Question 32 **(14 marks)**

Ammonia is manufactured industrially by the Haber process, the reaction equation being:

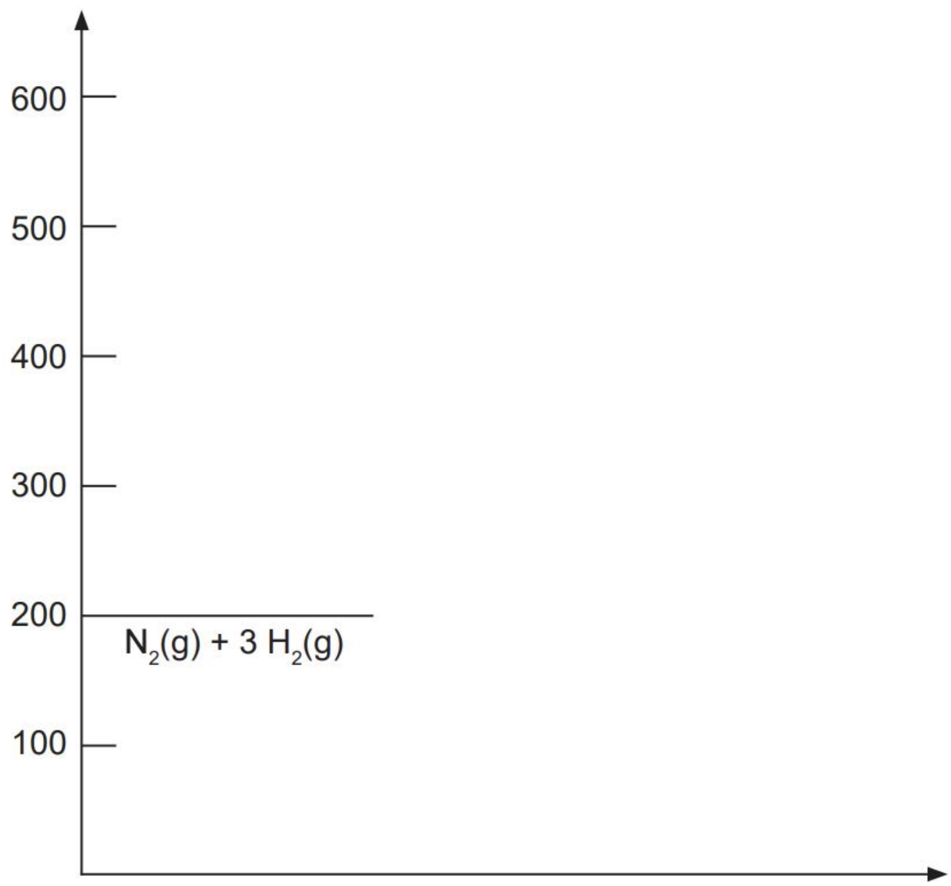
$$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g) + 92\ kJ$$

At 400 °C the equilibrium constant of this reaction is equal to 1.60×10^{-4} and the activation energy of the forward reaction is approximately 4.00×10^{2} kJ mol^{-1}.

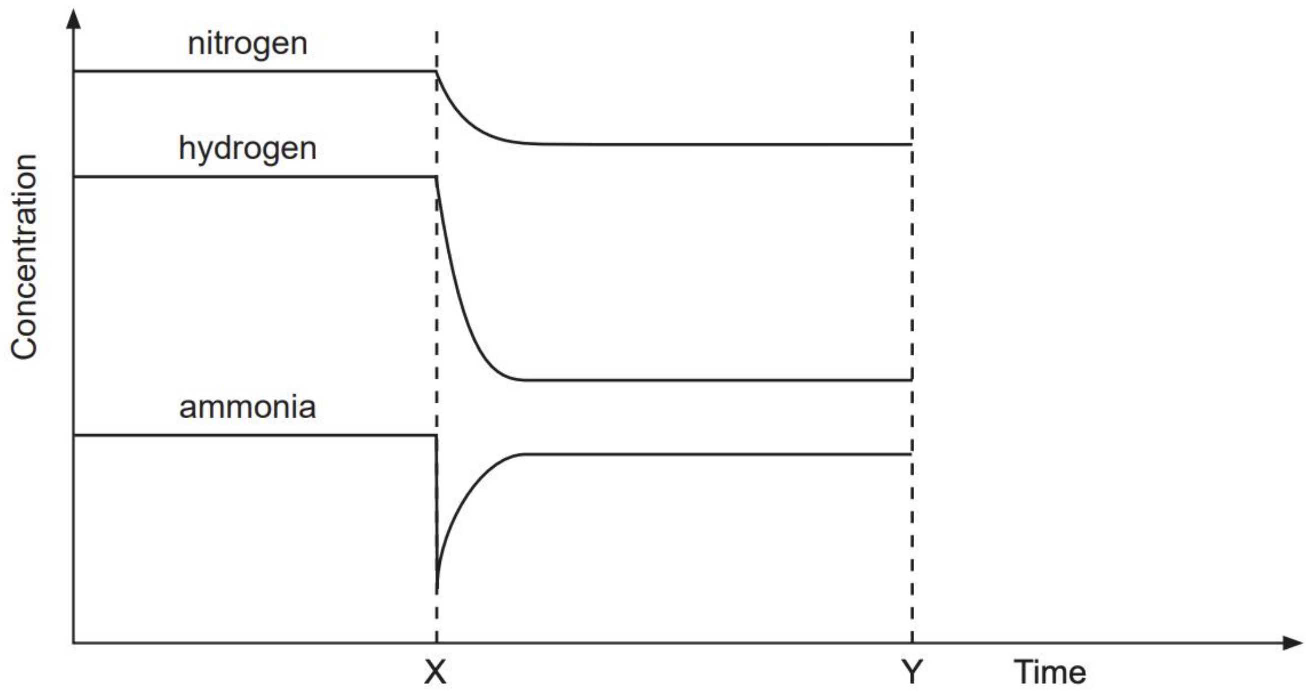
(a) Write the equilibrium constant expression for this reaction. (2 marks)

(b) Use the following axes to sketch an energy profile diagram for the Haber process. Label the:

- axes
- products
- activation energy
- change in enthalpy. (4 marks)



Some hydrogen, nitrogen and ammonia were sealed in a reaction vessel and their concentrations were monitored for a period of time, as shown in the following graph:



(c) A change was made to the reaction system at time X. Identify this change and use collision theory to explain the shapes of the curves in the region X–Y. (5 marks)

(d) The temperature of the reaction system was increased at time Y. Show on the graph how this affected the concentrations of hydrogen, nitrogen and ammonia as the system returned to equilibrium. (3 marks)