17.1 Equilibrium

Past Exam Questions (Paper 1, 2)

1. *[1 mark]*

When gaseous nitrosyl chloride, NOCl (g), decomposes, the following equilibrium is established:

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

2.0 mol of NOCl(g) were placed in a $1.0\ dm^3$ container and allowed to reach equilibrium. At equilibrium 1.0 mol of NOCl(g) was present. What is the value of K_c?

A. 0.50

B. 1.0

C. 1.5

D. 2.0

2. *[1 mark]*

A mixture of 2.0 mol of H_2 and 2.0 mol of I_2 is allowed to reach equilibrium in the gaseous state at a certain temperature in a $1.0\ dm^3$ flask. At equilibrium, 3.0 mol of HI are present. What is the value of K_c for this reaction?

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

A. $K_c = \frac{(3.0)^2}{(0.5)^2}$

B. $K_c = \frac{3.0}{(0.5)^2}$

C. $K_c = \frac{(3.0)^2}{(2.0)^2}$

D. $K_c = \frac{(0.5)^2}{(3.0)^2}$

3. *[1 mark]*

The equation for the reaction between two gases, A and B, is:

$$2A(g) + 3B(g) \rightleftharpoons C(g) + 3D(g)$$

When the reaction is at equilibrium at 600 K the concentrations of A, B, C and D are 2, 1, 3 and 2 $mol\ dm^{-3}$ respectively. What is the value of the equilibrium constant at 600 K?

A. $\frac{1}{6}$

B. $\frac{9}{7}$

C. 3

D. 6

4a. *[1 mark]*

Consider the following reaction studied at 263 K.

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

It was found that the forward reaction is first order with respect to Cl_2 and second order with respect to NO. The reverse reaction is second order with respect to NOCl.

State the rate expression for the forward reaction.

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4b. *[4 marks]*

1.0 mol of Cl_2 and 1.0 mol of NO are mixed in a closed container at constant temperature.

Sketch a graph to show how the concentration of NO and NOCl change with time until after equilibrium has been reached. Identify the point on the graph where equilibrium is established.

4c. *[1 mark]*

Consider the following equilibrium reaction.

$$Cl_2(g) + SO_2(g) \rightleftharpoons SO_2Cl_2(g)\ \Delta H^{\Theta} = -84.5\ kJ$$

In a 1.00 dm^3 closed container, at 375 °C, 8.60×10^{-3} mol of SO_2 and 8.60×10^{-3} mol of Cl_2 were introduced. At equilibrium, 7.65×10^{-4} mol of SO_2Cl_2 was formed.

Deduce the equilibrium constant expression, K_c, for the reaction.

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4d. *[3 marks]*

Determine the value of the equilibrium constant, K_c.

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4e. *[3 marks]*

If the temperature of the reaction is changed to 300 °C, predict, stating a reason in each case, whether the equilibrium concentration of SO_2Cl_2 and the value of K_c will increase or decrease.

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4f. *[3 marks]*

If the volume of the container is changed to $1.50\ dm^3$, predict, stating a reason in each case, how this will affect the equilibrium concentration of SO_2Cl_2 and the value of K_c.

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4g. *[2 marks]*

Suggest, stating a reason, how the addition of a catalyst at constant pressure and temperature will affect the equilibrium concentration of SO_2Cl_2.

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5a. *[2 marks]*

Consider the following equilibrium.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)\ \Delta H^{\Theta} = -\ 198\ kJ\ mol^{-1}$$

State and explain the effect of increasing the pressure on the yield of sulfur trioxide.

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5b. *[4 marks]*
When a mixture of 0.100 mol NO, 0.051 mol H_2 and 0.100 mol H_2O were placed in a $1.0\ dm^3$ flask at 300 K, the following equilibrium was established.

$2NO(g)\ +\ 2H_2(g) \rightleftharpoons N_2(g)\ +\ 2H_2O(g)$

At equilibrium, the concentration of NO was found to be $0.062\ mol\ dm^{-3}$. Determine the equilibrium constant, K_c, of the reaction at this temperature.

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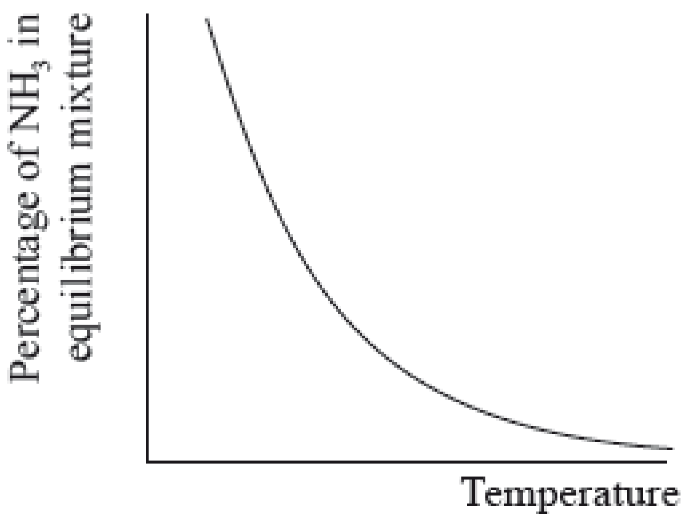
6. *[9 marks]*

The Haber process enables the large-scale production of ammonia needed to make fertilizers.

