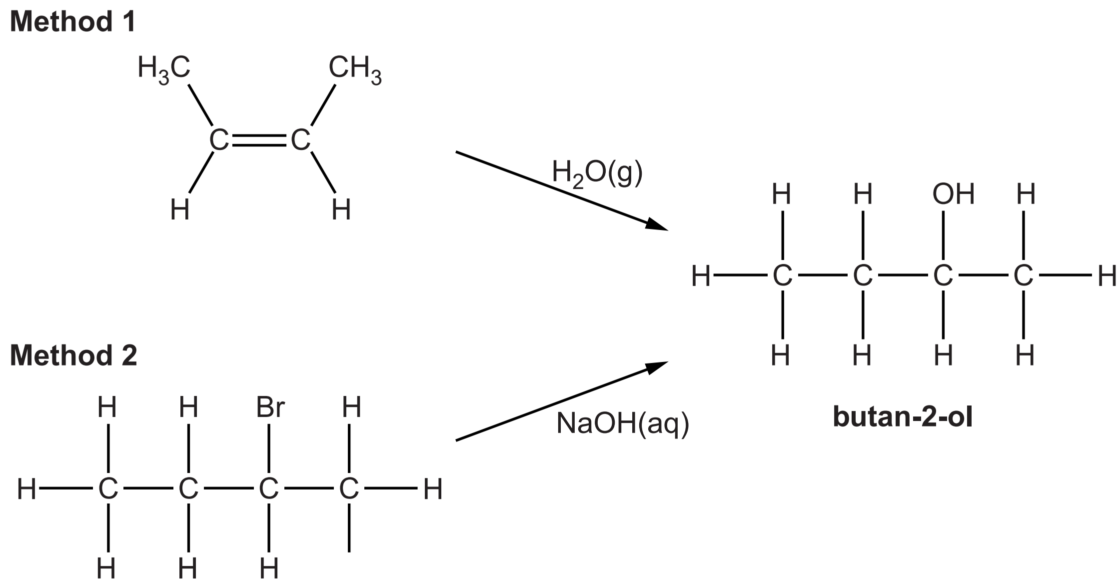
1 Butan-2-ol can be prepared using two different methods.



(a) Comment on the atom economy of each method, giving your reasons.

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.... **[2]**

(b) State the catalyst required for **Method 1**.

.... **[1]**

(c) Average bond enthalpies can be used to calculate enthalpy changes.

(i) What is meant by the term *average bond enthalpy*?

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.... **[2]**

(ii) Calculate the enthalpy change of reaction, ΔH_r, for preparing 1 mol of butan-2-ol by **Method 1**.

Average bond enthalpies are given below.

Bond	**Average bond enthalpy / kJ mol^{-1}**
O–H	464
C–H	413
C–C	347
C–O	358
C=C	612

ΔH_r = ... kJ mol^{-1} **[3]**

(d) A student uses **Method 2** to prepare 3.552 g of butan-2-ol from 2-bromobutane.
The percentage yield of butan-2-ol is 80.0%.

Calculate the mass of 2-bromobutane that the student uses.
Give your answer to **three** significant figures.

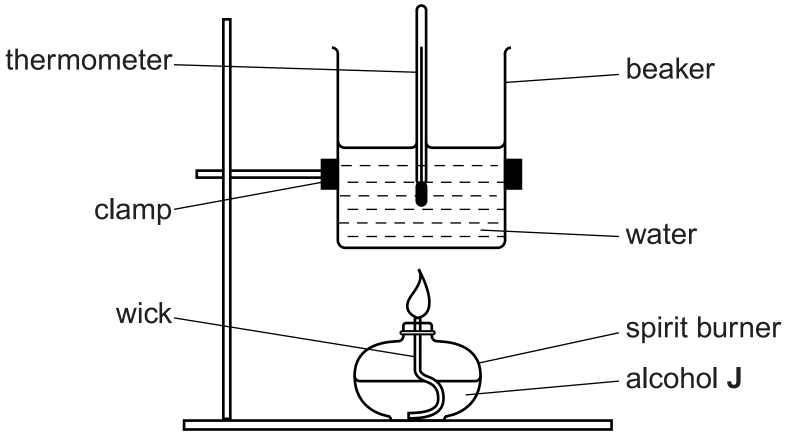
mass of 2-bromobutane = ... g **[3]**

[Total: 11]

2 A branched-chain alcohol **J** is a liquid and has the molecular formula $C_5H_{12}O$.

(a) A student does an experiment to measure the enthalpy change of combustion, ΔH_c, of alcohol **J**.

