

18 A student is asked to calculate ΔG at 25 °C for the combustion of butan-1-ol. The teacher provides two pieces of information.

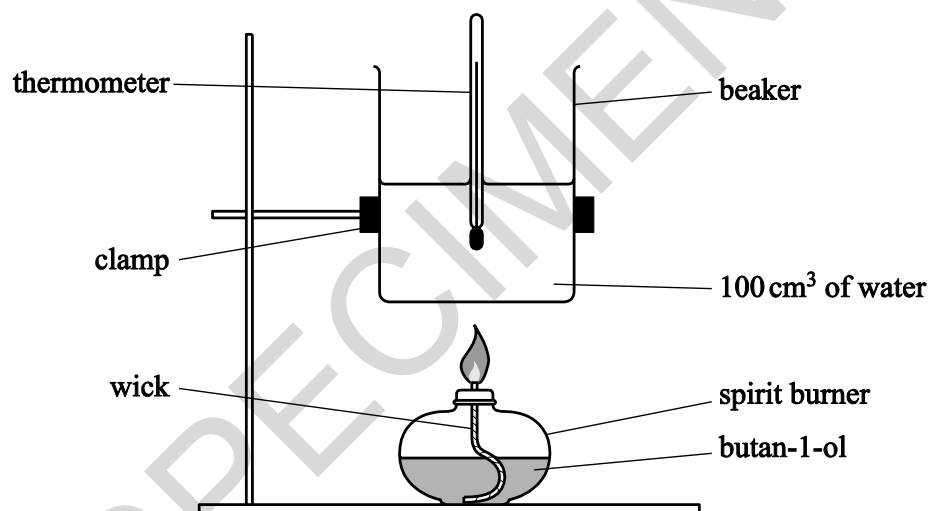
- The equation for the combustion of butan-1-ol.



- Standard entropies of butan-1-ol, oxygen, carbon dioxide and water.

| | $\text{CH}_3(\text{CH}_2)_3\text{OH}(\text{l})$ | $\text{O}_2(\text{g})$ | $\text{CO}_2(\text{g})$ | $\text{H}_2\text{O}(\text{l})$ |
|---|---|------------------------|-------------------------|--------------------------------|
| $S^\circ / \text{J K}^{-1} \text{mol}^{-1}$ | 228 | 205 | 214 | 70 |

The student carries out an experiment using the apparatus below and obtains the following results. The specific heat capacity of water is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$.



| | |
|--|--------|
| Mass of burner and butan-1-ol before burning / g | 98.997 |
| Mass of burner and butan-1-ol after burning / g | 98.738 |
| Initial temperature / °C | 18.5 |
| Maximum temperature reached / °C | 39.0 |

Use the information on the previous page to calculate ΔG , in kJ mol^{-1} , for the combustion of butan-1-ol according to **Equation 2** at $25\text{ }^\circ\text{C}$.

Show **all** your working.

SPECIMEN

$\Delta G = \dots\dots\dots \text{kJ mol}^{-1}$ [7]

18 This question is about free energy changes, ΔG , enthalpy changes, ΔH , and temperature, T .

(a) The Gibbs' equation is shown below.

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

A chemist investigates a reaction to determine how ΔG varies with T .
The results are shown in **Fig. 18.1**.

