SL Paper 2

Consider the following equilibrium:

$$4\mathrm{NH_3(g)} + 5\mathrm{O_2(g)} \rightleftharpoons 4\mathrm{NO(g)} + 6\mathrm{H_2O(g)} \quad \Delta H^{\ominus} = -909\ \mathrm{kJ}$$

Nitrogen reacts with hydrogen to form ammonia in the Haber process, according to the following equilibrium.

$$\mathrm{N_2(g)} + 3\mathrm{H_2(g)} \rightleftharpoons 2\mathrm{NH_3(g)} \quad \Delta H^{\ominus} = -92.6\ \mathrm{kJ}$$

a.i. Deduce the equilibrium constant expression, K_c, for the reaction. [1]

a.ii. Predict the direction in which the equilibrium will shift when the following changes occur. [4]

The volume increases.

The temperature decreases.

$\mathrm{H_2O(g)}$ is removed from the system.

A catalyst is added to the reaction mixture.

b. Define the term *activation energy*, E_a. [1]

c. Nitrogen monoxide, NO, is involved in the decomposition of ozone according to the following mechanism. [2]

$$\begin{aligned} &\mathrm{O_3} \rightarrow \mathrm{O_2} + \mathrm{O\bullet} \\ &\mathrm{O_3} + \mathrm{NO} \rightarrow \mathrm{NO_2} + \mathrm{O_2} \\ &\mathrm{NO_2} + \mathrm{O\bullet} \rightarrow \mathrm{NO} + \mathrm{O_2} \\ \mathrm{Overall:}\quad &2\mathrm{O_3} \rightarrow 3\mathrm{O_2} \end{aligned}$$

State and explain whether or not NO is acting as a catalyst.

d.i. Define the term *endothermic reaction*. [1]

d.ii. Sketch the Maxwell-Boltzmann energy distribution curve for a reaction with and without a catalyst, and label both axes. [3]

e.i. Define the term *rate of reaction*. [1]

f. Iron, used as the catalyst in the Haber process, has a specific heat capacity of $0.4490\ \mathrm{J\,g^{-1}K^{-1}}$. If 245.0 kJ of heat is supplied to 8.500 kg of iron, initially at a temperature of 15.25 °C, determine its final temperature in K. [3]