Questions

Q1.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

An equation for the formation of ammonia using the Haber process is shown.

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

(i) Calculate the enthalpy change for the forward reaction shown in the equation, selecting from the bond enthalpies in the table.
Include a sign in your answer.

(3)

Bond	Mean bond enthalpy / kJ mol^{-1}
N—N	158
N═N	410
N≡N	945
N—H	391
H—H	436

(ii) A data book gives the standard enthalpy change of formation of ammonia as –46.1 kJ mol^{-1}.

Give two reasons for the difference between this value and the value that you calculated in (a)(i).

(2)

Reason 1

.....

.....

.....

Reason 2

.....

.....

.....

(iii) What is the percentage atom economy, by mass, for ammonia in the forward reaction?

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

(1)

- ☒ **A** 17.6 %
- ☒ **B** 50.0 %
- ☒ **C** 82.4 %
- ☒ **D** 100 %

(iv) What is the equilibrium expression for K_c?

(1)

- ☒ **A** $K_c = \frac{[N_2][3H_2]}{[2NH_3]}$
- ☒ **B** $K_c = \frac{[2NH_3]}{[N_2][3H_2]}$
- ☒ **C** $K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$
- ☒ **D** $K_c = \frac{[N_2][H_2]^3}{[NH_3]^2}$

(Total for question = 7 marks)

Q2.

Methanol is manufactured from a mixture of carbon monoxide and hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -90.8\,kJ\,mol^{-1}$$

Explain why, in the industrial process involving this reaction, a catalyst is used.

(2)

.....

.....

.....

.....

.....

.....

(Total for question = 2 marks)

Q3.

This question is about equilibrium systems.

An equilibrium exists in aqueous solution between the chromate(VI) ions and the dichromate(VI) ions.

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$

Explain any change in the position of equilibrium if a few drops of sodium hydroxide solution are added to this equilibrium system.

(2)

.....

.....

.....

.....

.....

.....

(Total for question = 2 marks)

Q4.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Methanol is manufactured from a mixture of carbon monoxide and hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -90.8\,kJ\,mol^{-1}$$

(i) How does the equilibrium yield of methanol change if the temperature is increased at constant pressure or the pressure increased at constant temperature?

(1)

	Equilibrium yield when temperature is increased	Equilibrium yield when pressure is increased
☐ **A**	decrease	decrease
☐ **B**	decrease	increase
☐ **C**	increase	decrease
☐ **D**	Increase	increase

(ii) Explain your answer to (i).

(2)

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q5.

Phosphorus(V) chloride, PCl_5, can be thermally decomposed to phosphorus(III) chloride, PCl_3, and chlorine, Cl_2 . The equation for this reaction is

$$PCl_5(g) \rightarrow PCl_3(g) + Cl_2(g)$$

The enthalpy change for this reaction cannot be measured directly.

Another source gave a different value for the enthalpy change of this reaction.

$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ $\Delta_r H = +87.9$ kJ mol^{-1}

Explain the effect, if any, of increasing the temperature on the position of the equilibrium at constant volume.

(2)

.....

.....

.....

.....

.....

(Total for question = 2 marks)

Q6.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

This question is about equilibrium systems.

The equilibrium for the reaction between hydrogen gas and an oxide of iron is

$$Fe_3O_4(s) + 4H_2(g) \rightleftharpoons 3Fe(s) + 4H_2O(g)$$

The K_c expression for this equilibrium is

(1)

☐ **A** $K_c = \dfrac{[Fe] \times [H_2O]}{[Fe_3O_4] \times [H_2]}$

☐ **B** $K_c = \dfrac{[Fe]^3 \times [H_2O]^4}{[Fe_3O_4] \times [H_2]^4}$

☐ **C** $K_c = \dfrac{[H_2O]}{[H_2]}$

☐ **D** $K_c = \dfrac{[H_2O]^4}{[H_2]^4}$

(Total for question = 1 mark)

Q7.

An equation for the formation of ammonia using the Haber process is shown.

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

In the chemical industry, many processes involve reversible reactions. The product is often removed before equilibrium is attained.

Give three reasons why the product may be removed before its maximum concentration is achieved.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q8.

This question is about the oxidation of ammonia.

