1 When nitrogen and hydrogen react to form ammonia, the reaction can reach a dynamic equilibrium.

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

(a) Explain what is meant by a **dynamic equilibrium**.

(2)

(b) In industry, the reaction between nitrogen and hydrogen is affected by the conditions used.

(i) The pressure used is 250 atmospheres.
Explain how the use of a higher pressure would affect the equilibrium yield of ammonia.

(2)

(ii) The reaction between nitrogen and hydrogen to form ammonia is exothermic.
The temperature used is 450 °C.

Explain how the use of a lower temperature would affect the equilibrium yield of ammonia.

(2)

(iii) Even at 450 °C, the reaction is very slow.

State what is used in industry to overcome this problem.

(1)

.....

(c) (i) Calculate the minimum volume of hydrogen required to completely convert 1000 dm^3 of nitrogen into ammonia.

(1)

.....

.....

volume of hydrogen = ... dm^3

(ii) Ammonia is reacted with excess nitric acid, HNO_3, to make ammonium nitrate, NH_4NO_3.

$$NH_3 + HNO_3 \rightarrow NH_4NO_3$$

Calculate the mass of ammonium nitrate produced by the complete reaction of 34 g of ammonia.

(Relative atomic masses H = 1.0, N = 14, O = 16)

(3)

.....

.....

.....

.....

.....

.....

mass of ammonium nitrate produced = ... g

(Total for Question 1 = 11 marks)

2 Sulfur trioxide is produced by reacting sulfur dioxide with oxygen.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

(a) (i) This reaction takes place in industry at 1–2 atm pressure and can reach a dynamic equilibrium.

Explain the effect on the rate of attainment of equilibrium, if the process is carried out at a pressure higher than 1–2 atm.

(3)

.....

.....

.....

.....

.....

.....

(ii) What volume of oxygen, in cm^3, would react completely with 500 cm^3 sulfur dioxide?

(1)

☒ **A** 500

☒ **B** 500

☒ **C** 500

☒ **D** 500

(b) When there are alternative methods of producing a product, the final pathway is chosen by considering atom economy, cost of energy, yield of product and rates of reactions.

State another factor that should also be considered.

(1)

.....

*(c) The reaction between nitrogen and hydrogen is exothermic.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

If nitrogen and hydrogen were reacted at 150 atm pressure and 300 °C, without a catalyst, some ammonia would be formed.

In the Haber process a pressure of 150 atm and a temperature of 450 °C are used, in the presence of an iron catalyst.

Explain why the conditions used in the Haber process are better than the first set of conditions for the manufacture of ammonia.

(6)

(Total for Question 2 = 11 marks)

3 (a) Hydrogen reacts with oxygen to form water vapour.

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

If 200 cm^3 of hydrogen react completely with 100 cm^3 of oxygen, what is the maximum volume of water vapour formed, if all volumes are measured at the same temperature and pressure?

Put a cross (☒) in the box to show your answer.

(1)

☐ **A** 100 cm^3

☐ **B** 200 cm^3

☐ **C** 300 cm^3

☐ **D** 400 cm^3

(b) Zinc reacts with dilute hydrochloric acid to form zinc chloride and hydrogen.

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

Calculate the maximum volume of hydrogen formed, at room temperature and pressure, when 13.0 g of zinc reacts completely with excess hydrochloric acid.
(relative atomic mass: Zn = 65.0,
1 mol of any gas occupies 24 dm^3 at room temperature and pressure)

(2)

.....

.....

.....

.....

volume of hydrogen = ... dm^3

(c) In industry, ammonia is produced by the Haber process.

$$\text{nitrogen} + \text{hydrogen} \rightleftharpoons \text{ammonia}$$

(i) What is the source of the hydrogen used in the Haber process?

Put a cross (☒) in the box to show your answer.

(1)

☒ **A** air

☒ **B** reaction of zinc with dilute sulfuric acid

☒ **C** electrolysis of water

☒ **D** natural gas

(ii) When nitrogen reacts with hydrogen, the amount of ammonia gradually increases until it becomes constant.

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

Explain why the amount of ammonia remains constant.

(2)

.....

.....

.....

.....

*(d) The reaction between nitrogen and hydrogen is exothermic.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

If nitrogen and hydrogen were reacted at 90 atm pressure and 300 °C, without a catalyst, some ammonia would be formed eventually.

In the Haber process a pressure of 150 atm and a temperature of 450 °C are used, in the presence of an iron catalyst.

Explain, with reasons, why the Haber process conditions are better for the manufacture of ammonia.

(6)

(Total for Question 3 = 12 marks)

4 (a) Propene is a gaseous hydrocarbon.

Draw the structure of a molecule of propene, showing all bonds.

(2)

(b) Nitrogen reacts with hydrogen to form ammonia.

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

(i) Calculate the minimum volume of nitrogen, in dm^3, required to react completely with 1000 dm^3 of hydrogen.

All volumes are measured at the same temperature and pressure.

Put a cross (☒) in the box next to your answer.

(1)

☐ **A** 333 dm^3

☐ **B** 1000 dm^3

☐ **C** 3000 dm^3

☐ **D** 4666 dm^3

(ii) The minimum volumes of nitrogen and hydrogen that must react completely to form 5000 dm^3 of ammonia are calculated.

These volumes are mixed and left, under appropriate conditions, until the reaction reaches equilibrium.

Explain which gas or gases will be present when equilibrium is reached.

(2)

.....

.....

.....

.....

(iii) The Haber process is carried out under a pressure of about 200 atm.

Explain the effect on the **equilibrium yield** of ammonia, if the process is carried out at a pressure higher than 200 atm.

(2)

(iv) Explain the effect on the **rate of attainment of equilibrium**, if the process is carried out at a pressure higher than 200 atm.

(3)

(Total for Question 4 = 10 marks)