



# **A-Level Chemistry**

## **Gibb's Free Energy**

### **Question Paper**

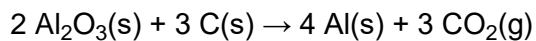
**Time available: 69 minutes**

**Marks available: 61 marks**

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**1.**

This question is about thermodynamics.  
Consider the reaction shown.



The table below shows some thermodynamic data.

Substance	$\text{Al}_2\text{O}_3(\text{s})$	$\text{Al}(\text{s})$	$\text{C}(\text{s})$	$\text{CO}_2(\text{g})$
$\Delta_f H^\ominus / \text{kJ mol}^{-1}$	-1669	0	0	-394
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	51	28	6	214

(a) Explain why the standard entropy value for carbon dioxide is greater than that for carbon.

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(1)

(b) State the temperature at which the standard entropy of aluminium is  $0 \text{ J K}^{-1} \text{ mol}^{-1}$

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(1)

- (c) Use the equation and the data in the table above to calculate the minimum temperature, in K, at which this reaction becomes feasible.

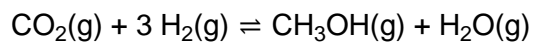
Minimum temperature \_\_\_\_\_ K

**(7)**

**(Total 9 marks)**

**2.**

Methanol is formed when carbon dioxide and hydrogen react.



The table contains enthalpy of formation and entropy data for these substances.

	<b>CO<sub>2</sub>(g)</b>	<b>H<sub>2</sub>(g)</b>	<b>CH<sub>3</sub>OH(g)</b>	<b>H<sub>2</sub>O(g)</b>
$\Delta_f H / \text{kJ mol}^{-1}$	-394	0	-201	-242
$S / \text{J K}^{-1} \text{mol}^{-1}$	214	131	238	189

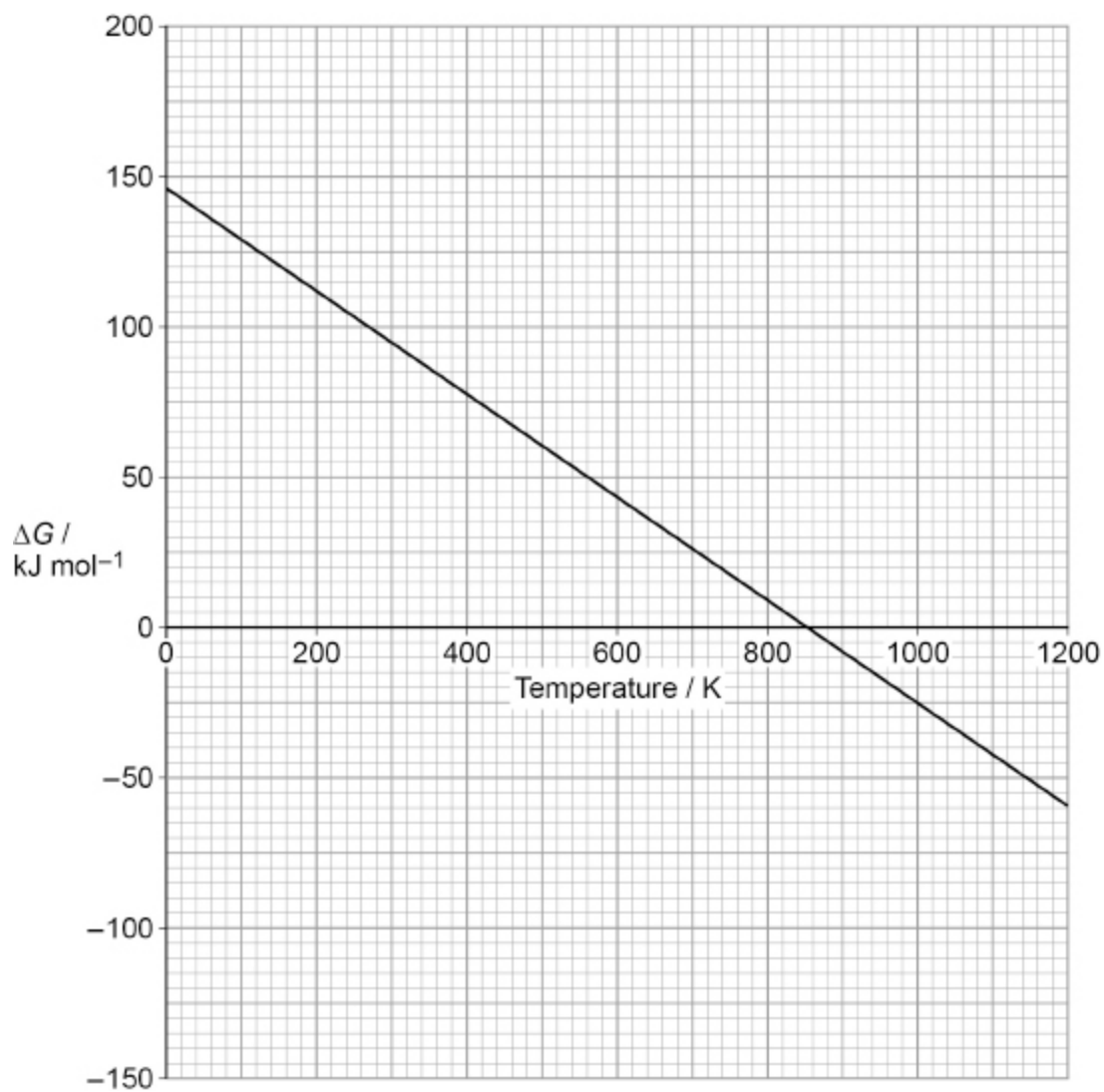
- (a) Use the equation and the data in the table above to calculate the Gibbs free-energy change ( $\Delta G$ ), in  $\text{kJ mol}^{-1}$ , for this reaction at 890 K

