Q1. This question is about the reaction given below.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

Enthalpy data for the reacting species are given in the table below.

Substance	CO(g)	$H_2O(g)$	$CO_2(g)$	$H_2(g)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	−110	−242	−394	0

Which one of the following statements is **not** correct?

A The value of K_p changes when the temperature changes.

B The activation energy decreases when the temperature is increased.

C The entropy change is more positive when the water is liquid rather than gaseous.

D The enthalpy change is more positive when the water is liquid rather than gaseous.

(Total 1 mark)

Q2. In which one of the following reactions is there a decrease in entropy?

A $[Fe(H_2O)_6]^{3+}(aq) + 3C_2O_4^{2-}(aq) \rightarrow [Fe(C_2O_4)_3]^{3-}(aq) + 6H_2O(l)$

B $[Cu(H_2O)_6]^{2+}(aq) + EDTA^{4-}(aq) \rightarrow [Cu(EDTA)]^{2-}(aq) + 6H_2O(l)$

C $[CoCl_4]^{2-}(aq) + 6H_2O(l) \rightarrow [Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq)$

D $Na_2CO_3(s) + 2H^+(aq) \rightarrow 2Na^+(aq) + CO_2(g) + H_2O(l)$

(Total 1 mark)

Q3. Using the information below, answer this question.

$Fe_2O_3(s) + 3H_2(g) \rightarrow 2Fe(s) + 3H_2O(g)$ $\quad \Delta H^{\ominus} = +96$ kJ mol^{-1}, $\Delta S^{\ominus} = +138$ J K^{-1} mol^{-1}

	$Fe_2O_3(s)$	**$H_2(g)$**	**Fe(s)**
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	−822.0	0	0

$\Delta S^{\ominus}$ / J K^{-1} mol^{-1}	90.0	131.0	27.0

The standard entropy value for steam is

A +332 J K^{-1} mol^{-1}

B +189 J K^{-1} mol^{-1}

C +145 J K^{-1} mol^{-1}

D +85 J K^{-1} mol^{-1}

(Total 1 mark)

Q4. Methanol can be regarded as a carbon-neutral fuel because it can be synthesised from carbon dioxide as shown in the equation below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Standard enthalpy of formation and standard entropy data for the starting materials and products are shown in the following table.

	$CO_2(g)$	$H_2(g)$	$CH_3OH(g)$	$H_2O(g)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	–394	0	–201	–242
$S^{\ominus}$ / J K^{-1} mol^{-1}	214	131	238	189

(a) Calculate the standard enthalpy change for this reaction.

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(b) Calculate the standard entropy change for this reaction.

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(c) Use your answers to parts (a) and (b) to explain why this reaction is **not** feasible at high temperatures.

Calculate the temperature at which the reaction becomes feasible.

Suggest why the industrial process is carried out at a higher temperature than you have calculated.

(If you have been unable to calculate values for ΔH and ΔS you may assume that they are –61 kJ mol^{-1} and –205 J K^{-1} mol^{-1} respectively. These are **not** the correct values.)

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(d) Write an equation for the complete combustion of methanol. Use your equation to

explain why the combustion reaction in the gas phase is feasible at all temperatures.

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(e) Give **one** reason why methanol, synthesised from carbon dioxide and hydrogen, may **not** be a carbon-neutral fuel.

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(Total 17 marks)

Q5. Chlorine is formed in a reversible reaction as shown by the equation

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

(a) Use the data below to calculate the standard enthalpy change, $\Delta H^{\ominus}$, and the standard entropy change, $\Delta S^{\ominus}$, for this reaction.

Substance	HCl(g)	$O_2(g)$	$Cl_2(g)$	$H_2O(g)$
$\Delta H_f^{\ominus}$/kJ mol^{-1}	–92	0	0	–242
$S^{\ominus}$/ J K^{-1} mol^{-1}	187	205	223	189

Standard enthalpy change, $\Delta H^{\ominus}$ .....

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Standard entropy change, $\Delta S^{\ominus}$ .....

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(b) The data below apply to a different gas phase reversible reaction.

Standard enthalpy change, $\Delta H^{\ominus}$ = +208 kJ mol^{-1}
Standard entropy change, $\Delta S^{\ominus}$ = +253 J K^{-1} mol^{-1}

(i) Deduce the effect of an increase in temperature on the position of the equilibrium in this reaction. Use Le Chatelier's principle to explain your answer.

Effect .....

Explanation .....

(ii) Calculate the minimum temperature at which this reaction is feasible.

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(Total 13 marks)

Q6. Refer to the following reaction

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H^{\ominus} = -11 \text{ kJ mol}^{-1}, \qquad \Delta S^{\ominus} = +20 \text{ J K}^{-1} \text{ mol}^{-1}$$

Which one of the following statements is correct?

A This is a redox reaction.