The equation for the Haber process is given below.

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

The percentage of ammonia in the equilibrium mixture varies with temperature.



(i) Use the graph to deduce whether the forward reaction is exothermic or endothermic and explain your choice.

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(ii) State and explain the effect of increasing the pressure on the yield of ammonia.

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(iii) Deduce the equilibrium constant expression, K_c, for the reaction.

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(iv) A mixture of 1.00 mol N_2 and 3.00 mol H_2 was placed in a $1.0\ dm^3$ flask at 400 °C. When the system was allowed to reach equilibrium, the concentration of was found to be $0.062\ mol\ dm^{-3}$. Determine the equilibrium constant, K_c, of the reaction at this temperature.

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(v) Iron is used as a catalyst in the Haber process. State the effect of a catalyst on the value of K_c.

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7a. *[3 marks]*

In an experiment conducted at 25.0 °C, the initial concentration of propanoic acid and methanol were $1.6\ mol\ dm^{-3}$ and $2.0\ mol\ dm^{-3}$ respectively. Once equilibrium was established, a sample of the mixture was removed and analysed. It was found to contain $0.80\ mol\ dm^{-3}$ of compound **X**.

Calculate the concentrations of the other three species present at equilibrium.

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7b. *[2 marks]*

State the equilibrium constant expression, K_c, and calculate the equilibrium constant for this reaction at 25.0 °C.

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8a. *[4 marks]*

An example of a homogeneous reversible reaction is the reaction between hydrogen and iodine.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

At a temperature just above 700 K it is found that when 1.60 mol of hydrogen and 1.00 mol of iodine are allowed to reach equilibrium in a $4.00\ dm^3$ flask, the amount of hydrogen iodide formed in the equilibrium mixture is 1.80 mol. Determine the value of the equilibrium constant at this temperature.

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8b. *[2 marks]*

Propene can be hydrogenated in the presence of a nickel catalyst to form propane. Use the data below to answer the questions that follow.

Compound	Formula	$\Delta H^{\ominus}_f$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
hydrogen	$H_2(g)$	0	+131
propane	$C_3H_8(g)$	−104	+270
propene	$C_3H_6(g)$	+20.4	+267

Determine the value of ΔG^{Θ} for the hydrogenation of propene at 298 K.

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8c. *[2 marks]*

At 298 K the hydrogenation of propene is a spontaneous process. Determine the temperature above which propane will spontaneously decompose into propene and hydrogen.

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9a. *[1 mark]*

To determine the enthalpy change of combustion of methanol, CH_3OH, 0.230 g of methanol was combusted in a spirit burner. The heat released increased the temperature of 50. 0 cm^3 of water from 24.5 °C to 45.8 °C.

Methanol can be produced according to the following equation.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$$

Calculate the standard entropy change for this reaction, ΔS^{Θ}, using Table 11 of the Data Booklet and given:

$S^{\Theta}(CO) = 198\,J\,K^{-1}mol^{-1}$ and $S^{\Theta}(H_2) = 131\,J\,K^{-1}mol^{-1}$.

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9b. *[3 marks]*

The manufacture of gaseous methanol from CO and H_2 involves an equilibrium reaction.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H^{\Theta} < 0$$

1.00 mol of CH_3OH is placed in a closed container of volume $1.00\ dm^3$ until equilibrium is reached with CO and H_2. At equilibrium 0.492 mol of CH_3OH are present. Calculate K_c.

10a. *[1 mark]*

Hydrogen gas reacts with iodine gas to form hydrogen iodide gas. A $2.00\ dm^3$ flask was filled with $1.50 \times 10^{-2}\ mol$ of hydrogen and $1.50 \times 10^{-2}\ mol$ of iodine at a temperature, T. The equilibrium constant, K_c, has a value of 53.0 at this temperature.

Deduce the equilibrium constant expression, K_c, for the formation of HI(g).

10b. *[4 marks]*

Determine the equilibrium concentrations, in $mol\,dm^{-3}$, of hydrogen, iodine and hydrogen iodide.

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11. *[7 marks]*

An equilibrium exists between nitrosyl chloride, NOCl, nitrogen oxide, NO, and chlorine, Cl_2.