$\Delta G$  \_\_\_\_\_  $\text{kJ mol}^{-1}$

(6)

The graph below shows how the Gibbs free-energy change varies with temperature in a different gas phase reaction.

The straight line graph for this gas phase reaction has been extrapolated to zero Kelvin.



- (b) Use the values of the intercept and gradient from the graph to calculate the enthalpy change ( $\Delta H$ ), in  $\text{kJ mol}^{-1}$ , and the entropy change ( $\Delta S$ ), in  $\text{J K}^{-1} \text{mol}^{-1}$ , for this reaction.

$$\Delta H \text{ _____ } \text{kJ mol}^{-1}$$
$$\Delta S \text{ _____ } \text{J K}^{-1} \text{mol}^{-1}$$

**(4)**

- (c) State what the graph above shows about the feasibility of the reaction.

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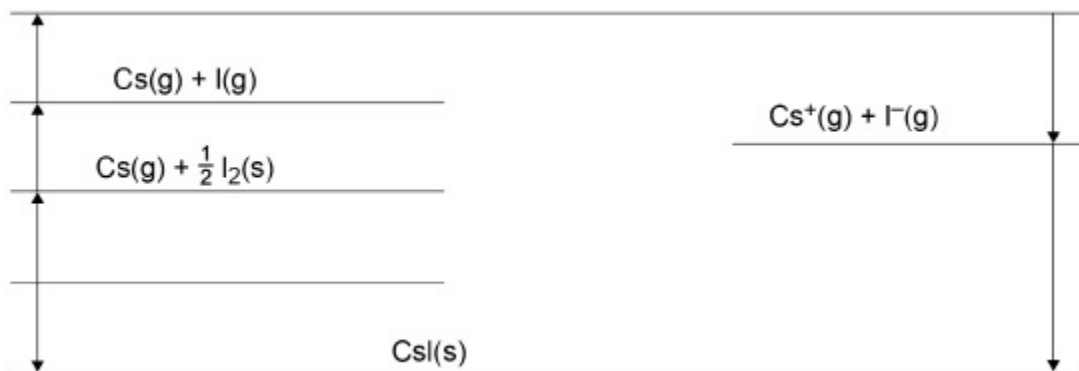
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**(1)**

**(Total 11 marks)**

3.

The diagram shows an incomplete Born–Haber cycle for the formation of caesium iodide. The diagram is not to scale.



**Table 1** gives values of some standard enthalpy changes.

**Table 1**

Name of enthalpy change	$\Delta H^\ominus / \text{kJ mol}^{-1}$
Enthalpy of atomisation of caesium	+79
First ionisation energy of caesium	+376
Electron affinity of iodine	-314
Enthalpy of lattice formation of caesium iodide	-585
Enthalpy of formation of caesium iodide	-337

- (a) Complete the diagram above by writing the formulas, including state symbols, of the appropriate species on each of the two blank lines. (2)
- (b) Use the diagram above and the data in **Table 1** to calculate the standard enthalpy of atomisation of iodine. (2)

Standard enthalpy of atomisation of iodine \_\_\_\_\_  $\text{kJ mol}^{-1}$

(2)

- (c) The enthalpy of lattice formation for caesium iodide in **Table 1** is a value obtained by experiment.

The value obtained by calculation using the perfect ionic model is  $-582 \text{ kJ mol}^{-1}$

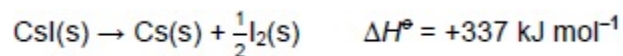
Deduce what these values indicate about the bonding in caesium iodide.

