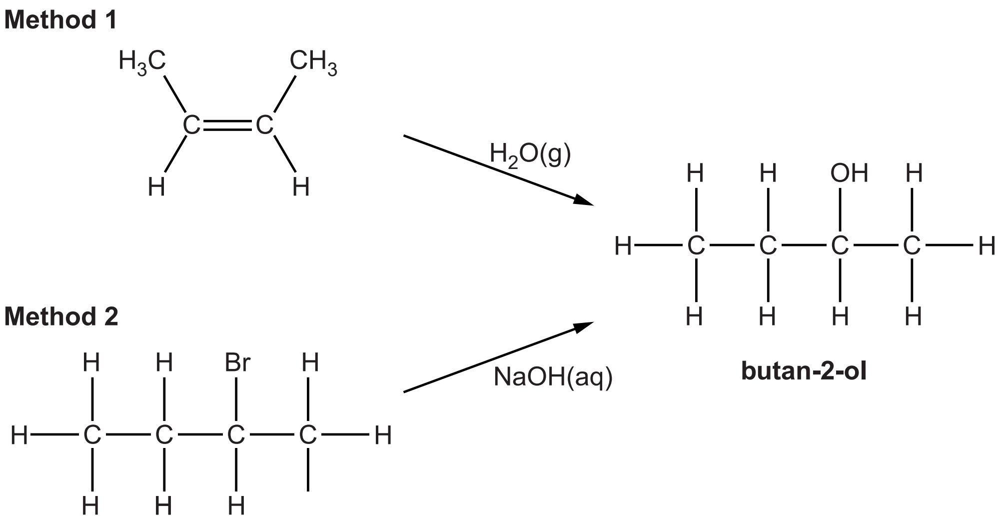
**1** Butan-2-ol can be prepared using two different methods.




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

..................................................................................................................................

..................................................................................................................................

..................................................................................................................................

..................................................................................................................................

.................................................................................................................................. **[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*?

..................................................................................................................................

..................................................................................................................................

..................................................................................................................................

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

**(ii)** Calculate the enthalpy change of reaction, $\Delta H_r$, 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 |

$\Delta H_r$ = ........................................... 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.

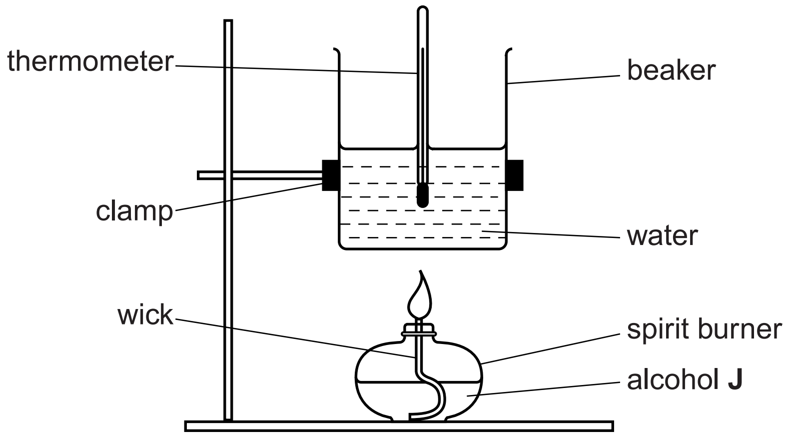
mass of 2-bromobutane = ...................................................... g **[3]**

**[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, $\Delta H_c$, 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, $\Delta H_c$, of alcohol **J**, in $kJ\,mol^{-1}$.

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

$\Delta H_c$ = ........................................... $kJ\,mol^{-1}$ **[4]**

**(ii)** The calculated value of $\Delta H_c$ 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.

..............................................................................................................................

..............................................................................................................................

..............................................................................................................................

.............................................................................................................................. **[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.

