APPLICATIONS OF CHEMICAL EQUILIBRIUM (LIVE) 19 MAY 2015

Section A: Summary Notes

What is equilibrium?

- Reactions that take place in both the forward and reverse directions simultaneously are calledreversible reactions.
- Observable macroscopic changes stop, while microscopic changes continue as reactants change to products, and products change back into reactants.
- When the rate of the forward reaction equals the rate of the reverse reaction, we say a state of dynamic equilibrium has been reached.

Le Chatelier's Principle

If the conditions of an equilibrium system are changed by changing temperature, pressure or concentration, a process takes place which tends to oppose the effect of the change.

- An equilibrium may be disturbed by changing any one (or more) of the factors for the equilibrium:
  - Temperature
  - Concentration (gases and solutions)
  - Pressure (gases only)

Changing Equilibrium Conditions

$$N_{2\,(g)} + 3H_{2\,(g)} \rightleftharpoons 2NH_{3\,(g)} \quad (\Delta H < 0)$$

Concentration

- An increase in concentration of any reactant will cause an increase in the reaction rate of the forward reaction.
- Increasing the concentration of the N_2 or H_2 would, therefore, increase the rate of the forward reaction, hence favouring the shift of the equilibrium towards the forward reaction.

Temperature

- An increase in temperature causes an increase in the rate of **both** reactions.
- ΔH refers to the forward reaction. If it is negative, the reaction is exothermic (energy is liberated).
- Increasing the temperature will favour the endothermic (reverse) reaction.

Pressure

- Pressure can be increased by decreasing the volume of the container.
- When the volume of the container decreases, the total concentration of all gases increases.
- According to Le Chatelier's, the reaction that will decrease the total number of gas moles in the space will be favoured. (favours side with lowest number of gas moles)

So to ensure maximum yield of ammonia:

- Use catalyst to reach equilibrium quickly.
- Once equilibrium is reached:
  - Drop temperature to 450 °C
  - Increase conc. of N_2 & H_2& decrease conc. of NH_3
  - Increase pressure in container by reducing volume.

Graph examples

Comparing reaction rates of the forward and reverse reactions

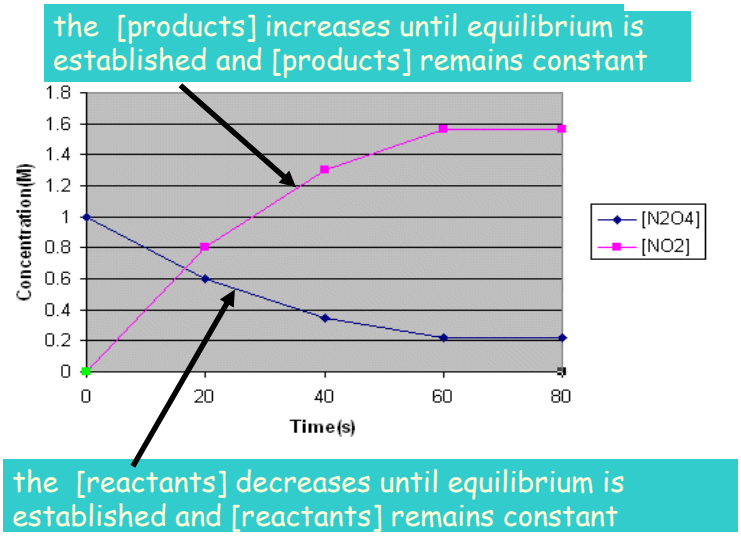
- [A] (square brackets mean concentration of A) and [B] initially decrease.
- [C] and [D] initially increase.
- The rate of the forward reaction becomes constant and becomes equal to the rate of the reverse reaction.
- At this point (equilibrium) the concentrations of reactants and products remain constant.

Comparing concentrations of products and reactants graphically.

$N_2O_{4\,(g)} \rightleftharpoons 2NO_{2(g)}$

light brown dark brown

- An increase in temperature causes more NO_2 to form.
- This suggests that the forward reaction must be endothermic. ($\Delta H > 0$)
- Also increasing pressure favours side with least gas moles (reactants) therefore reverse reaction (1 mole as opposed to 2 moles of gas) is favoured.



