1(a). This question is about energy changes.

Hydrogen peroxide decomposes as shown in **Reaction 16.1**.

$H_2O_2(l) \rightarrow H_2O(l) + \frac{1}{2}O_2(g)$ **Reaction 16.1**

The table shows enthalpy changes of formation and entropies.

	ΔH_f°/kJ mol^{1}	S° / J K^{-1} mol^{-1}
$H_2O_2(l)$	−188	110
$H_2O(l)$	−286	70.0
$O_2(g)$	0	205

i. Calculate the free-energy change, ΔG, in kJ mol^{-1}, of **Reaction 16.1** at 25 °C.

Give your answer to **3** significant figures.

ΔG = ... kJ mol^{-1} **[4]**

ii. The decomposition of hydrogen peroxide shown in **Reaction 16.1** is feasible.

Suggest why **Reaction 16.1** does **not** take place at 25 °C despite being feasible.

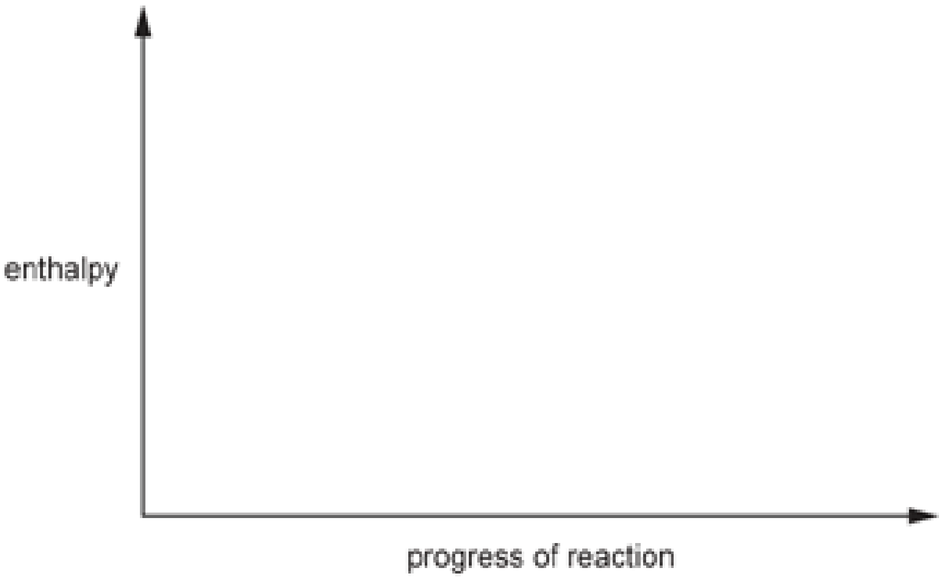
[1]

(b). The rate of decomposition of hydrogen peroxide shown in **Reaction 16.1** can be increased by adding a small amount of powdered manganese(IV) oxide, MnO_2.

The MnO_2 acts as a catalyst.

i. Complete the enthalpy profile diagram for **Reaction 16.1** using formulae for the reactants and products.

- Use E_a to label the activation energy **without** MnO_2.
- Use E_c to label the activation energy **with** MnO_2.
- Use ΔH to label the enthalpy change of reaction.



[3]

ii. Explain why MnO_2 is described as a **heterogeneous** catalyst for this reaction.

[1]

iii. Mn_3O_4 is a compound in which Mn has two different oxidation states. The two oxidation states are different from the Mn in MnO_2.

Suggest the two oxidation states of manganese in Mn_3O_4.

[1]

(c). Manganese(II) oxide, MnO, has a giant ionic lattice structure.