(i) The student burns alcohol **J** using the apparatus below.



The student found that combustion of 1.54 g of alcohol **J** changes the temperature of 180 g of water from 22.8 °C to 75.3 °C.

The specific heat capacity of water is 4.18 J g^{-1} K^{-1}.

- Calculate the amount, in mol, of alcohol **J** that burns.
- Calculate the enthalpy change of combustion, ΔH_c, of alcohol **J**, in kJ mol^{-1}.

Give your final answer to **three** significant figures.

ΔH_c = ... kJ mol^{-1} **[4]**

(ii) The calculated value of ΔH_c from this experiment is different from the value obtained from data books.

Apart from heat loss, suggest **two** reasons for the difference.

Assume that the calculation has been carried out correctly.

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.... **[2]**

(b) The enthalpy change of combustion for alcohol **J** can also be determined indirectly from standard enthalpy changes of formation.

(i) Write an equation, including state symbols, for the chemical change that represents the standard enthalpy change of formation of the liquid alcohol **J**, $C_5H_{12}O$.

.... **[1]**

(ii) The equation for the complete combustion of alcohol **J** is shown below.

$$C_5H_{12}O(l) + 7\tfrac{1}{2}O_2(g) \rightarrow 5CO_2(g) + 6H_2O(l)$$

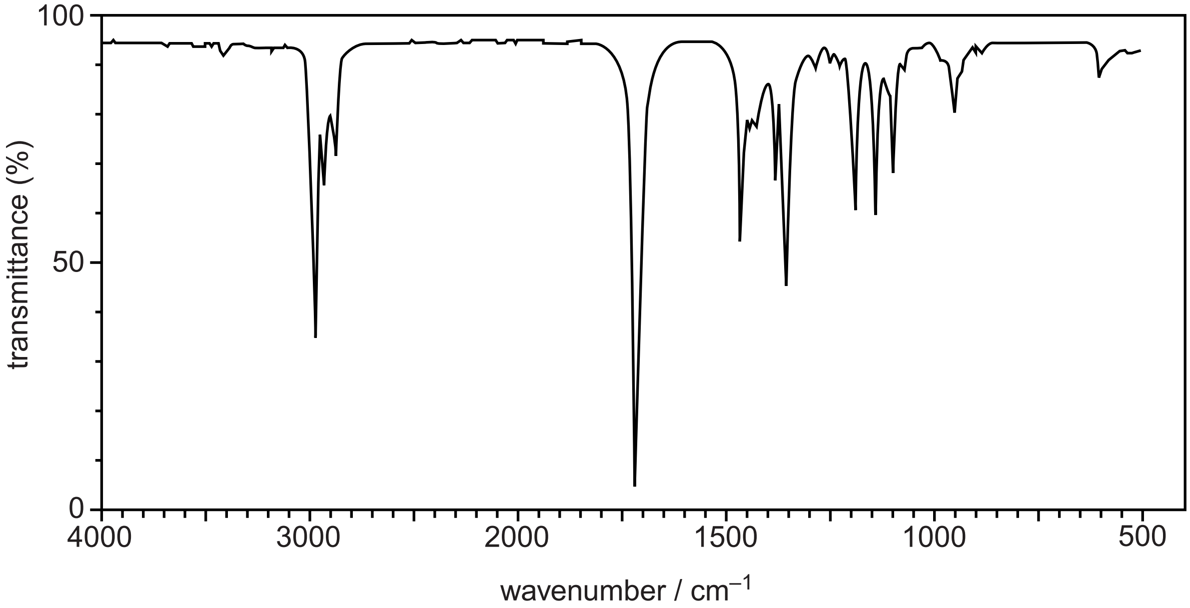
Enthalpy changes of formation, ΔH_f, are shown in the table.

Substance	**$C_5H_{12}O(l)$**	**$CO_2(g)$**	**$H_2O(l)$**
ΔH_f / kJ mol^{-1}	−366	−394	−286

Calculate the enthalpy change of combustion, ΔH_c, of alcohol **J** from the information given above.

ΔH_c = ... kJ mol^{-1} **[3]**

(c) The branched-chain alcohol **J**, $C_5H_{12}O$, was heated under reflux with excess $H_2SO_4/K_2Cr_2O_7$ to form an organic compound **K** with the infrared spectrum below.