In fact, this oxidation to form nitrogen(II) oxide is an equilibrium reaction.

(i) Explain the effect, if any, of increasing pressure on the equilibrium **yield** of NO in this reaction.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$$

(2)

.....

.....

.....

.....

.....

.....

(ii) Explain the effect, if any, of an increase in pressure on the **rate** of this reaction.

(2)

.....

.....

.....

.....

.....

.....

(iii) The platinum-rhodium catalyst used in this reaction is a **heterogeneous** catalyst. State what is meant by the term 'heterogeneous' and why a catalyst has no effect on the yield of the products in the reaction.

(2)

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q9.

One of the stages in the production of sulfuric acid from sulfide ores involves the oxidation of sulfur dioxide to sulfur trioxide. The equation for the reaction is

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta rH = -197 \text{ kJ mol}^{-1}$

The conditions used in one industrial process are: 420°C and a pressure of 1.7 atm together with a vanadium(V) oxide catalyst.

It is proposed to change the conditions to 600°C and 10 atm pressure, while still using the same catalyst.

* Evaluate the feasibility of each of these changes in terms of their effect on the rate, yield and economics of the reaction.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q10.

This question is about the oxidation of ammonia.

One equation for the oxidation of ammonia is

$$4NH_3(g) + 3O_2(g) \rightleftharpoons 2N_2(g) + 6H_2O(g)$$

Write the expression, including units, for the equilibrium constant K_c for for this reaction.

(2)

Expression

Units .....

(Total for question = 2 marks)

Q11.

This question concerns alkenes and some halogen compounds.

Chloroethene can be manufactured by a two-stage process.

(i) In stage 1, chlorine is reacted with ethene at a temperature between 50 °C and 80 °C

$$Cl_2 + CH_2{=}CH_2 \rightleftharpoons CH_2Cl{-}CH_2Cl \qquad \Delta H = -178\,kJ\,mol^{-1}$$

Give **one** reason why a temperature below 50 °C and **another** reason, apart from costs, why a temperature above 80 °C would not be used for this process.

(2)

.....

.....

.....

.....

.....

.....

(ii) In stage 2, the product from the first reaction is converted to chloroethene:

$$CH_2Cl{-}CH_2Cl \rightarrow CH_2{=}CHCl + HCl \qquad \Delta H = +71\,kJ\,mol^{-1}$$

Both products are required for use in other processes.
Which method would be most suitable for the separation of these two products?

(1)

- ☒ **A** fractional distillation
- ☒ **B** solvent extraction using a separating funnel
- ☒ **C** heating under reflux
- ☒ **D** bubble through dilute alkali

(Total for question = 3 marks)

Q12.

Methanol, CH_3OH, is a liquid fuel.

Methanol can be synthesised from methane and steam by a process that occurs in two steps.

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

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

(i) Explain the effects of increasing the pressure on the yield of the products and on the rate of the reaction in Step **1**.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) Step **2** is carried out at a compromise temperature of 500 K.

Explain why 500 K is considered to be a compromise for Step **2** by considering what would happen at higher and lower temperatures.

(3)

.....

.....

.....

.....

.....

.....

.....

(Total for question = 7 marks)

Q13.

Methanol is manufactured from a mixture of carbon monoxide and hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -90.8\,kJ\,mol^{-1}$$

Give **two** characteristics of all reactions at equilibrium.

(2)

.....

.....

.....

.....

.....

(Total for question = 2 marks)

Q14.

Nitrogen monoxide and chlorine gases react together to form a single product, nitrosyl chloride, NOCl.

Below 100 °C the yield of NOCl is almost 100 %, but as the temperature rises the yield of NOCl decreases as the equilibrium position shifts to the left.

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) \qquad \Delta_r H^{\ominus} = -75.6 \text{ kJ mol}^{-1}$$

A 1 dm^3 reaction vessel, initially containing 2 mol of NO and 1 mol of Cl_2, was allowed to come to equilibrium at 225 °C to produce 1.82 mol of NOCl.

(i) Calculate the number of moles of NO and Cl_2 at equilibrium.