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

(i) Deduce the equilibrium constant expression for this reaction.

(ii) Explain the effect on the position of equilibrium and the value of K_c when pressure is decreased and temperature is kept constant.

(iii) 2.00 mol of NOCl was placed in a $1.00\ dm^3$ container and allowed to reach equilibrium at 298 K. At equilibrium, 0.200 mol of NO was present. Determine the equilibrium concentrations of NOCl and Cl_2, and hence calculate the value of K_c at this temperature.

(iv) The value of K_c is 1.60×10^{-5} at 318 K. State and explain whether the forward reaction is exothermic or endothermic.

12a. *[1 mark]*

A class studied the equilibrium established when ethanoic acid and ethanol react together in the presence of a strong acid, using propanone as an inert solvent. The equation is given below.

$$CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$$

One group made the following **initial mixture**:

Liquid	Volume / cm^3
Ethanoic acid	5.00 ± 0.05
Ethanol	5.00 ± 0.05
$6.00\ mol\ dm^{-3}$ aqueous hydrochloric acid	1.00 ± 0.02
Propanone	39.0 ± 0.5

After one week, a $5.00 \pm 0.05\ cm^3$ sample of the final equilibrium mixture was pipetted out and titrated with $0.200\ mol\ dm^{-3}$ aqueous sodium hydroxide to determine the amount of ethanoic acid remaining. The following titration results were obtained:

Titration number	1	2	3
Initial reading / $cm^3 \pm 0.05$	1.20	0.60	14.60
Final reading / $cm^3 \pm 0.05$	28.80	26.50	40.70
Titre / cm^3	27.60	25.90	26.10

Deduce the equilibrium constant expression for the reaction.

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12b. *[1 mark]*

The other concentrations in the equilibrium mixture were calculated as follows:

Compound	C_2H_5OH	$CH_3COOC_2H_5$	H_2O
Concentration / mol dm^{-3}	0.884	0.828	1.80

Use these data, along with your answer to part (iii), to determine the value of the equilibrium constant. (If you did not obtain an answer to part (iii), assume the concentrations of ethanol and ethanoic acid are equal, although this is not the case.)

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12c. *[1 mark]*

Outline how you could establish that the system had reached equilibrium at the end of one week.

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12d. *[1 mark]*

Outline why changing the temperature has only a very small effect on the value of the equilibrium constant for this equilibrium.

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12e. *[2 marks]*

Outline how adding some ethyl ethanoate to the initial mixture would affect the amount of ethanoic acid converted to product.

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13a. *[2 marks]*

The rate of reaction is an important factor in industrial processes such as the Contact process to make sulfur trioxide, $SO_3(g)$.

The Contact process involves this homogeneous equilibrium:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -198\ kJ$$

State and explain how increasing the pressure of the reaction mixture affects the yield of SO_3.

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13b. *[4 marks]*

The Contact process involves this homogeneous equilibrium:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -198\ kJ$$

2.00 mol of $SO_2(g)$ are mixed with 3.00 mol of $O_2(g)$ in a $1.00\ dm^3$ container until equilibrium is reached. At equilibrium there are 0.80 mol of $SO_3(g)$.

Determine the equilibrium constant (K_c) assuming all gases are at the same temperature and pressure.

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13c. *[1 mark]*

The Contact process involves this homogeneous equilibrium:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -198\ kJ$$

State the effect of increasing temperature on the value of K_c for this reaction.

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13d. *[2 marks]*

Outline the economic importance of using a catalyst in the Contact process.

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14a. *[2 marks]*

When nitrogen gas and hydrogen gas are allowed to react in a closed container the following equilibrium is established.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \ \Delta H = -92.6\ kJ$$

Outline **two** characteristics of a reversible reaction in a state of dynamic equilibrium.

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14b. *[2 marks]*

Predict, with a reason, how each of the following changes affects the position of equilibrium.

The volume of the container is increased.

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Ammonia is removed from the equilibrium mixture.

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14c. *[3 marks]*

Typical conditions used in the Haber process are 500 °C and 200 atm, resulting in approximately 15% yield of ammonia.

(i) Explain why a temperature lower than 500 °C is **not** used.

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(ii) Outline why a pressure higher than 200 atm is **not** often used.

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14d. *[1 mark]*

Deduce the equilibrium constant expression, K_c, for the reaction in part 14.a.

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14e. *[2 marks]*

When 1.00 mol of nitrogen and 3.00 mol of hydrogen were allowed to reach equilibrium in a $1.00\ dm^3$ container at a temperature of 500 °C and a pressure of 1000 atm, the equilibrium mixture contained 1.46 mol of ammonia.

Calculate the value of K_c at 500 °C.

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