- Determine the structures for the branched-chain alcohol **J** and compound **K**.
  Your answer should explain all your reasoning using the evidence given.

- Write an equation for the reaction of **J** when heated under reflux with excess $H_2SO_4/K_2Cr_2O_7$ to form **K**.
  Use [O] to represent the oxidising agent.

Your answer needs to be clear and well organised using the correct terminology.

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.... **[6]**

(d) The alcohol **J** is soluble in water.

Explain why alcohol **J** is soluble in water.

Use a labelled diagram to support your answer.

Include relevant dipoles and lone pairs.

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.... **[1]**

[Total: 17]

3 Hydrogen iodide, HI, is a colourless gas that can be made from the reaction of hydrogen, H_2, and iodine, I_2.

This reversible reaction is shown in **equilibrium 3.1** below.

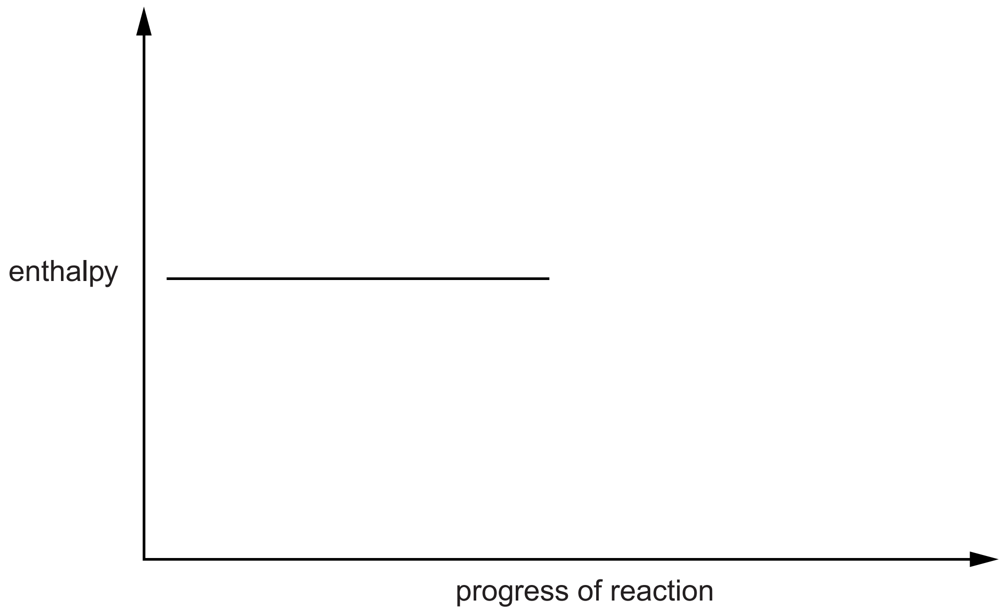
$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -9\,kJ\,mol^{-1} \qquad \textbf{equilibrium 3.1}$$

The activation energy for the forward reaction is $173\,kJ\,mol^{-1}$.

(a) Complete the enthalpy profile diagram below for the forward reaction in **equilibrium 3.1**.

On your diagram:

- Label the activation energy, E_a
- Label the enthalpy change of reaction, ΔH
- Include the formulae of the reactants and products.



[2]

(b) Calculate the activation energy, E_a, for the reverse reaction.

E_a (reverse reaction) = ... $kJ\,mol^{-1}$ **[1]**

(c) When the reverse reaction takes place hydrogen iodide, HI, decomposes to form iodine and hydrogen.

Calculate the enthalpy change when $336\,dm^3$ of hydrogen iodide, measured at room temperature and pressure, decomposes.

Include the sign for enthalpy change in your answer.

enthalpy change .... kJ **[2]**

(d) A student mixes hydrogen and iodine at room temperature and pressure and allows the mixture to reach dynamic equilibrium.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -9\,kJ\,mol^{-1} \qquad \textbf{equilibrium 3.1}$$

(i) A closed system is required for dynamic equilibrium to be established.

State **one** other feature of this dynamic equilibrium.

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.... **[1]**

(ii) The student heats the equilibrium mixture keeping the volume constant.

Predict how the composition of the equilibrium mixture changes on heating.

Explain your answer.

