Equilibrium

1. This question is about ammonia, NH_3.

In industry, ammonia is made from nitrogen and hydrogen. This is a reversible reaction, as shown in **equilibrium 24.1** below.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H = -92 \text{ kJ mol}^{-1}$ **Equilibrium 24.1**

i. Explain how le Chatelier's principle can be used to predict the conditions of temperature and pressure for a maximum **equilibrium** yield of ammonia.

--- **[4]**

ii. Using certain conditions, **equilibrium 24.1** has the equilibrium concentrations in the table.

Substance	Equilibrium concentration / mol dm^{-3}
$N_2(g)$	1.25
$H_2(g)$	2.75
$NH_3(g)$	0.862

Calculate the numerical value for K_c for **equilibrium 24.1** under these conditions.

Give your answer to an **appropriate** number of significant figures and in **standard form**.

K_c = ... **[2]**

2(a). The reaction of ammonia, NH_3, with oxygen to form nitrogen monoxide, NO, is an important industrial process.

The equation for this reaction is shown in **equilibrium 4.1** below.

$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H = -905\ kJ\ mol^{-1}$ **Equilibrium 4.1**

Write an expression for the equilibrium constant, K_c, in **equilibrium 4.1**.

[1]

(b). Predict the conditions of temperature and pressure for a maximum equilibrium yield of nitrogen monoxide in **equilibrium 4.1**.

- Explain your prediction in terms of le Chatelier's principle.
- State and explain how these conditions could be changed to achieve a compromise between equilibrium yield, rate and other operational factors.

--- **[5]**

3. Nitrogen can be reacted with hydrogen in the presence of a catalyst to make ammonia in the Haber process.

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

A mixture of N_2 and H_2 was left to react until it reached equilibrium. The equilibrium mixture had the following composition:

N_2	1.20 mol dm^{-3}
H_2	2.00 mol dm^{-3}
NH_3	0.877 mol dm^{-3}

i. Calculate a value for K_c for this equilibrium.

K_c = ...dm^6 mol^{-2} **[3]**

ii. Explain how the following changes would affect the amount of NH_3 present in the equilibrium mixture.

Use of a catalyst:

A higher temperature:

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[3]

4. A chemist investigates the equilibrium that produces methanol:

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH\ (g)$

The chemist mixes CO(g) with $H_2(g)$ and leaves the mixture to react until equilibrium is reached. The equilibrium mixture is analysed and found to contain the following concentrations.

Substance	**Concentration/mol dm^{-3}**
CO (g)	0.310
$H_2(g)$	0.240
$CH_3OH(g)$	0.260

Calculate the numerical value of K_c for this equilibrium.

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

K_c = ... dm^6 mol^{-2} **[2]**

5(a). When potassium chromate(VI), K_2CrO_4, is dissolved in water an equilibrium is set up. The position of equilibrium is well to the left and the solution is a yellow colour.

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

The addition of aqueous acid turns the solution an orange colour.
Aqueous alkali is then added and the solution turns a yellow colour.

Explain these observations in terms of le Chatelier's principle.

--- **[2]**

(b). This question is about equilibrium and catalysts.

The equilibrium between NO_2 and N_2O_4 gases is set up in a gas syringe at room temperature. The two gases are different in appearance.

$$\underset{\text{brown}}{2NO_2(g)} \rightleftharpoons \underset{\text{colourless}}{N_2O_4(g)} \qquad \Delta H = -58\,\text{kJ mol}^{-1}$$

Using le Chatelier's principle, predict and explain how the following changes would affect the appearance of the equilibrium mixture.

i. The gas mixture is compressed by pushing in the plunger of the gas syringe.

-- **[2]**

ii. The gas syringe is placed in a warm water bath.

-- **[2]**

6(a). Sulfur trioxide, SO_3, is used for the industrial manufacture of sulfuric acid.

SO_3 is produced by reacting sulfur dioxide, SO_2, and oxygen, O_2, as shown in **equilibrium 25.1** below.

Equilibrium 25.1 $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H = -197$ kJ mol^{-1}

Le Chatelier' s principle can be used to predict how different conditions affect the equilibrium position.

- Using le Chatelier' s principle, show that a low temperature and a high pressure should be used to obtain a maximum **equilibrium** yield of SO_3.
- Explain why the actual conditions used in industry may be different from the conditions needed for a maximum equilibrium yield.

[5]

(b). Under certain conditions, K_c for **equilibrium 25.1** is 0.160 $dm^3\ mol^{-1}$.

The equilibrium mixture under these conditions has the following concentrations of SO_2 and O_2.

Species	**Equilibrium concentration / mol dm^{-3}**
SO_2	2.00
O_2	1.20

- Using the value of K_c, explain whether the equilibrium position will be towards the right or towards the left under these conditions.
- Calculate the concentration of SO_3 in the equilibrium mixture.

--- **[4]**

7(a). State le Chatelier's principle.

--- **[1]**

(b). Methanol, CH_3OH, is an important feedstock for the chemical industry.

In the manufacture of methanol, carbon dioxide and hydrogen are reacted together in the reversible reaction shown below.

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

High pressures and low temperatures would give a maximum equilibrium yield of methanol.

i. Explain this statement in terms of le Chatelier's principle.

--- **[3]**

ii. Explain why the actual conditions used by the chemical industry might be different.

--- **[2]**

8. A student mixes hydrogen and iodine at room temperature and pressure and allows the mixture to reach dynamic equilibrium.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -9 \text{ kJ mol}^{-1}$$ **equilibrium 3.1**

i. A closed system is required for dynamic equilibrium to be established.

State **one** other feature of this dynamic equilibrium.

--- **[1]**

ii. The student heats the equilibrium mixture keeping the volume constant.

Predict how the composition of the equilibrium mixture changes on heating.

Explain your answer.

--- **[2]**

iii. Predict and explain what effect, if any, an increase in the pressure would have on the position of the equilibrium.

effect

....

explanation

....

--- **[1]**

9. The following reaction is used in industry to make sulfur trioxide gas, SO_3.

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

This preparation is carried out in the presence of a catalyst.

* Explain the conditions of temperature and pressure that could be used to obtain the maximum equilibrium yield of sulfur trioxide.
Discuss the importance of a compromise between equilibrium yield and reaction rate when deciding the operational conditions for this process.

-- **[6]**

10(a). This question looks at equilibrium reactions used by industry for preparing important chemicals.

Methanol can be manufactured by reacting carbon monoxide with hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

An equilibrium mixture contains 3.10×10^{-3} mol dm^{-3} CO, 2.40×10^{-3} mol dm^{-3} H_2 and an unknown concentration of CH_3OH.

i. Write an expression for the equilibrium constant, K_c.

[1]

ii. The value of K_c for this equilibrium is 14.6 dm^6 mol^{-2}.

Determine the equilibrium concentration methanol, $CH_3OH(g)$.

Give your answer to **three** significant figures.

equilibrium concentration of $CH_3OH(g)$ = ... dm^6 mol^{-2}

[2]

(b). Ammonia is used in the manufacture of nitric acid. The first stage of this process is a dynamic equilibrium.

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

i. When the temperature is increased, K_c for this reaction decreases.

State the effect, if any, on the equilibrium yield of NO in this reaction.

Explain your answer.

-- **[1]**

ii. Which element has been oxidised and which element has been reduced in the reaction?

Include signs with the oxidation numbers.

Oxidised .... Oxidation number change from .... to ....

Reduced .... Oxidation number change from .... to ....

[2]

END OF QUESTION PAPER