Section B: Practice Questions

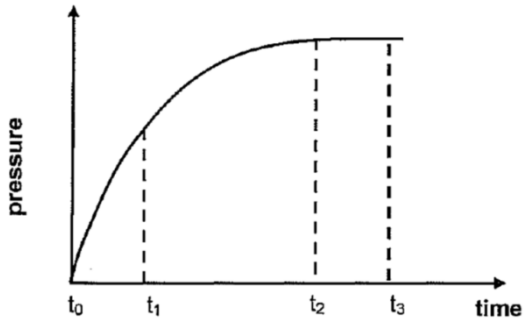
Question 1

(Taken from Preparatory Exam 2008)

William wants to determine the equilibrium constant for the decomposition of calcium carbonate ($CaCO_3$). He seals 2,0 g of $CaCO_3$ in an evacuated 1,0 dm^3 metal flask and connects a pressure gauge to the flask. The flask is placed in an oven and heated to a temperature of 800°C at which equilibrium was reached according to the following equation:

$$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g) \qquad \Delta H > 0$$

The graph obtained for pressure versus time for the decomposition of calcium carbonate is shown below:



1.1. How does the rate of the reverser reaction change from t_o to t_1? (2)

1.2. What is the reason for the horizontal line between t_2 and t_3? (1)

1.3. Draw a sketch graph to show how the mass of $CaCO_3$ changes for the period t_o to t_3. (4)

1.4. During a power failure the temperature of the oven drops to 500°C. What effect (only write INCREASES, DECREASES or STAYS THE SAME) does this decrease in temperature have on the following:

1.4.1. The rate of the forward reaction. (1)
1.4.2. The concentration of CO_2 (1)
1.4.3. The value of K_c (1)

1.5. Give a reason for your answer to Question 1.4.3. (4)

[14]

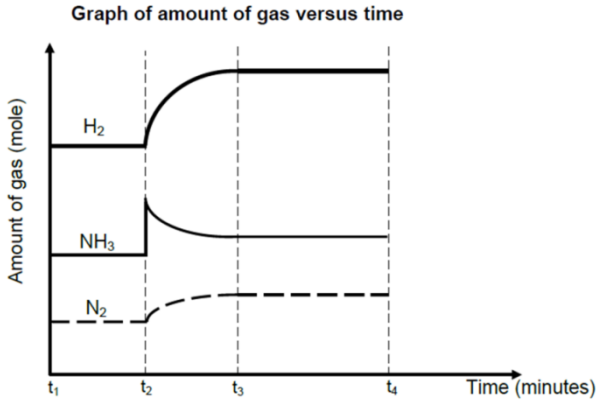
Question 2

(Taken from November Exam 2008)

The following equation represents a reversible reaction that has reached equilibrium at 470°C in a closed container.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H < 0$$

A change was then made to the NH_3 in the equilibrium mixture at t_2. A graph showing the effect of this change is draw below. (The graph is not drawn to scale)



2.1. What is the meaning of the horizontal lines between t_1 and t_2? (1)
2.2. State the change that was made to the NH_3 in the mixture at time t_2 (1)
2.3. Explain how the change mentioned in Question 2.2, affected the concentration of H_2 and N_2 gases as shown in the graph. (3)

[5]

Question 3

(Taken from Gauteng Preparatory Exam 2009)

HI is a colourless gas that reacts with oxygen to give water and iodine. With moist air, HI gives a mist (or fumes) of hydrochloric acid. It is exceptionally soluble in water, giving hydroiodic acid.

8 mol HI is placed in an empty reaction vessel containing 2 mol I_2 and no H_2. The reaction chamber is at a temperature of 130°C and has a volume of 500 cm^3. When equilibrium is reached, there are 4 mol HI left.

$$I_2(g) + H_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H > 0$$

3.1. If the temperature of the system is increased, explain what will happen to the concentration of the HI(g) in terms of Le Chatelier's Principle. (4)

3.2. If a catalyst is added to the system, what will happen to the HI(g) concentration. State only INCREASE, DECREASE or REMAIN THE SAME. (2)

3.3. Explain your answer to Question 3.2. (2)

3.4. If the pressure of the system is increased, what will happen to the H_2(g) concentration. State only INCREASE, DECREASE or REMAIN THE SAME. (2)

[10]

