# A-Level Chemistry

## Equilibria and Le Chatelier's Principle

### Question Paper

**Time available: 62 minutes**
**Marks available: 54 marks**

**1.** Hydrogen can be prepared on an industrial scale using the reversible reaction between methane and steam.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3\ H_2(g) \qquad \Delta H = +206\ kJ\ mol^{-1}$$

The reaction is done at a temperature of 800 °C and a low pressure of 300 kPa in the presence of a nickel catalyst.

Explain, in terms of equilibrium yield and cost, why these conditions are used.

**(Total 6 marks)**

**2.** Hydrogen gas can be made by reacting ethanol with steam in the presence of a catalyst.

$$C_2H_5OH(g) + H_2O(g) \rightleftharpoons 2\ CO(g) + 4\ H_2(g)$$

(a) Give an expression for $K_c$ for this equilibrium.

State its units.

*K*c

Units of $K_c$ _____

**(2)**

(b) The table shows the amount of each substance in an equilibrium mixture in a container of volume 750 $cm^3$

| **Substance** | $C_2H_5OH(g)$ | $H_2O(g)$ | $CO(g)$ | $H_2(g)$ |
|---|---|---|---|---|
| **Amount of substance / mol** | 0.0750 | 0.156 | 0.110 | 0.220 |

Calculate $K_c$

*K*c _____

**(3)**

(c) The pressure of the equilibrium mixture was increased by reducing the volume of the container at constant temperature.

Predict the effect of increasing the pressure on the equilibrium yield of hydrogen. Explain your answer.

Predict the effect of increasing the pressure on the value of $K_c$

Effect on equilibrium yield of hydrogen _____

_____

Explanation _____

_____

_____

_____

_____

_____

Effect on value of $K_c$ _____

_____

**(4)**

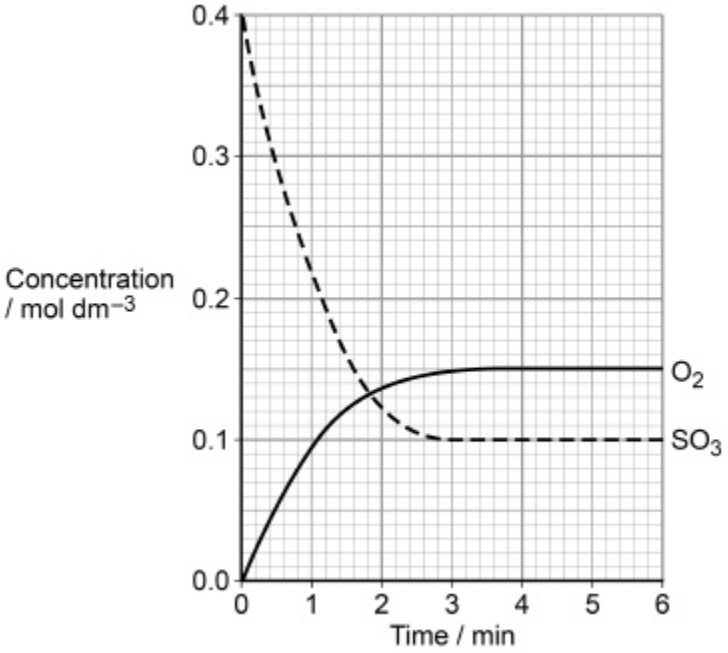
**(Total 9 marks)**

**3.** This question is about equilibrium.

Sulfur trioxide decomposes to form sulfur dioxide and oxygen at temperature $\boldsymbol{T}_1$ according to the equilibrium shown.

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g) \qquad \Delta H = +196 \text{ kJ mol}^{-1}$$

The graph shows the concentrations of sulfur trioxide and of oxygen over a period of 6 minutes at temperature $\boldsymbol{T}_1$




(a) State the time, to the nearest minute, when equilibrium is first established.
Explain your answer.

Time _____ minutes

Explanation _____

_____

_____

_____

_____

**(2)**

(b) Sketch on the graph above how the concentration of sulfur dioxide changes over these 6 minutes at temperature $\boldsymbol{T}_1$

**(2)**

(c) The temperature of the mixture was changed to $T_2$ and the mixture left to establish a new equilibrium.
In the new equilibrium mixture the concentration of sulfur trioxide was found to be 0.07 mol $dm^{-3}$

Deduce which of $T_1$ and $T_2$ is the higher temperature.
Explain your deduction.

