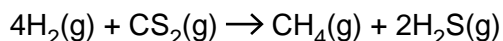


1 This question looks at two reactions involving sulfur compounds.

(a) Hydrogen reacts with carbon disulfide as shown below.



For this reaction,  $\Delta H = -234 \text{ kJ mol}^{-1}$  and  $\Delta S = -164 \text{ JK}^{-1} \text{ mol}^{-1}$ .

(i) Why does the reaction have a negative entropy change?

.....  
..... [1]

(ii) Standard entropies are shown in the table below.

substance	$\text{CS}_2(\text{g})$	$\text{CH}_4(\text{g})$	$\text{H}_2\text{S}(\text{g})$
$S^\ominus / \text{JK}^{-1} \text{ mol}^{-1}$	238	186	206

Calculate the standard entropy for  $\text{H}_2$ .

$$S^\ominus = \dots\dots\dots \text{JK}^{-1} \text{ mol}^{-1} \text{ [2]}$$

(iii) Explain, with a calculation, whether this reaction is feasible at  $25^\circ\text{C}$ .

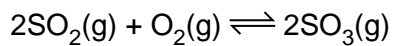
Show your working.

.....  
..... [3]

(iv) Explain, with a calculation, the significance of temperatures above  $1154^\circ\text{C}$  for this reaction.

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

- (b) A chemist investigated methods to improve the synthesis of sulfur trioxide from sulfur dioxide and oxygen.



The chemist:

- mixed together 1.00 mol  $\text{SO}_2$  and 0.500 mol  $\text{O}_2$  with a catalyst at room temperature
- compressed the gas mixture to a volume of  $250 \text{ cm}^3$
- allowed the mixture to reach equilibrium at constant temperature and without changing the total gas volume.

At equilibrium, 82.0% of the  $\text{SO}_2$  had been converted into  $\text{SO}_3$ .

- (i) Determine the concentrations of  $\text{SO}_2$ ,  $\text{O}_2$  and  $\text{SO}_3$  present at equilibrium and calculate  $K_c$  for this reaction.

$K_c = \dots\dots\dots$  units  $\dots\dots\dots$  [6]

(ii) Explain what would happen to the pressure as the system was allowed to reach equilibrium.

.....  
.....  
..... [1]

(iii) The value of  $K_c$  for this equilibrium decreases with increasing temperature.

Predict the sign of the enthalpy change for the forward reaction. State the effect on the equilibrium yield of  $\text{SO}_3$  of increasing the temperature at constant pressure.

$\Delta H$ : .....  
Effect on  $\text{SO}_3$  yield: ..... [1]

(iv) The chemist repeated the experiment at the same temperature with 1.00 mol  $\text{SO}_2$  and an excess of  $\text{O}_2$ .  
The gas mixture was still compressed to a volume of  $250 \text{ cm}^3$ .

State and explain, in terms of  $K_c$ , how the equilibrium yield of  $\text{SO}_3$  would be different from the yield in the first experiment.

.....  
.....  
.....  
.....  
.....  
.....  
..... [3]

[Total: 19]

2 This question looks at different aspects of entropy.

(a) Three processes are given below.

For each process, state and explain whether the change would be accompanied by an increase or decrease in entropy.

(i) The freezing of water.

increase or decrease .....

explanation .....

..... [1]

(ii) The reaction of calcium carbonate with hydrochloric acid.

increase or decrease .....

explanation .....

..... [1]

(iii) The formation of  $O_3(g)$  from  $O_2(g)$ .

increase or decrease .....

explanation .....

..... [1]

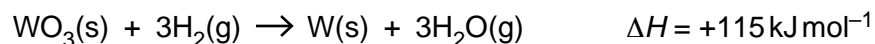
(b) The enthalpy and entropy changes of a reaction both have a negative sign.

Discuss how the feasibility of this reaction will change as the temperature increases.

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

- (c) The metal tungsten is obtained on a large scale from its main ore, wolframite. Wolframite contains tungsten(VI) oxide,  $\text{WO}_3$ .

Tungsten is extracted from wolframite by reduction with hydrogen:



Standard entropies are given in the table below.

Substance	$\text{WO}_3(\text{s})$	$\text{H}_2(\text{g})$	$\text{W}(\text{s})$	$\text{H}_2\text{O}(\text{g})$
$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$	76	131	33	189

- (i) Calculate the free energy change,  $\Delta G$ , in  $\text{kJ mol}^{-1}$ , for this reaction at  $25^\circ\text{C}$ .

Show your working.

$$\Delta G \text{ at } 25^\circ\text{C} = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

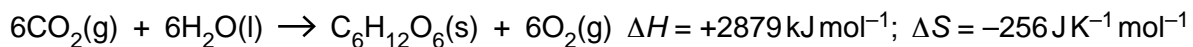
- (ii) Calculate the minimum temperature, in K, at which this reaction becomes feasible.

Show your working.

$$\text{minimum temperature} = \dots\dots\dots \text{ K} \quad [2]$$

[Total: 9]

- 3 The equation for the reaction of CO<sub>2</sub> and H<sub>2</sub>O to produce glucose, C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>, and O<sub>2</sub> is shown below.



Standard entropies are given in the table below.

<b>Substance</b>	CO <sub>2</sub> (g)	H <sub>2</sub> O(l)	O <sub>2</sub> (g)
<b>S<sup>⊖</sup> / JK<sup>-1</sup> mol<sup>-1</sup></b>	214	70	205

- (a) (i) Calculate the standard entropy of glucose.

$$S^\ominus = \dots\dots\dots \text{ JK}^{-1} \text{ mol}^{-1} \quad [2]$$

- (ii) Calculate ΔG, in kJ mol<sup>-1</sup>, at 25 °C.

Show all your working.

$$\Delta G = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

- (iii) Explain why this reaction is **not** feasible at **any** temperature.

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

[1]

- (b) Although the reaction between  $\text{CO}_2$  and  $\text{H}_2\text{O}$  to form  $\text{C}_6\text{H}_{12}\text{O}_6$  and  $\text{O}_2$  appears not to be feasible, plants are able to make the reaction take place spontaneously by photosynthesis.

Each year,  $3.4 \times 10^{18}$  kJ of solar energy is taken in by all the plants on the Earth to make photosynthesis take place.

Calculate the mass of carbon dioxide that is removed each year from the atmosphere by photosynthesis on Earth.

mass of  $\text{CO}_2$  = ..... [2]

[Total: 7]

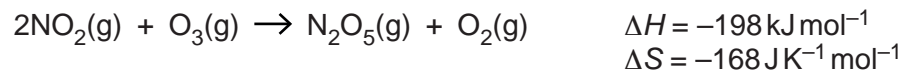




(ii) Suggest a possible two-step mechanism for this reaction.

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

(b) The feasibility of the reaction between  $\text{NO}_2$  and  $\text{O}_3$  is influenced by the enthalpy change and entropy change of the reaction and the temperature.



(i) Explain why this reaction has a negative entropy change.

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

(ii) Calculate the value of  $\Delta G$ , in  $\text{kJ mol}^{-1}$ , at  $25^\circ\text{C}$  for the reaction of  $\text{NO}_2$  with  $\text{O}_3$ .

$\Delta G = \dots\dots\dots \text{ kJ mol}^{-1}$  [3]

(iii) State and explain how the feasibility of this reaction will change with increasing temperature.

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

[Total: 17]