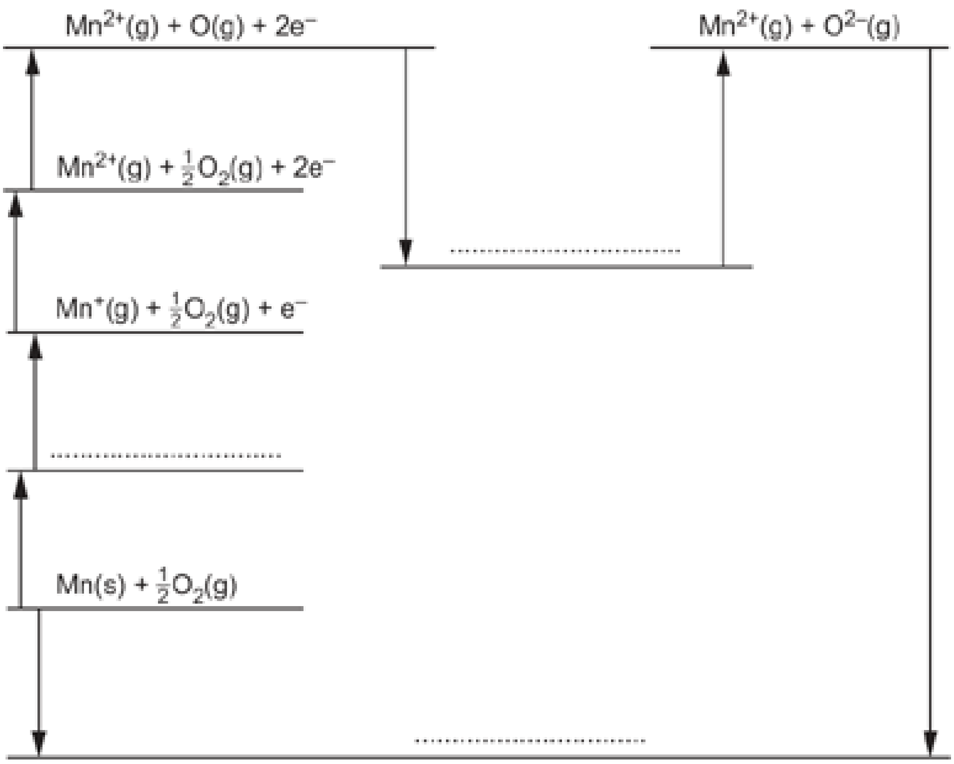
The table shows the enthalpy changes that are needed to determine the lattice enthalpy of MnO.

	enthalpy change / kJ mol^{-1}
atomisation of manganese	+281
atomisation of oxygen	+249
first ionisation energy of manganese	+717
second ionisation energy of manganese	+1509
first electron affinity of oxygen	−141
second electron affinity of oxygen	+798
formation of manganese(II) oxide	−385

i. Define the term **lattice enthalpy**.

[2]

ii. The diagram shows an incomplete Born-Haber cycle that can be used to determine the lattice enthalpy of MnO.



Complete the diagram by adding the species present on the dotted lines, include state symbols.

[3]

iii. Calculate the lattice enthalpy of MnO.

lattice enthalpy = ... kJ mol^{-1} **[2]**

2. The table below shows standard entropies, $S^{\ominus}$.

Substance	SO_2(g)	O_2(g)	SO_3(l)
$S^{\ominus}$/J K^{-1} mol^{-1}	248	204	96

What is the standard entropy change, $\Delta S^{\ominus}$, in J K mol^{-1}, for the formation of 1 mol of SO_3(l) from SO_2(g) and O_2(g)?

A –508
B –254
C +254
D +508

Your answer ☐ **[1]**

3. Chlorine trifluoride can be decomposed into its elements forming the equilibrium mixture below.

$2ClF_3$(g)	$\rightleftharpoons$	Cl_2(g)	+	$3F_2$(g)	ΔH = +318 kJ mol^{-1}
colourless gas		green gas		yellow gas	

Which statement(s) is/are correct?

1 The decomposition is a redox reaction.
2 When the equilibrium mixture is cooled, the colour fades.
3 The decomposition has a negative entropy change.

A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer ☐ **[1]**

4. This question is about enthalpy changes of reactions involving hydrocarbons.

Ethene can be produced from ethanol, as shown in **Reaction 2** below.

$C_2H_5OH(g) \rightarrow C_2H_4(g) + H_2O(g)$ **Reaction 2**

i. Predict the sign of the entropy change, ΔS, for **Reaction 2**.

Explain your reasoning.

[1]

ii. **Reaction 2** is repeated:
$C_2H_5OH(g) \rightarrow C_2H_4(g) + H_2O(g)$ **Reaction 2**

The Gibbs equation is shown below.

$\Delta G = \Delta H - T\Delta S$

The enthalpy change, ΔH, and the entropy change, ΔS, can be assumed to be constant at different temperatures.