Higher temperature _____

Explanation _____

_____

_____

_____

_____

**(2)**

**(Total 6 marks)**

**4.** Methanol can be manufactured in a reversible reaction as shown by the equation.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

(a) State and explain the effect of using a catalyst on the yield of methanol in this equilibrium.

_____

_____

_____

_____

_____

_____

**(2)**

(b) Give an expression for the equilibrium constant ($K_c$) for this reaction.

**(1)**

(c) A mixture of carbon monoxide and hydrogen was allowed to reach equilibrium in a container of volume 250 $cm^3$ at temperature *T*.

At equilibrium, the mixture contained 0.340 mol of carbon monoxide, 0.190 mol of hydrogen and 0.0610 mol of methanol.

Calculate the value of the equilibrium constant ($K_c$) for this reaction at temperature *T*.

$K_c$ _____ $mol^{-2}\ dm^6$

**(3)**

(d) Methanol decomposes on heating in a reaction that is the reverse of that used in its manufacture.

$$CH_3OH(g) \rightleftharpoons CO(g) + 2H_2(g)$$

Use your answer from part (c) to determine the value of $K_c$ for this equilibrium at temperature *T*.
State the units for this value of $K_c$

(If you were unable to complete the calculation in part (c), assume a value of $K_c = 0.825\ mol^{-2}\ dm^6$. This is not the correct value.)

Value of $K_c$ _____

Units of $K_c$ _____

**(2)**

**(Total 8 marks)**

**5.** Compounds **A** and **B** react together to form an equilibrium mixture containing compounds **C** and **D** according to the equation

$$2\mathbf{A} + \mathbf{B} \rightleftharpoons 3\mathbf{C} + \mathbf{D}$$

(a) A beaker contained 40 $cm^3$ of a 0.16 mol $dm^{-3}$ aqueous solution of A.
$9.5 \times 10^{-3}$ mol of **B** and $2.8 \times 10^{-2}$ mol of **C** were added to the beaker and the mixture was left to reach equilibrium.
The equilibrium mixture formed contained $3.9 \times 10^{-3}$ mol of **A**.

Calculate the amounts, in moles, of **B**, **C** and **D** in the equilibrium mixture.

Amount of **B** _____ mol

Amount of **C** _____ mol

Amount of **D** _____ mol

**(5)**

(b) Give the expression for the equilibrium constant ($K_c$) for this equilibrium **and** its units.

$K_c$

Units _____

**(2)**

(c) A different equilibrium mixture of these four compounds, at a different temperature, contained 0.21 mol of **B**, 1.05 mol of **C** and 0.076 mol of **D** in a total volume of $5.00 \times 10^2$ $cm^3$ of solution.
At this temperature the numerical value of $K_c$ was 116

Calculate the concentration of **A**, in mol $dm^{-3}$, in this equilibrium mixture.
Give your answer to the appropriate number of significant figures.

Concentration of **A** _____ mol $dm^{-3}$

**(3)**

(d) Justify the statement that adding more water to the equilibrium mixture in part (c) will lower the amount of **A** in the mixture.

_____

_____

_____

_____

_____

_____

_____

**(3)**

**(Total 13 marks)**

**6.** Hydrogen can be manufactured by the reaction of methane with steam. An equilibrium is established as shown by the equation.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

(a) Use Le Chatelier's principle to predict the effect on the equilibrium yield of hydrogen if the overall pressure is increased.
Explain your answer.

Effect on yield _____

Explanation _____

_____

_____

_____

**(3)**

(b) Explain why the equilibrium yield of hydrogen is unchanged if a catalyst is used in the reaction.

_____

_____

_____

_____

_____

**(2)**

(c) The table shows the standard enthalpy of formation and the standard entropy for each substance in this equilibrium reaction.

| | $CH_4(g)$ | $H_2O(g)$ | $CO(g)$ | $H_2(g)$ |
|---|---|---|---|---|
| $\Delta_f H^\theta$ / kJ mol$^{-1}$ | −75 | −242 | −111 | 0 |
| Sθ / J K$^{-1}$ mol$^{-1}$ | 186 | 189 | 198 | 131 |

Use data from the table to calculate the standard enthalpy change for this equilibrium reaction.

Standard enthalpy change _____ kJ mol$^{-1}$

**(2)**

Use your answer from part **(c)** and the entropy data from the table above to calculate the minimum temperature, in °C, needed for this reaction to be feasible.
Give your answer to the appropriate number of significant figures.

(If you did not complete part **(c)** you should assume a value of 120 kJ mol$^{-1}$ for the standard enthalpy change. This is **not** the correct value).

Minimum temperature _____ °C

**(5)**

**(Total 12 marks)**