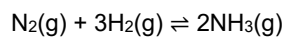


# Equilibrium

1. This question is about ammonia,  $\text{NH}_3$ .

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



$$\Delta H = -92 \text{ kJ mol}^{-1}$$

**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 / $\text{mol dm}^{-3}$
$\text{N}_2(\text{g})$	1.25
$\text{H}_2(\text{g})$	2.75
$\text{NH}_3(\text{g})$	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**.

$$K_c = \dots\dots\dots \text{ [2]}$$

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



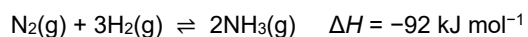
[1]

- 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]

**[5]**

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



A mixture of  $\text{N}_2$  and  $\text{H}_2$  was left to react until it reached equilibrium. The equilibrium mixture had the following composition:

$\text{N}_2$	$1.20 \text{ mol dm}^{-3}$
$\text{H}_2$	$2.00 \text{ mol dm}^{-3}$
$\text{NH}_3$	$0.877 \text{ mol dm}^{-3}$

- i. Calculate a value for  $K_c$  for this equilibrium.

$$K_c = \dots\dots\dots \text{dm}^6 \text{ mol}^{-2} \quad [3]$$

- ii. Explain how the following changes would affect the amount of  $\text{NH}_3$  present in the equilibrium mixture.

Use of a catalyst:

-----

-----

A higher temperature:

-----

-----

[3]

$$\text{CO(g)} + 2\text{H}_2\text{(g)} \rightleftharpoons \text{CH}_3\text{OH (g)}$$

Substance	Concentration/mol dm <sup>-3</sup>
CO (g)	0.310
H <sub>2</sub> (g)	0.240
CH <sub>3</sub> OH(g)	0.260

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

$$K_c = \dots \text{ dm}^6 \text{ mol}^{-2} \text{ [2]}$$

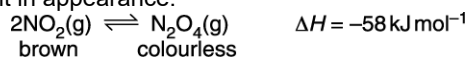
$$\underset{\text{yellow}}{2\text{CrO}_4^{2-}(\text{aq})} + 2\text{H}^+(\text{aq}) \rightleftharpoons \underset{\text{orange}}{\text{Cr}_2\text{O}_7^{2-}(\text{aq})} + \text{H}_2\text{O}(\text{l})$$

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

[2]

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

The equilibrium between  $\text{NO}_2$  and  $\text{N}_2\text{O}_4$  gases is set up in a gas syringe at room temperature. The two gases are different in appearance.



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]

SO<sub>3</sub> is produced by reacting sulfur dioxide, SO<sub>2</sub>, and oxygen, O<sub>2</sub>, as shown in **equilibrium 25.1** below.

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  $\text{SO}_3$ .
- 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  $0.160 \text{ dm}^3 \text{ mol}^{-1}$ .

The equilibrium mixture under these conditions has the following concentrations of  $\text{SO}_2$  and  $\text{O}_2$ .

Species	Equilibrium concentration / $\text{mol dm}^{-3}$
$\text{SO}_2$	2.00
$\text{O}_2$	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  $\text{SO}_3$  in the equilibrium mixture.

-----

-----

-----

-----

-----

-----

-----

-----

-----

-----

[4]

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

-----

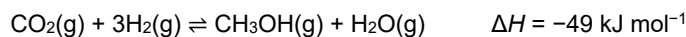
-----

-----

[1]

- (b). Methanol, CH<sub>3</sub>OH, 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.



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.

-----

-----

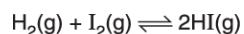
-----

-----

-----

**[2]**

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



$$\Delta H = -9 \text{ kJ mol}^{-1}$$

**equilibrium 3.1**

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

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

-----

-----

**[1]**

- Explain your answer.

[2]

- effect

explanation

[1]

- $$2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g}) \quad \Delta H^\ominus = -196 \text{ kJ mol}^{-1}$$

Discuss the importance of a compromise between equilibrium yield and reaction rate when deciding the operational conditions for this process.

[illegible]

-----

-----

-----

-----

-----

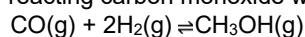
-----

-----

[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.



An equilibrium mixture contains  $3.10 \times 10^{-3} \text{ mol dm}^{-3}$  CO,  $2.40 \times 10^{-3} \text{ mol dm}^{-3}$  H<sub>2</sub> and an unknown concentration of CH<sub>3</sub>OH.

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

[1]

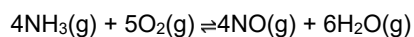
- ii. The value of  $K_c$  for this equilibrium is  $14.6 \text{ dm}^6 \text{ mol}^{-2}$ .

Determine the equilibrium concentration methanol, CH<sub>3</sub>OH(g).

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

equilibrium concentration of CH<sub>3</sub>OH(g) = .....  $\text{dm}^6 \text{ mol}^{-2}$   
[2]

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



- 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