13.2.1 t = 15 s
13.2.2 t = 75 s
13.2.3 t = 165 s (4)

13.3 Explain why the number of moles of each of the species in the mixture changed between t = 45 s and t = 105 s. (6)

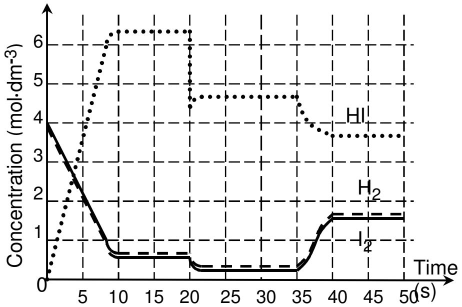
At t = 120 s the piston was pulled outwards and the volume doubled to 2 dm^3.
The reaction quickly reached equilibrium again at the same temperature.

13.4 Calculate the equilibrium constant using data for t = 165 s, and show that the value of K is still 0,20.(4)

13.5 Using data for t = 225 s, K is calculated as 0,31. What was done at t = 180 s that can account for the change in K, and the change in the number of moles of each species when equilibrium is re-established? Explain your answer. (5)

14 The graph shows the concentration of all three species of the system when plotted against time:

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



14.1 After how many seconds does the reaction reach equilibrium for the first time? (2)

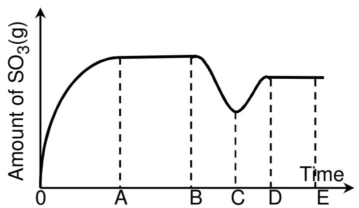
14.2 Write down the equilibrium expression for this reaction and calculate the equilibrium constant. (5)

14.3 Give an explanation for the change which occurs at t = 20 s. (2)

14.4 If the change at t = 35 s is due to a rapid increase in the temperature of the system, state whether the forward reaction is exothermic or endothermic. Give a reason for your choice. (5)

15 Consider the following reaction: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H < 0$

A graph of the **AMOUNT** of $SO_3(g)$ was plotted against time as shown:



15.1 How does the rate of the forward reaction compare to the rate of the reverse reaction during the following intervals: (Write down only **GREATER THAN**, **EQUAL TO** or **LESS THAN**.)

15.1.1 OA (2)
15.1.2 BC (2)
15.1.3 DE (2)

15.2 If the changes in the graph from B to D are due to changes in the **TEMPERATURE**, at which points (B, C or D) will the temperature be the lowest? (2)

15.3 Give an explanation for the answer to 15.2. (2)

15.4 At which point (B, C or D) will the K_c value be the **greatest**? (2)

15.5 Give an explanation for the answer to 15.4. (2)

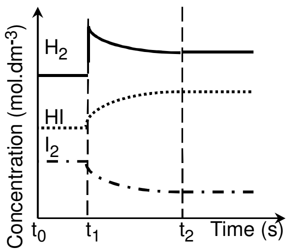
15.6 If the changes in the graph from B to D are due to **PRESSURE** changes, at which point (B, C or D) will the pressure be the **lowest**? (2)

15.7 Give an explanation for the answer to 15.6. (2)

16 Hydrogen and iodine are injected into a closed container at constant temperature. The reaction reaches equilibrium according to the following equation:

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

The graph illustrates changes that were then made to the equilibrium mixture.



16.1 What information about the reaction can be obtained from the graph between times t_0 and t_1? (1)

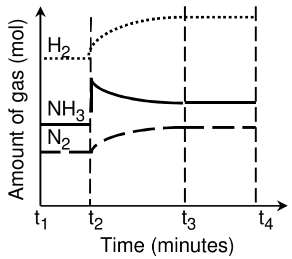
16.2 Describe all the changes that occurred in the system between t_1 and t_2. (4)

17 The following equation represents a reversible reaction that has reached equilibrium at 470 ºC in a closed container:

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

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 shown.
(The graph is not drawn to scale.)

Graph of amount of gas versus time



17.1 What is the meaning of the horizontal lines between t_1 and t_2? (1)

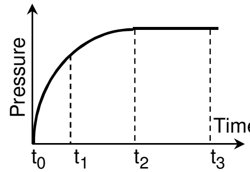
17.2 State the change that was made to the NH_3 in the mixture at time t_2. (1)

17.3 Explain how this change affected the concentration of N_2 and H_2 gases as shown in the graph. (3)

18 William wants to determine the equilibrium constant for the decomposition of calcium carbonate ($CaCO_3$). He seals 2,0 kg $CaCO_3$ 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 ºC at which equilibrium was reached according to the following equation:

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

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



18.1 How does the rate of the reverse reaction change from t_0 to t_1? (2)

18.2 What is the reason for the horizontal line between t_2 to t_3? (1)

18.3 Draw a sketch graph to show how the mass of $CaCO_3$ changes for the period t_0 to t_3. (4)

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

18.4.1 The rate forward reaction (1)
18.4.2 The concentration of CO_2 (1)
18.4.3 The value of K_c (1)

18.5 Give a reason for your answer to question 18.4.3. (4)

18.6 When equilibrium was established at 800 ºC, the concentration of CO_2 present in the flask was 1,4 x 10^{-10} $mol \cdot dm^{-3}$. Calculate the equilibrium constant (K_c) at 800 ºC for this reaction. (2)

Graphs of Rate/Time

- The forward reaction rate starts at a high value (because the concentration of reagents is initially high) and gradually decreases, while the reverse reaction rate starts at zero and gradually increases.
- Equilibrium is reached when the rates of the forward and reverse reactions are equal, i.e. where the two graphs coincide.
- At equilibrium the graphs are horizontal, because the rates remain the same.
- When **temperature**, **pressure** or **concentration** is increased, the **rates of both the forward and reverse reactions** will increase. But one will increase more than the other, i.e. it is **favoured**, which has to be determined using Le Chatelier's Principle.
- The addition of a **catalyst** causes both the forward and reverse reaction rates to increase by the same amount, e.g.