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

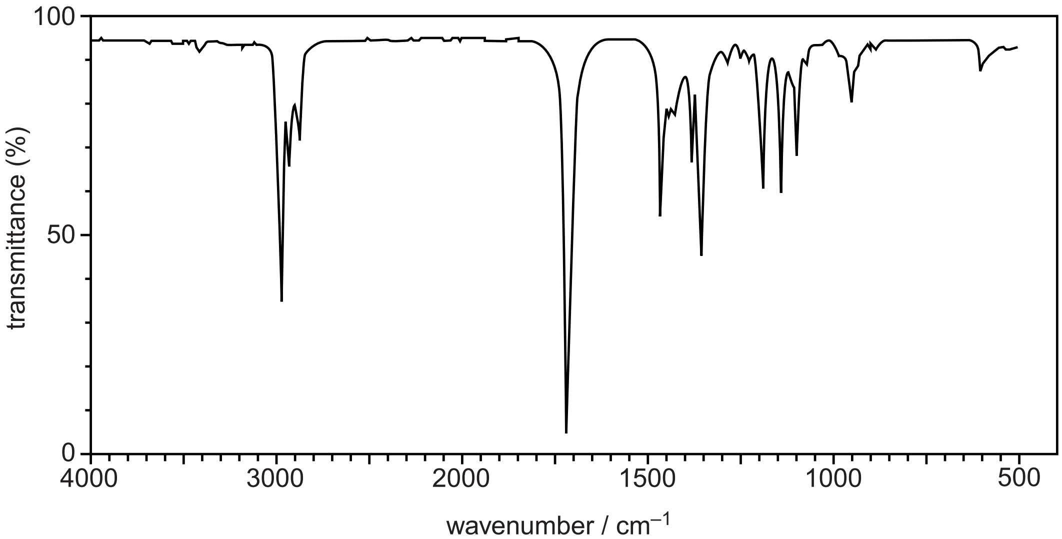
Enthalpy changes of formation, $\Delta H_f$, are shown in the table.

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

Calculate the enthalpy change of combustion, $\Delta H_c$, of alcohol **J** from the information given above.

$\Delta H_c$ = .......................................... 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.*

...............................................................................................................................................

...............................................................................................................................................

...............................................................................................................................................

...............................................................................................................................................

...............................................................................................................................................

...............................................................................................................................................

...............................................................................................................................................

...............................................................................................................................................

...............................................................................................................................................

...............................................................................................................................................

............................................................................................................................................ **[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.

..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................... **[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.

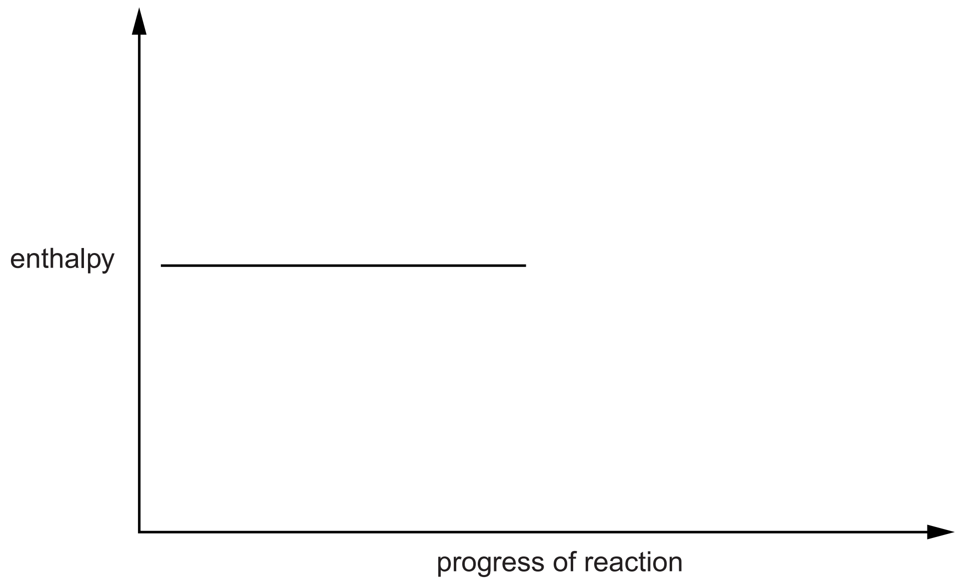
$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ $\Delta H = -9\,kJ\,mol^{-1}$ **equilibrium 3.1**

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, $\Delta H$
- 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.

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

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

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

..................................................................................................................................

.......................................................................................................................... **[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.

..................................................................................................................................

..................................................................................................................................

..................................................................................................................................

.......................................................................................................................... **[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, $\Delta H_r$, for the reaction below.

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

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

Calculate $\Delta H_r$, in kJ $mol^{-1}$.

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

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

$\Delta H_r$ = .......................................... 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.

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

| **Substance** | **Standard enthalpy change of formation, $\Delta H_f$ / 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.

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................... **[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.

$$4CH_3NHNH_2(l) + 5N_2O_4(l) \rightarrow 4CO_2(g) + 12H_2O(g) + 9N_2(g)$$ **equation 5.1**

Some enthalpy changes of formation, $\Delta H_f$, are shown in the table.

| **Substance** | **$\Delta H_f$ / 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, $\Delta H_f$, 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**.

