A-Level Chemistry

Equilibrium Constant (Kc)

Question Paper

Time available: 67 minutes
Marks available: 59 marks

1. Sulfur dioxide reacts with oxygen to form sulfur trioxide.

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

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

K_c

(1)

(b) A mixture of sulfur dioxide and oxygen is allowed to reach equilibrium in a container of volume 1800 cm^3 at temperature T.

At equilibrium, the mixture contains 0.176 mol of sulfur dioxide and 0.461 mol of sulfur trioxide.

At temperature T the equilibrium constant, K_c = 15.0 mol^{-1} dm^3

Calculate the amount, in moles, of oxygen at equilibrium.

Amount of oxygen _______________ mol

(3)

(c) At a different temperature, a mixture contains

0.025 mol of sulfur dioxide
0.049 mol of oxygen
0.034 mol of sulfur trioxide.

The total pressure of the mixture in a 3500 cm^3 reaction vessel is 255 kPa

Use the data to calculate the temperature, in °C, of the mixture.

The ideal gas constant, R = 8.31 J K^{-1} mol^{-1}

Temperature ____________________ °C

(5)

(Total 9 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.

Kc

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

Kc ________________________________

(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. Nitrogen monoxide reacts with chlorine to form nitrosyl chloride (NOCl).

$$2\ NO(g) + Cl_2(g) \rightleftharpoons 2\ NOCl(g)$$

(a) 1.50 mol of NO are mixed with 1.00 mol of Cl_2 and the mixture is left to reach equilibrium at a given temperature.
The equilibrium mixture contains 0.350 mol of NOCl

Calculate the amount, in moles, of NO and of Cl_2 in the equilibrium mixture.

Amount of NO ________________________________ mol

Amount of Cl_2 ________________________________ mol

(2)

(b) Give the expression for the equilibrium constant, K_c, for the reaction between nitrogen monoxide and chlorine to form nitrosyl chloride.

K_c =

(1)

(c) A different equilibrium mixture is prepared in a flask of volume 800 cm^3 at a different temperature.
At equilibrium this mixture contains 0.850 mol of NO and 0.458 mol of Cl_2
For the reaction at this temperature $K_c = 1.32 \times 10^{-2}\ mol^{-1}\ dm^3$

Determine the amount, in moles, of NOCl in this equilibrium mixture.

Amount of NOCl ______________________________ mol

(4)

(Total 7 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.
9.5×10^{-3} mol of **B** and 2.8×10^{-2} mol of **C** were added to the beaker and the mixture was left to reach equilibrium.
The equilibrium mixture formed contained 3.9×10^{-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 5.00×10^2 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. When substances **P** and **Q** react together to form substance **R** an equilibrium is established according to the equation

$$P(g) + Q(g) \rightleftharpoons 2R(g)$$

The equilibrium constant expression is $K_c = \dfrac{[R]^2}{[P][Q]}$

1.0 mol of **P** and 1.0 mol of **Q** were mixed in a container with volume 1.0 dm^3

At equilibrium, $\boldsymbol{x}$ mol of **P** had reacted.

(a) The amount, in moles, of each of P and Q at equilibrium is $(1 - x)$.

Deduce in terms of $\boldsymbol{x}$ the amount, in moles, of **R** in the equilibrium mixture.

____

(1)

(b) At 298 K the value of the equilibrium constant K_c = 3.6

Calculate a value for the equilibrium concentration, in mol dm^{-3}, of **R**.

Equilibrium concentration of **R** ____________________ mol dm^{-3}

(3)

(Total 4 marks)

7. Ethanoic acid and ethane-1,2-diol react together to form the diester ($C_6H_{10}O_4$) as shown.

$$2CH_3COOH(l) \ + \ HOCH_2CH_2OH(l) \ \rightleftharpoons \ C_6H_{10}O_4(l) \ + \ 2H_2O(l)$$

(a) Draw a structural formula for the diester $C_6H_{10}O_4$

(1)

(b) A small amount of catalyst was added to a mixture of 0.470 mol of ethanoic acid and 0.205 mol of ethane-1,2-diol.

The mixture was left to reach equilibrium at a constant temperature.

Complete **Table 1**.

Table 1

Amount in the mixture / mol				
	CH_3COOH	$HOCH_2CH_2OH$	$C_6H_{10}O_4$	H_2O
At the start	0.470	0.205	0	0
At equilibrium	0.180			

Space for working

(3)

(c) Write an expression for the equilibrium constant, K_c, for the reaction.

The total volume of the mixture does not need to be measured to allow a correct value for K_c to be calculated.

Justify this statement.

Expression

Justification ____

____

(2)

(d) A different mixture of ethanoic acid, ethane-1,2-diol and water was prepared and left to reach equilibrium at a different temperature from the experiment in part (b)

The amounts present in the new equilibrium mixture are shown in **Table 2**.

Table 2

Amount in the mixture / mol				
	CH_3COOH	$HOCH_2CH_2OH$	$C_6H_{10}O_4$	H_2O
At new equilibrium	To be calculated	0.264	0.802	1.15

The value of K_c was 6.45 at this different temperature.

Use this value and the data in **Table 2** to calculate the amount, in mol, of ethanoic acid present in the new equilibrium mixture.

Give your answer to the appropriate number of significant figures.

Amount of ethanoic acid ______________________ mol

(3)

(Total 9 marks)