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.... **[2]**

(iii) Predict and explain what effect, if any, an increase in the pressure would have on the position of the equilibrium.

effect ....

explanation ....

.... **[1]**

(e) Calculate the bond enthalpy for the H–I bond in **equilibrium 3.1**, given the following information.

Bond	**Bond Enthalpy / $kJ\,mol^{-1}$**
H–H	436
I–I	151

bond enthalpy .... $kJ\,mol^{-1}$ **[2]**

[Total: 11]

4 This question is about the determination of enthalpy changes.

(a) A student carries out an experiment to find the enthalpy change of reaction, ΔH_r, for the reaction below.

$$Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + CO_2(g) + H_2O(l)$$

In the experiment, 3.18 g of Na_2CO_3 are added to 50.0 g of 2.00 mol dm^{-3} HCl, an excess. The temperature of the reaction mixture increases by 5.5 °C.

Calculate ΔH_r, in kJ mol^{-1}.

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

The specific heat capacity, *c*, of the reaction mixture is 4.18 J g^{-1} K^{-1}.

ΔH_r = ... kJ mol^{-1} **[4]**

(b) The booster rocket of a spacecraft uses a mixture of aluminium and ammonium chlorate(VII), NH_4ClO_4, as a fuel. The equation and some enthalpy changes are shown below.

$3Al(s) + 3NH_4ClO_4(s) \longrightarrow Al_2O_3(s) + \quad l_3(s) + 6H_2O(g) + 3NO(g) \qquad \Delta H = -2677\,kJ\,mol^{-1}$

Substance	Standard enthalpy change of formation, ΔH_f / $kJ\,mol^{-1}$
$NH_4ClO_4(s)$	–295
$Al_2O_3(s)$	–1676
$AlCl_3(s)$	–704
$H_2O(g)$	–242

(i) What is meant by the term *standard enthalpy change of formation*?

Give the standard conditions.

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.... **[3]**

(ii) Write the equation, including state symbols, for the reaction that represents the standard enthalpy change of formation of $NH_4ClO_4(s)$.

.... **[2]**

(iii) Calculate the enthalpy change of formation of NO(g) using the data above.

enthalpy change of formation of NO(g) = ... $kJ\,mol^{-1}$ **[3]**

[Total: 12]

5 Nitrogen forms several oxides including N_2O_4, N_2O and NO.

(a) A rocket uses the reaction between N_2O_4 and methylhydrazine, CH_3NHNH_2, **equation 5.1**, to release a large amount of energy.

$$4CH_3NHNH_2(l) + 5N_2O_4(l) \rightarrow 4CO_2(g) + 12H_2O(g) + 9N_2(g) \quad \textbf{equation 5.1}$$

Some enthalpy changes of formation, ΔH_f, are shown in the table.

Substance	ΔH_f / kJ mol^{-1}
$CH_3NHNH_2(l)$	+54
$N_2O_4(l)$	–20
$CO_2(g)$	–394
$H_2O(g)$	–242

Using the enthalpy changes of formation, ΔH_f, calculate the enthalpy change of reaction in **equation 5.1**.

enthalpy change of reaction = ... kJ mol^{-1} **[3]**

(b) Under certain conditions nitrogen reacts with oxygen to make N_2O.

$$2N_2(g) + O_2(g) \rightleftharpoons 2N_2O(g) \quad \textbf{equation 5.2}$$

The enthalpy profile diagram for this reaction is shown in **Fig. 5.3**.

