A-Level Chemistry

Kp Equilibrium Constant

Question Paper

Time available: 64 minutes
Marks available: 57 marks

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1. This question is about the equilibrium

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

(a) State and explain the effect, if any, of a decrease in overall pressure on the equilibrium yield of SO_3

Effect ____

Explanation ____

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(3)

(b) A 0.460 mol sample of SO_2 is mixed with a 0.250 mol sample of O_2 in a sealed container at a constant temperature.
When equilibrium is reached at a pressure of 215 kPa, the mixture contains 0.180 mol of SO_3

Calculate the partial pressure, in kPa, of SO_2 in this equilibrium mixture.

Partial pressure of SO_2 ________________ kPa

(4)

(c) A different mixture of SO_2 and O_2 reaches equilibrium at a different temperature.

The table below shows the partial pressures of the gases at equilibrium.

Gas	**Partial pressure / kPa**
SO_2	1.67×10^2
O_2	1.02×10^2
SO_3	1.85×10^2

Give an expression for the equilibrium constant (Kp) for this reaction.

Calculate the value of the equilibrium constant for this reaction and give its units.

K_p

K_p ________________

Units ___________

(3)

(d) What is the effect on the value of K_p if the pressure of this equilibrium mixture is increased at a constant temperature?

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

Tick (✓) **one** box.

The value of K_p

increases. ☐

stays the same. ☐

decreases. ☐

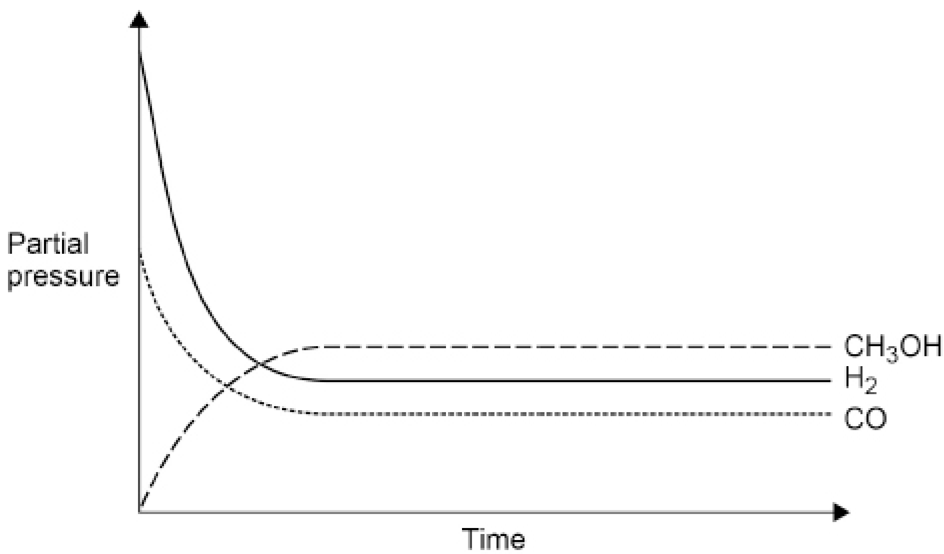
(1)

(Total 11 marks)

2. Methanol can be manufactured in a reversible reaction as shown.

$CO(g) + 2\ H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H^\ominus = -91\ \text{kJ mol}^{-1}$

The graph below shows how the partial pressures change with time at a constant temperature.



(a) Draw a cross (x) on the appropriate axis of the graph when the mixture reaches equilibrium.

(1)

(b) A 0.230 mol sample of carbon monoxide is mixed with hydrogen in a 1:2 mol ratio and allowed to reach equilibrium in a sealed flask at temperature *T*.
At equilibrium the mixture contains 0.120 mol of carbon monoxide.
The total pressure of this mixture is 1.04×10^4 kPa

Calculate the partial pressure, in kPa, of hydrogen in the equilibrium mixture.

Partial pressure of hydrogen _______________ kPa

(4)

(c) Give an expression for the equilibrium constant (K_p) for this reaction.

State the units.

K_p

Units _______________

(2)

(d) Some more carbon monoxide is added to the mixture in part (b). The new mixture is allowed to reach equilibrium at temperature *T*.

State the effect, if any, on the partial pressure of methanol and on the value of K_p

Effect on partial pressure of methanol _________________________

Effect on value of K_p ____

(2)

(e) State the effect, if any, of the addition of a catalyst on the value of K_p for this equilibrium. Explain your answer.