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(1)

- (d) Use data from **Table 2** to show that this reaction is **not** feasible at 298 K



**Table 2**

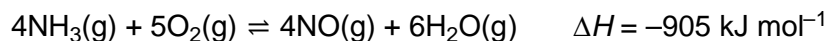
	<b>CsI(s)</b>	<b>Cs(s)</b>	<b>I<sub>2</sub>(s)</b>
<b>S<sup>⊖</sup> / J K<sup>-1</sup> mol<sup>-1</sup></b>	130	82.8	117

(4)

(Total 9 marks)

4.

The equation for the reaction between ammonia and oxygen is shown.



Some standard entropies are given in the table.

<b>Gas</b>	<b>S<sup>⊖</sup> / J K<sup>-1</sup> mol<sup>-1</sup></b>
NH <sub>3</sub> (g)	193
O <sub>2</sub> (g)	205
NO(g)	211
H <sub>2</sub> O(g)	189



- (a) Calculate the entropy change for the reaction between ammonia and oxygen.

Entropy change \_\_\_\_\_ J K<sup>-1</sup> mol<sup>-1</sup>

**(2)**

- (b) Calculate a value for the Gibbs free-energy change ( $\Delta G$ ), in kJ mol<sup>-1</sup>, for the reaction between ammonia and oxygen at 600 °C

(If you were unable to obtain an answer to part (a), you should assume that the entropy change is 211 J K<sup>-1</sup> mol<sup>-1</sup>. This is not the correct answer.)

$\Delta G$  \_\_\_\_\_ kJ mol<sup>-1</sup>

**(2)**

- (c) The reaction between ammonia and oxygen was carried out at a higher temperature. Explain how this change affects the value of  $\Delta G$  for the reaction.

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**(2)**

- (d) Platinum acts as a heterogeneous catalyst in the reaction between ammonia and oxygen. It provides an alternative reaction route with a lower activation energy.

Describe the stages of this alternative route.

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**(3)**

- (e) Deduce the change in oxidation state of nitrogen, when  $\text{NH}_3$  is oxidised to  $\text{NO}$

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**(1)**

- (f) When ammonia reacts with oxygen, nitrous oxide ( $\text{N}_2\text{O}$ ) can be produced instead of  $\text{NO}$

Give an equation for this reaction.

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**(1)**

**(Total 11 marks)**

**5.**

Titanium(IV) chloride can be made from titanium(IV) oxide as shown in the equation.



Some entropy data are shown in the table.

Substance	TiO <sub>2</sub> (s)	C(s)	Cl <sub>2</sub> (g)	CO(g)	TiCl <sub>4</sub> (l)
S <sup>⊖</sup> / J K <sup>-1</sup> mol <sup>-1</sup>	50.2	5.70	223	198	253

Use the equation and the data in the table to calculate the Gibbs free-energy change for this reaction at 989 °C

Give your answer to the appropriate number of significant figures.

Use your answer to explain whether this reaction is feasible.

Gibbs free-energy change \_\_\_\_\_ kJ mol<sup>-1</sup>

Explanation \_\_\_\_\_

\_\_\_\_\_

**(Total 6 marks)**

**6.**

Hydrogen can be manufactured from the reaction of steam with methane.



(a) The table contains some enthalpy of formation and entropy data.

Substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
$\text{CH}_4(\text{g})$	-75	186
$\text{H}_2\text{O}(\text{g})$	-242	189
$\text{CO}(\text{g})$	-111	198
$\text{H}_2(\text{g})$	0	131
$\text{CO}_2(\text{g})$	-394	214

(i) Use data from the table to calculate the enthalpy change,  $\Delta H$ , for the reaction of steam with methane.

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**(3)**(ii) Use data from the table to calculate the entropy change,  $\Delta S$ , for the reaction of steam with methane.

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**(2)**

- (b) Use your values of  $\Delta H$  and  $\Delta S$  from parts (a)(i) and (a)(ii) to calculate the temperature above which this reaction is feasible.

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(4)

- (c) The temperature used for this manufacture of hydrogen is usually about 1300 K.

Suggest **one** reason, other than changing the position of equilibrium, why this temperature is used rather than the value that you calculated in part (b).

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(1)

- (d) Hydrogen can also be obtained by reaction of carbon monoxide with steam.



- (i) Explain, using a calculation, why this reaction should **not** occur at 1300 K.

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(3)

- (ii) Explain how the conditions for the reaction could be changed to allow this reaction to take place.

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**(2)**  
**(Total 15 marks)**