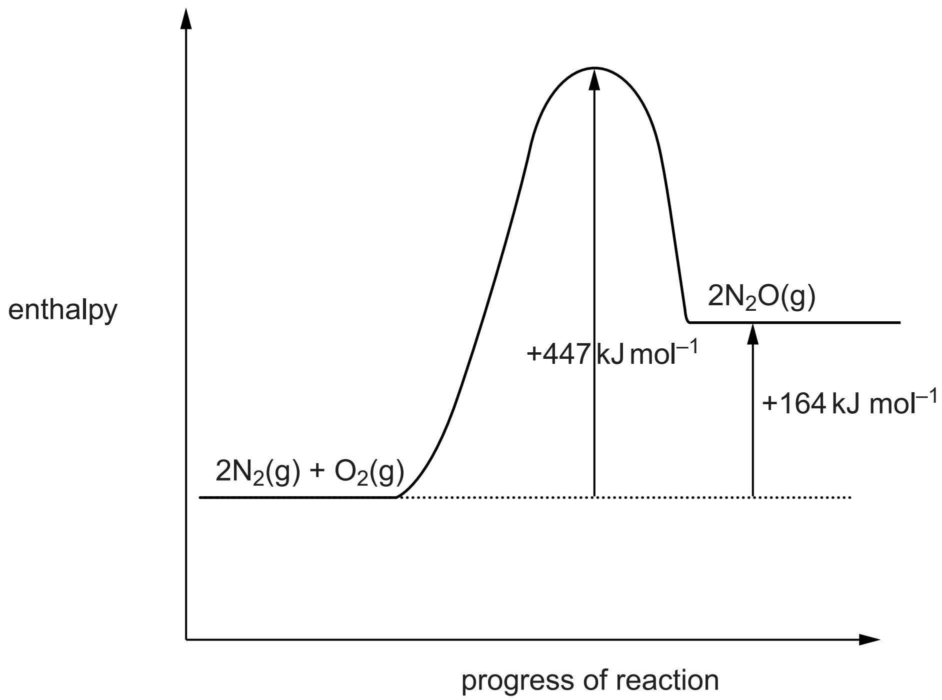

Fig. 5.3

(i) Calculate the enthalpy change when 240 dm^3 of $N_2O(g)$, measured at room temperature and pressure, is formed from N_2 and O_2.

enthalpy change = ... kJ **[2]**

(ii) What is the enthalpy change of formation, ΔH_f, of $N_2O(g)$?

ΔH_f = ... $kJ\,mol^{-1}$ **[1]**

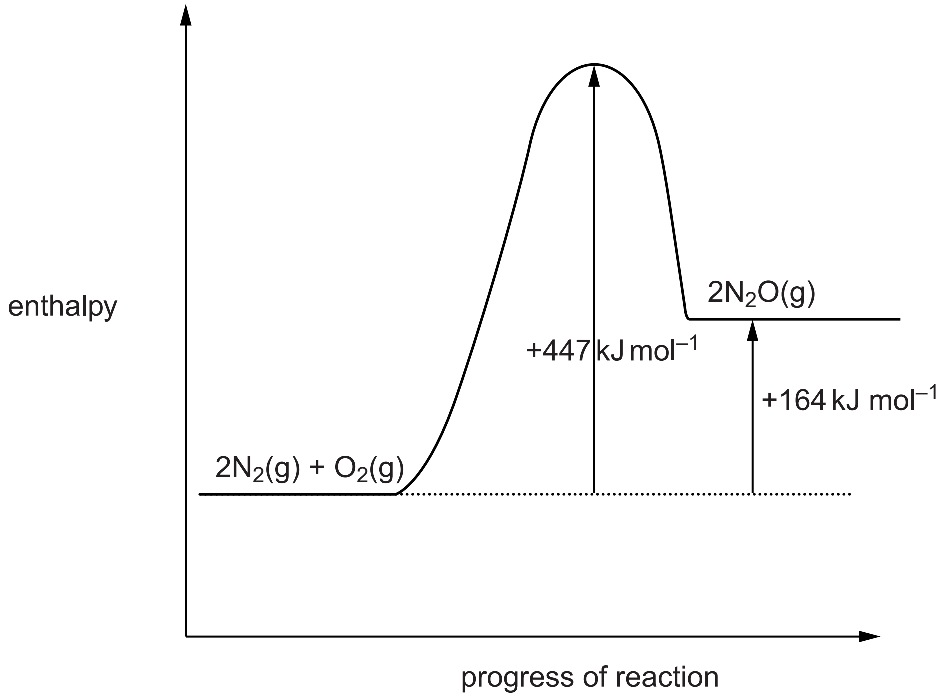

Fig. 5.3 (repeated)

(iii) The reaction in **equation 5.2** is reversible.

$$2N_2(g) + O_2(g) \rightleftharpoons 2N_2O(g) \quad \textbf{equation 5.2}$$

Calculate the activation energy, E_a, for the reverse reaction.

E_a (reverse reaction) = ... kJ mol^{-1} **[1]**

(c) Describe and explain, using equations, how the concentration of ozone in the stratosphere is maintained.

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.... **[2]**

(d) In the stratosphere, NO catalyses the breakdown of ozone.

Write **two** equations to show how NO catalyses this breakdown.

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.... **[2]**

[Total: 11]