Fig. 18.1 shows values of the free energy change, ΔG, in kJ mol^{-1}, at different temperatures, T, in K, for **Reaction 2**.

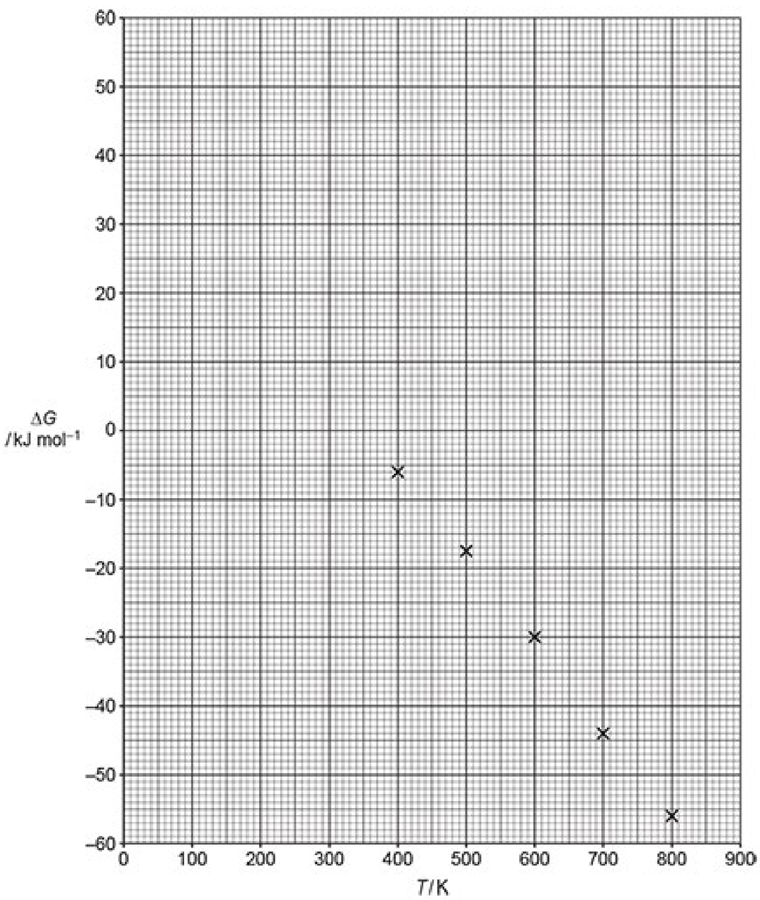


Fig. 18.1

Use the graph in **Fig. 18.1** to answer the following:

- Draw the best-fit line on the graph in **Fig. 18.1**.
- Determine Δ*S*, in J K^{-1} mol^{-1}, for **Reaction 2**.
- Determine the minimum temperature, *T*, at which the reaction is feasible.
- Determine Δ*H* for **Reaction 2**.

Δ*S* = ... J K^{-1} mol^{-1}
minimum *T* = ... K
Δ*H* = ... kJ mol^{-1}
[5]

5. This question is about energy changes.

Carbon disulfide, CS_2, reacts with dinitrogen oxide, N_2O, as shown in **Reaction 17.2**.

$4CS_2(l) + 8N_2O(g) \rightarrow S_8(s) + 4CO_2(g) + 8N_2(g)$ **Reaction 17.2**

Standard entropies, $S^{\ominus}$, are shown in the table.

Substance	CS_2(l)	N_2O(g)	S_8(s)	CO_2(g)	N_2(g)
$S^{\ominus}$/**JK^{-1} mol^{-1}**	151	220	256	214	192

i. Explain the term **entropy**.

[1]

ii. The free energy change, ΔG, of **Reaction 17.2** is −2672 kJ mol^{-1} at 25°C.

Calculate the enthalpy change, ΔH, of **Reaction 17.2**, in kJ mol^{-1}.

ΔH = ... kJ mol^{-1} **[3]**

iii. A student concludes that **Reaction 17.2** is feasible at all temperatures.

Explain whether the student is correct or not.

[2]

6. For the condensation of ammonia gas, what are the signs of ΔH and ΔS?

A ΔH −ve ΔS −ve
B ΔH −ve ΔS +ve
C ΔH +ve ΔS +ve
D ΔH +ve ΔS −ve

Your answer ☐ **[1]**

END OF QUESTION PAPER