Equilibrium (Quantitative)
AS & A Level

Question Paper 1

Level	A Level
Subject	Chemistry
Exam Board	OCR
Module	Physical Chemistry & Transition Elements
Topic	Equilibrium (Quantitative)
Paper	AS & A Level
Booklet	Question Paper 1

Time allowed: **78 minutes**

Score: **/58**

Percentage: **/100**

Grade Boundaries:

A*	A	B	C	D	E
>85%	73%	60%	47%	34%	21%

A chemist carries out an investigation on the equilibrium system shown below.

$$2CO(g) + 2NO(g) \rightleftharpoons 2CO_2(g) + N_2(g) \qquad \Delta H = -788\,kJ\,mol^{-1}$$

The chemist mixes 0.46 mol of CO with 0.45 mol of NO. The mixture is left to reach equilibrium at constant temperature.

The student analyses the equilibrium mixture and finds that 0.25 mol NO remains. The total volume of the equilibrium mixture is 1.0 dm^3.

(a) (i) Write the K_c expression for this equilibrium. [1]

(ii) What are the units of this equilibrium constant? [1]

(iii) Determine the value of K_c for this equilibrium mixture.

Show all your working. [4]

(iv) What does your value of K_c suggest about the position of equilibrium in this experiment?
[1]

(b) The chemist increases **both** the temperature and the pressure of the equilibrium mixture. The mixture is left to reach equilibrium again.

(i) What is the effect, if any, on the value of K_c? Explain your answer.
[1]

(ii) Explain why it is difficult to predict what would happen to the position of equilibrium after these changes in temperature and pressure.
[2]

[Total 10 Marks]

Nitric acid, HNO_3, is manufactured in large quantities. The main use of nitric acid is in the manufacture of fertilisers.

In its industrial preparation, nitric acid is produced in three main stages.

Stage 1
Ammonia is heated with oxygen in the air to form nitrogen monoxide, NO.

Stage 2
The hot nitrogen monoxide gas is then mixed with air and cooled under pressure. Nitrogen dioxide, NO_2, forms in a reversible reaction.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g) \quad \Delta H = -115 \text{ kJ mol}^{-1}$$

Stage 3
The nitrogen dioxide is reacted with water in a series of reactions to form nitric acid, HNO_3. The first of these reactions forms a mixture of nitric acid, HNO_3, and nitrous acid, HNO_2.

(a) In **Stage 2**, explain why the equilibrium mixture is both cooled **and** put under pressure. [3]

(b) Construct an equation for
- the reaction that takes place in **Stage 1**
- the first reaction that takes place in **Stage 3**. [2]

(c) An industrial chemist carries out some research into the $NO/O_2/NO_2$ equilibrium used in **Stage 2** of the manufacture of nitric acid.

- The chemist mixes together 0.80 mol NO(g) and 0.70 mol of O_2(g) in a container with a volume of 2.0 dm^3.
- The chemist heats the mixture and allows it to stand at constant temperature to reach equilibrium.
  The container is kept under pressure so that the total volume is maintained at 2.0 dm^3.
- At equilibrium, 75% of the NO has reacted.

(i) Write an expression for K_c for this equilibrium. [1]

(ii) Calculate the equilibrium constant, K_c, including units, for this equilibrium. [5]

[Total 11 Marks]

Dinitrogen tetroxide, $N_2O_4(g)$, and nitrogen dioxide, $NO_2(g)$, coexist in the following equilibrium.

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \quad \Delta H = -57\,kJ\,mol^{-1}$$

A chemist adds 4.00 mol NO_2 to a container with a volume of 2.00 dm^3. The container is sealed, heated to a constant temperature and allowed to reach equilibrium.

The equilibrium mixture contains 3.20 mol NO_2.

(a) Calculate the value for K_c under these conditions. [5]

(b) The experiment is repeated but the pressure in the container is doubled.