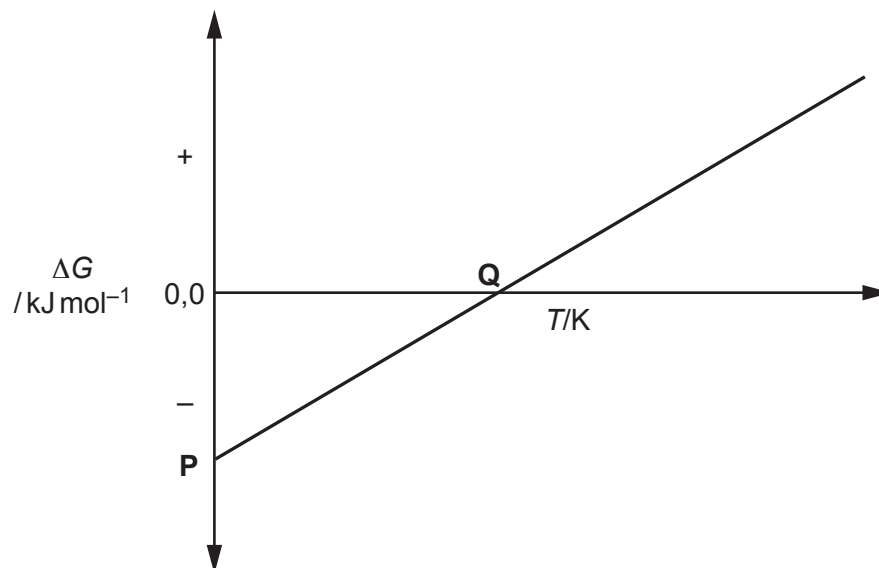


Fig. 18.1

What is significant about the gradient of the line and the values **P** and **Q** shown in **Fig. 18.1**?
Explain your reasoning.

.....

.....

.....

.....

.....

.....

.....

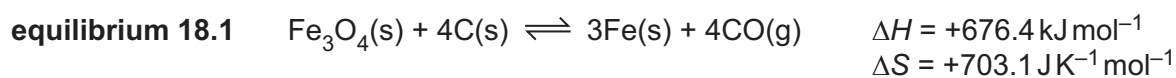
.....

.....

.....

..... [4]

- (b) Iron can be extracted from its ore Fe_3O_4 using carbon.
Several equilibria are involved including **equilibrium 18.1**, shown below.



- (i) Why is **equilibrium 18.1** a *heterogeneous* equilibrium?

.....
 [1]

- (ii) Write the expression for K_p for **equilibrium 18.1**.

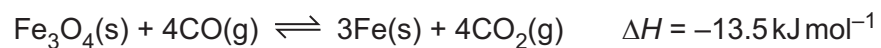
[1]

- (iii) The forward reaction in **equilibrium 18.1** is only feasible at high temperatures.

- Show that the forward reaction is **not** feasible at 25°C .
- Calculate the minimum temperature, in K, for the forward reaction to be feasible.

minimum temperature = K [3]

(iv) Another equilibrium involved in the extraction of iron from Fe_3O_4 is shown below.



Enthalpy changes of formation, $\Delta_f H$, for $\text{Fe}_3\text{O}_4(\text{s})$ and $\text{CO}_2(\text{g})$ are shown in the table.

| Compound | $\Delta_f H / \text{kJ mol}^{-1}$ |
|-----------------------------------|-----------------------------------|
| $\text{Fe}_3\text{O}_4(\text{s})$ | -1118.5 |
| $\text{CO}_2(\text{g})$ | -393.5 |

Calculate the enthalpy change of formation, $\Delta_f H$, for $\text{CO}(\text{g})$.

$\Delta_f H$, for $\text{CO}(\text{g}) = \dots\dots\dots \text{kJ mol}^{-1}$ [3]

| Question | Answer | Marks | Guidance |
|----------|---|-------|--|
| 18 | <p>ΔH calculation from experiment</p> <p>$q = 100 \times 4.18 \times 20.5$ OR 8569 J OR 8.569 kJ ✓</p> <p>Amount of butan-1-ol = $\frac{0.259}{74} = 3.5 \times 10^{-3}$ mol ✓</p> <p>$\Delta H = -2448$ kJ mol⁻¹ ✓</p> <p>ΔS calculation</p> <p>$\Delta S = S_{\text{products}} - S_{\text{reactants}}$</p> <p>$\Delta S = (4 \times 214) + (5 \times 70) - [(228) + (6 \times 205)]$ OR $\Delta S = 1206 - 1458$ ✓</p> <p>$\Delta S = -252$ J K⁻¹ mol⁻¹ OR -0.252 kJ K⁻¹ mol⁻¹ ✓</p> <p>ΔG calculation</p> <p>$\Delta G = \Delta H - T\Delta S$</p> <p>$\Delta G = -2448 - (298 \times -0.252)$ ✓</p> <p>$\Delta G = -2373$ (kJ mol⁻¹) ✓</p> | 7 | <p>ALLOW Calculator value for $\Delta H = -2448.285714$ correctly rounded to three or more significant figures</p> <p>Mark for use of correct expression with ΔS in kJ K⁻¹ mol⁻¹</p> <p>ALLOW three or more sig figs for ΔG</p> |
| | Total | 7 | |