Question 4

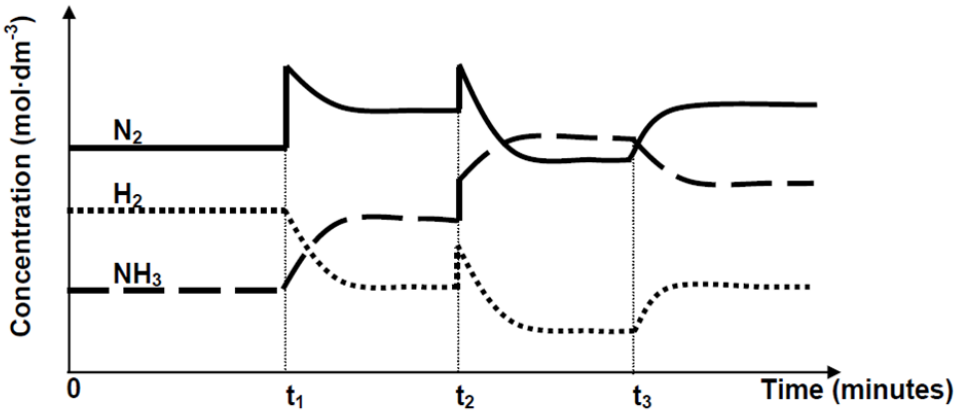
(Taken from Feb – March 2011)

A fertiliser company produces ammonia on a large scale at a temperature of 450°C. The balanced equation below represents the reaction that takes place in a sealed container.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H < 0$$

To meet an increased demand for fertiliser, the management of the company instructs their engineer to make the necessary adjustments to increase the yield of ammonia.

In a trial run on small scale in the laboratory, the engineer makes adjustments to the TEMPERATURE, PRESSURE and CONCENTRATION of the equilibrium mixture. The graphs below represent the results obtained.



4.1. Identify the changes made to the equilibrium mixture at each of the following times:

4.1.1. t_1 (2)

4.1.2. t_2 (2

4.1.3. t_3 (2)

4.2. At which of the above time(s) did the change made to the reaction mixture lead to a higher yield of ammonia? Write down only **t_1** and / or **t_2** and / or **t_3**. (2)

[8]

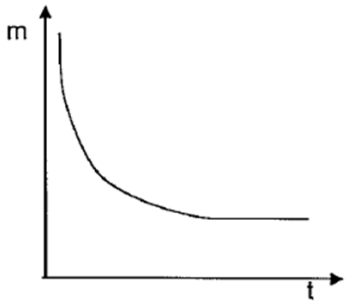
Section C: Solutions

Question 1

1.1. It starts at zero at t_o✓and increases to time t_1✓ (2)

1.2. Equilibrium is reached ✓ (1)

1.3.



Criteria for graph

- *Axes labelled correctly* ✓
- *Gradient of graph initially high* ✓
- *Gradient decreases with time* ✓
- *Graph ends parallel to x-axes to represent equilibrium* ✓ (4)

1.4.1. Decreases ✓ (1)

1.4.2. Decreases ✓ (1)

1.4.3. Decreases ✓ (1)

1.5. At lower temperature, the exothermic reaction is favoured ✓
Therefore the reverse reaction is favoured ✓
Reducing the concentration of the gas (products) ✓
$K_c = [CO_2]$ will decrease ✓ (4)

Question 2

2.1. The system is in equilibrium ✓ (1)

2.2. The concentration of the ammonia was increased ✓ (1)

2.3. When the concentration of NH_3 is increased,
The reverse reaction is favoured ✓
Because this reaction decreases the excess NH_3 ✓
The result is an increase in the concentration of H_2 and N_2 until a new equilibrium is established. ✓ (3)

Question 3

3.1. According to Le Chatelier, if the equilibrium is disturbed the equilibrium will move in order to compensate for the change.
The increase in temperature will favour the endothermic reaction. ✓
In this reaction the endothermic reaction is the forward reaction ✓
Thus it will be favoured ✓
The [HI] will increase ✓ (4)

3.2. Remain the same ✓✓ (2)

3.3. A catalyst will not influence the yield or amount of product formed ✓
It will only increase the rate of the forward and reverse reactions simultaneously so that the reaction takes place faster. ✓ (2)

3.3. Remains the same ✓✓ (2)

Question 4

4.1.1. The concentration of nitrogen is increased (2)

4.1.2. The pressure on the system is increased (2)

4.1.3. The temperature is increased (2)

4.2. t_1 and t_2 (2)