Explain in terms of K_c the effect on the concentrations of NO_2 and N_2O_4 when the mixture has reached equilibrium. [3]

[Total 8 Marks]

Nitrogen monoxide, NO, and oxygen, O_2, react to form nitrogen dioxide, NO_2, in the reversible reaction shown in **equilibrium 18.1**.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$$ **Equilibrium 18.1**

(a) Write an expression for K_c for this equilibrium and state the units.

K_c =

Units = ... **[2]**

(b) A chemist mixes together nitrogen and oxygen and pressurises the gases so that their total gas volume is 4.0 dm^3.

- The mixture is allowed to reach equilibrium at constant temperature and volume.
- The equilibrium mixture contains 0.40 mol NO and 0.80 mol O_2.
- Under these conditions, the numerical value of K_c is 45.

Calculate the amount, in mol, of NO_2 in the equilibrium mixture. **[4]**

(c) The values of K_p for **equilibrium 18.1** at 298 K and 1000 K are shown below.

$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ **Equilibrium 18.1**

Temperature / K	K_p / atm^{-1}
298	$K_p = 2.19 \times 10^{12}$
1000	$K_p = 2.03 \times 10^{-1}$

(i) Predict, with a reason, whether the forward reaction is exothermic or endothermic.

[1]

(ii) The chemist increases the pressure of the equilibrium mixture at the same temperature.

State, and explain in terms of K_p, how you would expect the equilibrium position to change.

[3]

(Total 10 marks)

This question is about equilibrium reactions.

(a) Hydrogen gas is manufactured by the chemical industry using the reaction of methane and steam. This is a reversible reaction, shown in **equilibrium 20.1** below.

equilibrium 20.1 $CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ $\Delta H = +210\,kJ\,mol^{-1}$

Explain, in terms of le Chatelier's principle, the conditions of pressure and temperature for a maximum yield of hydrogen from **equilibrium 20.1**, and explain why the operational conditions used by the chemical industry may be different.

[4]

(b) A chemist investigates the equilibrium reaction between sulfur dioxide, oxygen, and sulfur trioxide, shown below.

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

- The chemist mixes together SO_2 and O_2 with a catalyst.
- The chemist compresses the gas mixture to a volume of 400 cm^3.
- The mixture is heated to a constant temperature and is allowed to reach equilibrium without changing the total gas volume.

The equilibrium mixture contains 0.0540 mol SO_2 and 0.0270 mol O_2.

At the temperature used, the numerical value for K_c is 3.045×10^4 $dm^3 mol^{-1}$.

(i) Write the expression for K_c and the units of K_c for this equilibrium. **[2]**

(ii) Determine the amount, in mol, of SO_3 in the equilibrium mixture at this temperature.

Give your final answer to an **appropriate** number of significant figures.

Show all your working. **[4]**

(Total 10 marks)

Ammonia can be manufactured from nitrogen and hydrogen gases in the Haber process.
The equilibrium is shown below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92 \text{ kJ mol}^{-1}$$

(a) Write an expression for K_c for this equilibrium. [1]

(b) A chemist carries out a series of experiments to investigate the conversion of nitrogen and hydrogen into ammonia under different conditions.

- The chemist mixes together 10.40 mol N_2 and 22.50 mol H_2 and pressurises the gases so that the total gas volume is 5.00 dm^3.
- The mixture is allowed to reach equilibrium at constant temperature and without changing the total gas volume.
- The equilibrium mixture contains 5.60 mol NH_3.

Calculate K_c, including units, at this temperature.
Give your answer to **three** significant figures. [6]

(c) The chemist repeats the experiment several times. In each experiment, the chemist makes one change.

(i) The chemist heats the mixture to a higher temperature at constant pressure.

Explain whether the value of K_c would be greater, smaller or the same. [1]

(ii) The chemist increases the pressure of the mixture at constant temperature.
Explain whether the value of K_c would be greater, smaller or the same. [1]

[Total: 9 Marks]