| Question | | Answer | Marks | Guidance | |
|----------|-----|---|-------|--|---|
| 18 | (a) | $\Delta G = \Delta H - T\Delta S$ linked to $y = mx + c$ (somewhere) ✓ gradient = $-\Delta S$ ✓ P: ΔH / enthalpy change ✓ Q: (temperature) for reaction to be feasible/unfeasible OR (temperature) at which feasibility changes ✓ | 4 | Could be: $\Delta G = -\Delta S T + \Delta H$ – sign required ALLOW $\Delta S = -\text{gradient}$ ALLOW ‘point of feasibility’ For Feasibility: ALLOW can take place/happen OR is spontaneous IGNORE ‘minimum/maximum temperature’ | |
| | (b) | (i) | 1 | (Species have) different states/phases ✓ | |
| | | (ii) | 1 | $(K_p =) p(\text{CO}(\text{g}))^4$ ✓ Allow species without state symbols and without brackets, e.g. p_{CO}^4 , $pp\text{CO}^4$, PCO^4 , $p(\text{CO}^4)$ etc. DO NOT ALLOW square brackets | |
| | | (iii) | 3 | ΔG at 25 C $\Delta G = \Delta H - T\Delta S = 676.4 - (298 \times 0.7031)$ = (+) 467 (kJ mol ⁻¹) OR (+) 466876 (J mol ⁻¹) ✓ <i>Non-feasibility statement</i> Non-feasible when $\Delta G > 0$ OR $\Delta G > 0$ OR $\Delta H > T\Delta S$ ✓ <i>Minimum temperature</i> minimum temperature = $\frac{\Delta H}{\Delta S} = \frac{676.4}{0.7031}$ = 962(.0) K ✓ | IGNORE units ALLOW (+) 467 up to calculator value of 466.8762 correctly rounded ECF for any positive value determined in M1 ALLOW 962 up to calculator value of 962.0253165 correctly rounded |

| Question | Answer | Marks | Guidance |
|----------|--|-----------|--|
| (iv) | <p>FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = -110.5, Award 3 marks.</p> <p>-----</p> <p>Correct expression $-13.5 = (4 \times -393.5) - (-1118.5 + 4 \times \Delta_f H(\text{CO})) \checkmark$</p> <p>Correct subtraction using ΔH and $\Delta_f H(\text{Fe}_3\text{O}_4)$ $4 \times \Delta_f H(\text{CO}) = (4 \times -393.5) - (-1118.5) + 13.5$ $= -442(.0) \text{ (kJ mol}^{-1}\text{)} \checkmark$</p> <p>Calculation of $\Delta_f H(\text{CO})$ formation</p> $\Delta_f H(\text{CO}) = -\frac{442}{4} = -110.5 \text{ (kJ mol}^{-1}\text{)} \checkmark$ | 3 | <p>For answer, ALLOW -111 (kJ mol⁻¹)</p> <p>-----</p> <p>NOTE: IF any values are omitted, DO NOT AWARD any marks. e.g. -393.5 OR -13.5 may be missing</p> <p>-----</p> <p>Common errors</p> <p>(+)110.5 <i>wrong/omitted sign</i> 2 marks</p> <p>(+)184.625 / 184.63 / 184.6 / 185 2 marks <i>No 4CO₂</i></p> <p>(+)738.5 / 739 <i>No 4CO₂ and no CO/4</i> 1 mark</p> <p>-117.25 / -117.3 / -117 <i>Wrong cycle</i> 2 marks</p> <p>-469 <i>Wrong cycle, no CO/4</i> 1 mark</p> <p>(+)177.875 / 177.88 / 177.9 / 178 1 mark <i>Wrong cycle, no 4CO₂</i></p> <p>-360.5 <i>Used 118.5</i> 2 marks</p> <p>Any other number: CHECK for ECF from 1st marking point for expressions using ALL values with ONE error only e.g. one transcription error:, e.g. 395.3 for 393.5</p> |
| | Total | 12 | |