Effect on value of K_p ____

Explanation ____

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(2)

(Total 11 marks)

3. Sulfur trioxide decomposes on heating to form an equilibrium mixture containing sulfur dioxide and oxygen.

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

(a) A sample of sulfur trioxide was heated and allowed to reach equilibrium at a given temperature.
The equilibrium mixture contained 6.08 g of sulfur dioxide.

Calculate the mass, in g, of oxygen gas in the equilibrium mixture.

Mass ______________________ g

(2)

(b) A different mass of sulfur trioxide was heated and allowed to reach equilibrium at 1050 K

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

The amounts of each substance in the equilibrium mixture are shown in the table.

Substance	**Amount at equilibrium / mol**
sulfur trioxide	0.320
sulfur dioxide	1.20
oxygen	0.600

For this reaction at 1050 K the equilibrium constant, K_p = 7.62 x 10^5 Pa

Calculate the mole fraction of each substance at equilibrium.
Give the expression for the equilibrium constant, K_p
Calculate the total pressure, in Pa, of this equilibrium mixture.

Mole fraction SO_3 ___________________________

Mole fraction SO_2 ___________________________

Mole fraction O_2 ___________________________

K_p

Total pressure ___________________________ Pa

(4)

(c) For this reaction at 1050 K the equilibrium constant, K_p = 7.62 x 10^5 Pa
For this reaction at 500 K the equilibrium constant, K_p = 3.94 x 10^4 Pa

Explain how this information can be used to deduce that the forward reaction is endothermic.

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(2)

(d) Use data from part **(c)** to calculate the value of K_p, at 500 K, for the equilibrium represented by this equation.
Deduce the units of K_p

$$SO_3(g) \rightleftharpoons SO_2(g) + \frac{1}{2}O_2(g)$$

K_p ______________________________

Units ______________________________

(2)

(Total 10 marks)

4. Nitrogen and hydrogen were mixed in a 1:3 mole ratio and left to reach equilibrium in a flask at a temperature of 550 K. The equation for the reaction between nitrogen and hydrogen is shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(a) When equilibrium was reached, the total pressure in the flask was 150 kPa and the mole fraction of $NH_3(g)$ in the mixture was 0.80

Calculate the partial pressure of each gas in this equilibrium mixture.

Partial pressure of nitrogen ____________________ kPa

Partial pressure of hydrogen ____________________ kPa

Partial pressure of ammonia ____________________ kPa

(3)

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

K_p

(1)

(c) In a different equilibrium mixture, under different conditions, the partial pressures of the gases are shown in the table.

Gas	**Partial pressure / kPa**
N_2	1.20×10^2
H_2	1.50×10^2
NH_3	1.10×10^3

Calculate the value of the equilibrium constant (K_p) for this reaction and give its units.

K_p ____________________ Units ____________________

(2)

(d) The enthalpy change for the reaction is –92 kJ mol^{-1}

State the effect, if any, of an increase in temperature on the value of K_p for this reaction. Justify your answer.

Effect on K_p ____

Justification ____

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(3)

(Total 9 marks)

5. Many chemical processes release waste products into the atmosphere. Scientists are developing new solid catalysts to convert more efficiently these emissions into useful products, such as fuels. One example is a catalyst to convert these emissions into methanol. The catalyst is thought to work by breaking a H–H bond.

An equation for this formation of methanol is given below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \quad \Delta H = -49 \text{ kJ mol}^{-1}$$

Some mean bond enthalpies are shown in the following table.

Bond	C=O	C–H	C–O	O–H
Mean bond enthalpy / kJ mol^{-1}	743	412	360	463

(a) Use the enthalpy change for the reaction and data from the table to calculate a value for the H–H bond enthalpy.

H–H bond enthalpy = _______________ kJ mol^{-1}

(3)

(b) A data book value for the H–H bond enthalpy is 436 kJ mol^{-1}.

Suggest **one** reason why this value is different from your answer to part (a).

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(1)

(c) Suggest **one** environmental advantage of manufacturing methanol fuel by this reaction.

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(1)

(d) Use Le Chatelier's principle to justify why the reaction is carried out at a high pressure rather than at atmospheric pressure.

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(3)

(e) Suggest why the catalyst used in this process may become less efficient if the carbon dioxide and hydrogen contain impurities.

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(1)

(f) In a laboratory experiment to investigate the reaction shown in the equation below, 1.0 mol of carbon dioxide and 3.0 mol of hydrogen were sealed into a container. After the mixture had reached equilibrium, at a pressure of 500 kPa, the yield of methanol was 0.86 mol.

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

Calculate a value for K_p
Give your answer to the appropriate number of significant figures.
Give units with your answer.

K_p = ________________ Units = ________________

(7)

(Total 16 marks)