(2)

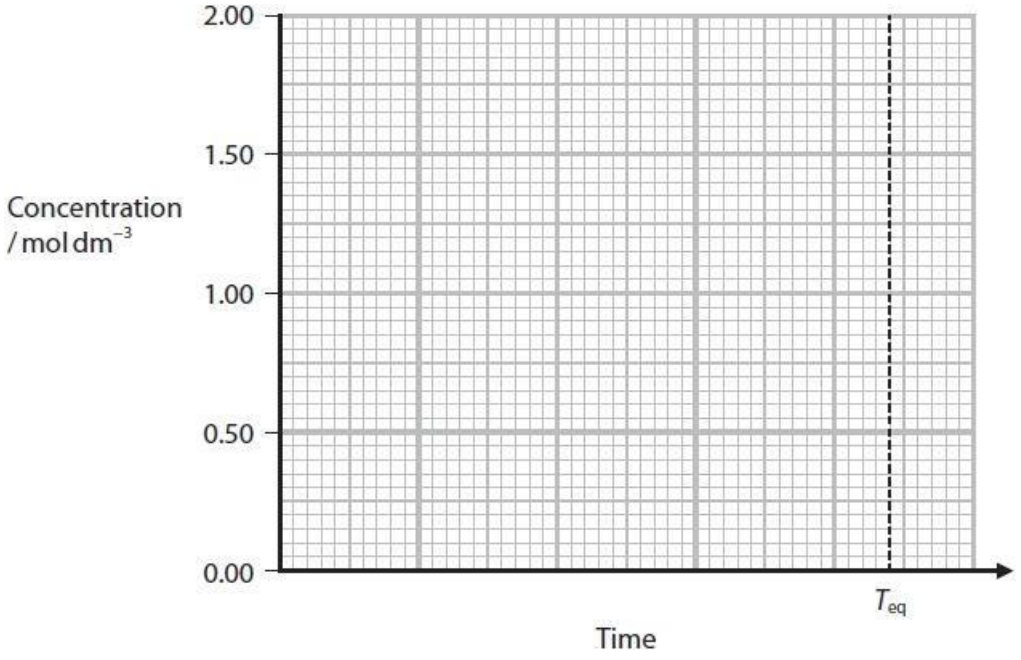
Moles of NO .....

Moles of Cl_2 .....

(ii) Sketch three lines showing the change in concentration over time of the three components of the reaction using the axes given.

You should assume that the reaction reaches equilibrium at time T_{eq}.

(3)



(iii) The expression for the equilibrium constant, K_c , for this reaction is

(1)

☒ **A** $K_c = \dfrac{2[NOCl]}{2[NO][Cl_2]}$

☒ **B** $K_c = \dfrac{[NOCl]^2}{[NO]^2[Cl_2]}$

☒ **C** $K_c = \dfrac{2[NO][Cl_2]}{2[NOCl]}$

☒ **D** $K_c = \dfrac{[NO]^2[Cl_2]}{[NOCl]^2}$

(iv) Give the reason why the equilibrium yield of NOCl decreases when the temperature changes from 25 °C to 225 °C.

The enthalpy change for the reaction at 25 °C is −75.6 kJ mol^{-1}.

(1)

.....

.....

.....

(Total for question = 7 marks)

Q15.

Ethene reacts with steam to form ethanol in a reversible reaction.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \quad \Delta H = -45 \text{ kJ mol}^{-1}$$

At 300°C and a pressure of 65 atm, the equilibrium yield of ethanol is 5%.

(i) State the effect, if any, on the yield of ethanol when the temperature is **increased**.

(1)

.....

.....

(ii) State the effect, if any, on the yield of ethanol when the pressure is **decreased**.

(1)

.....

.....

(iii) What is the expression for the equilibrium constant, K_c, for this reaction?

(1)

☒ **A** $\dfrac{[C_2H_4(g)]+[H_2O(g)]}{[C_2H_5OH(g)]}$

☒ **B** $\dfrac{[C_2H_4(g)][H_2O(g)]}{[C_2H_5OH(g)]}$

☒ **C** $\dfrac{[C_2H_5OH(g)]}{[C_2H_4(g)]+[H_2O(g)]}$

☒ **D** $\dfrac{[C_2H_5OH(g)]}{[C_2H_4(g)][H_2O(g)]}$

(Total for question = 3 marks)