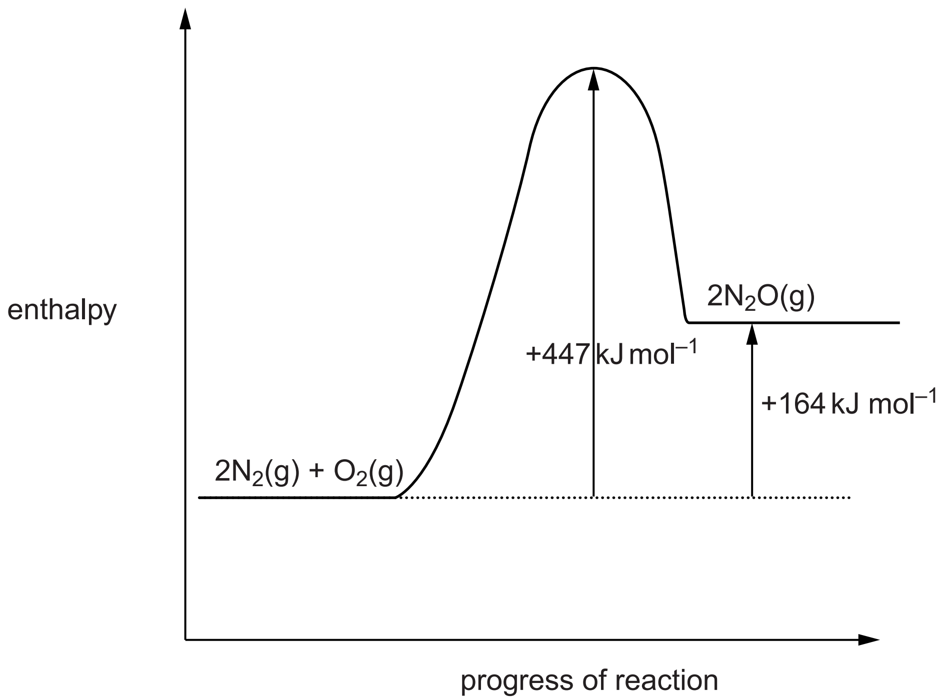



**Fig. 5.3**

**(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, $\Delta H_f$, of $N_2O(g)$?

$\Delta H_f$ = ............................................ $kJ\,mol^{-1}$ **[1]**

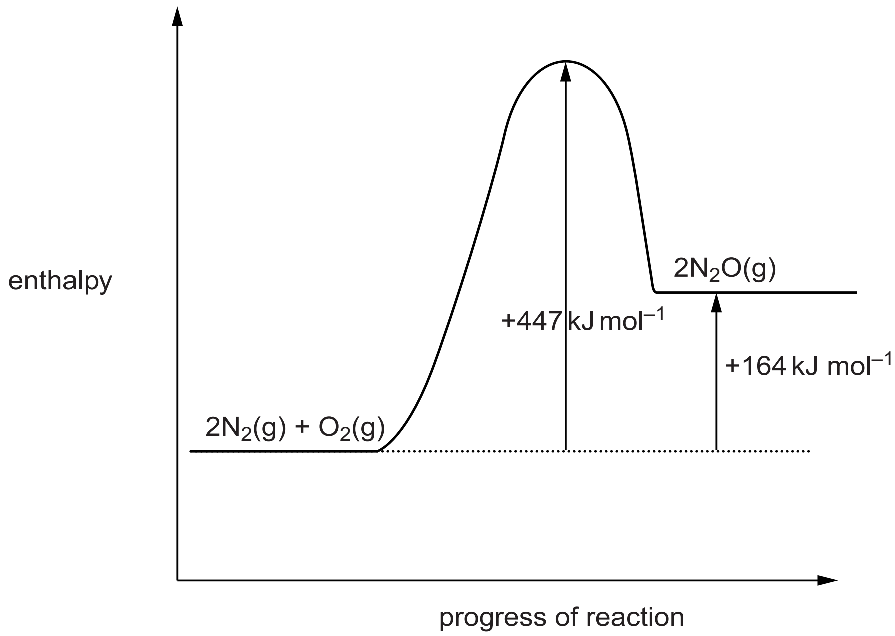



**Fig. 5.3 (repeated)**

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

$$2N_2(g) + O_2(g) \rightleftharpoons 2N_2O(g)$$ **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.

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

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

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

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

..........................................................................................................................................

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

**[Total: 11]**