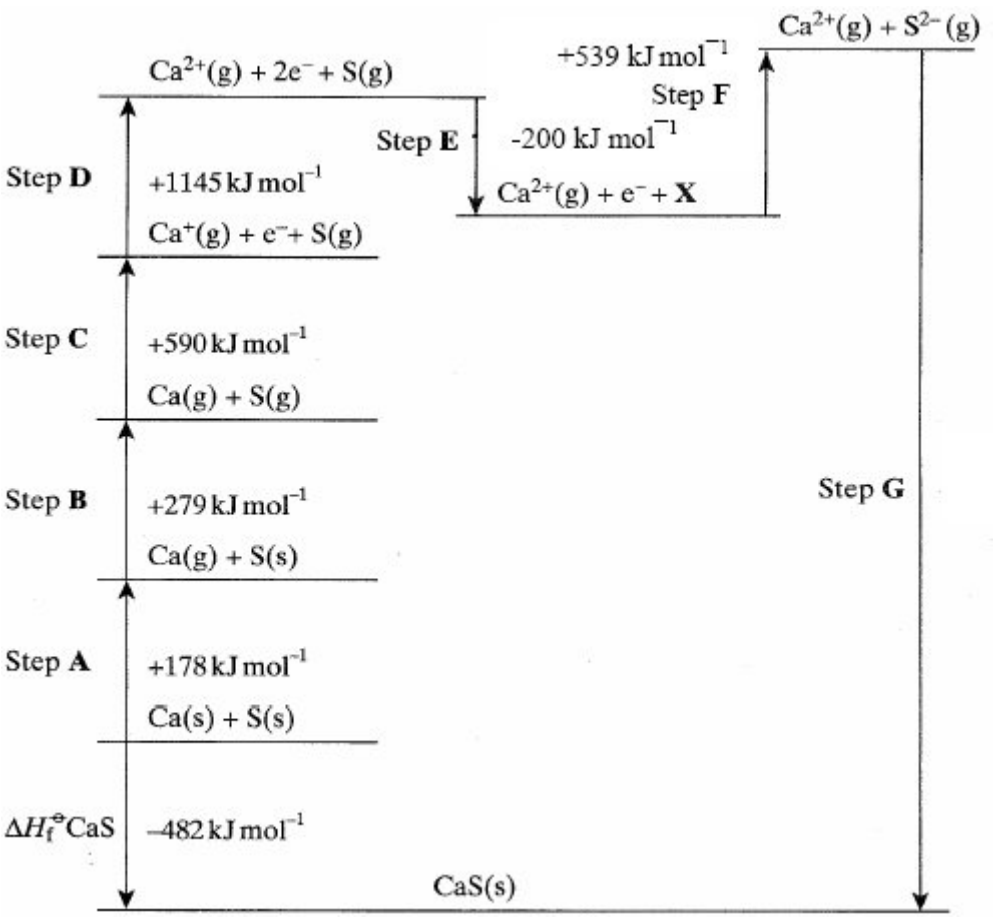
B The reaction is **not** feasible below 298 K

C At equilibrium, the yield of hydrogen iodide is changed by increasing the pressure.

D At equilibrium, the yield of hydrogen iodide increases as the temperature is increased.

(Total 1 mark)

Q7. (a) A Born–Haber cycle for the formation of calcium sulphide is shown below. The cycle includes enthalpy changes for all steps except step **G**. (The cycle is not drawn to scale.)



(i) Give the full electronic configuration of the ion S^{2-}

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(ii) Suggest why step **F** is an endothermic process.

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(iii) Name the enthalpy changes in steps **B** and **D**.

*Step **B*** .....

*Step **D*** .....

(iv) Explain why the enthalpy change for step **D** is larger than that for step **C**.

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(v) Use the data shown in the cycle to calculate a value for the enthalpy change for
step **G**.

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(b) Using a Born–Haber cycle, a value of –905 kJ mol^{-1} was determined for the lattice enthalpy of silver chloride. A value for the lattice enthalpy of silver chloride using the ionic model was –833 kJ mol^{-1}.

Explain what a scientist would be able to deduce from a comparison of these values.

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(c) Some endothermic reactions occur spontaneously at room temperature. Some exothermic reactions do not occur if the reactants are heated together to a very high temperature.

In order to explain the following observations, another factor, the entropy change, ΔS,
must be considered. The equation which relates ΔS to ΔH is given below.

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

(i) Explain why the following reaction occurs at room temperature even though the reaction is endothermic.

$$NaHCO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$$

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(ii) Explain why the following reaction does not occur at very high temperatures even though the reaction is exothermic.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

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(6)
(Total 18 marks)

Q8. Which one of the following reactions in aqueous solution has the most positive change in entropy?

A $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$

B $[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$

C $[Cu(H_2O)_6]^{2+} + EDTA^{4-} \rightarrow [Cu(EDTA)]^{2-} + 6H_2O$

D $[Cu(H_2O)_6]^{2+} + 2H_2NCH_2CH_2NH_2 \rightarrow [Cu(H_2NCH_2CH_2NH_2)_2(H_2O)_2]^{2+} + 4H_2O$

(Total 1 mark)

Q9. Which one of the equations below represents a reaction that is feasible at all temperatures?

A $P(s) \rightarrow Q(s) + R(g)$ endothermic

B $2L(g) + M(g) \rightarrow 2N(g)$ exothermic

C $S(g) \rightarrow 2T(g)$ exothermic

D $A(g) + B(g) \rightarrow C(g)$ endothermic

(Total 1 mark)