1 Iodine reacts with chlorine to form iodine monochloride, ICl

(a) Write a chemical equation for this reaction.

(1)

.....

(b) Iodine monochloride reacts reversibly with chlorine to form iodine trichloride.

$$\underset{\text{dark brown}}{ICl} + Cl_2 \rightleftharpoons \underset{\text{yellow}}{ICl_3}$$

The reaction mixture is allowed to reach a state of dynamic equilibrium.

(i) One feature of a reaction that is in dynamic equilibrium is that both the forward reaction and the backward reaction occur simultaneously.

Give two other features of a reaction that is in dynamic equilibrium.

(2)

1 .....

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2 .....

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(ii) When the equilibrium mixture is heated, it becomes darker brown in colour.

Explain whether the backward reaction is exothermic or endothermic.

(2)

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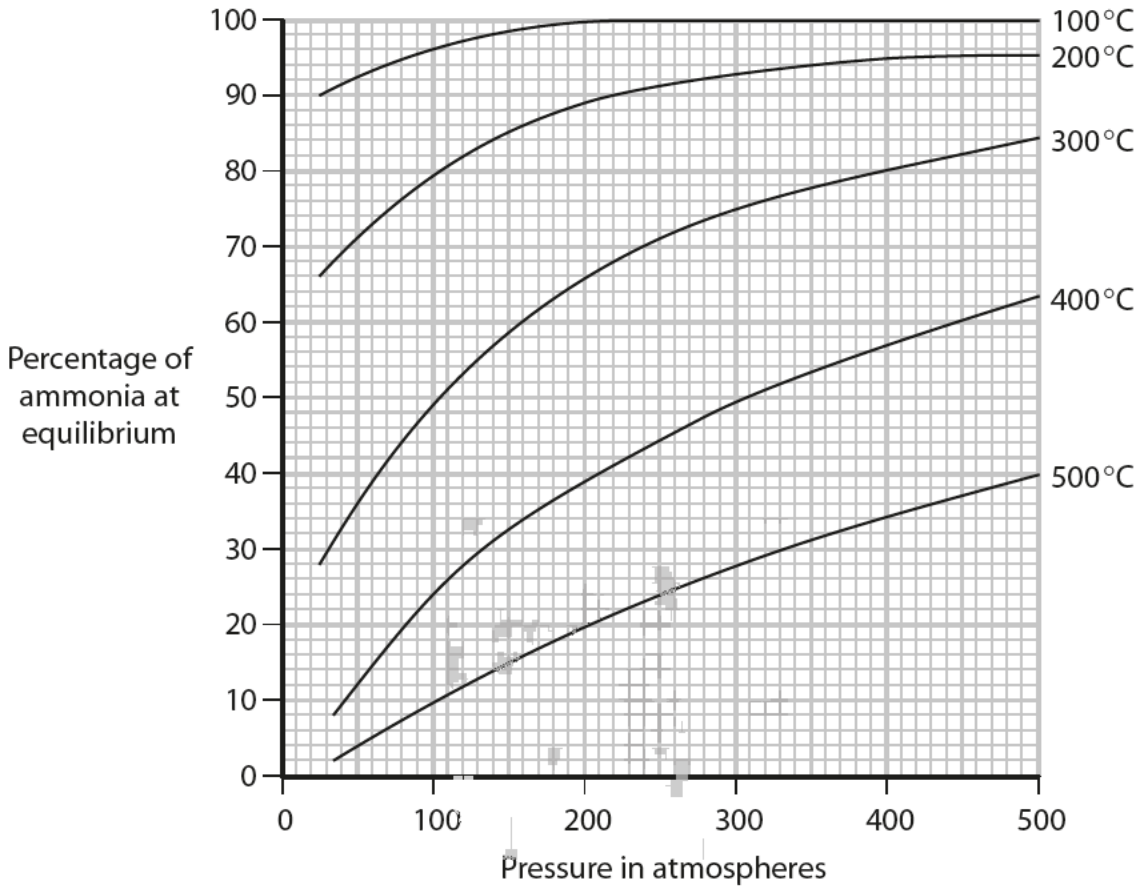
(Total for Question 1 = 5 marks)

2 Ammonia (NH_3) can be made by reacting nitrogen and hydrogen, in the presence of an iron catalyst, according to the equation

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\ kJ/mol$$

The reaction is reversible and the reaction mixture can, if left for long enough, reach a position of dynamic equilibrium.

The graph shows how the percentage of ammonia at equilibrium depends on the temperature and pressure used.



(a) State two features of a reaction mixture that is in dynamic equilibrium.

(2)

1 .....

.....

2 .....

.....

(b) (i) Use the graph to state the effect on the percentage of ammonia at equilibrium of the following changes

- an increase in temperature at constant pressure
- an increase in pressure at constant temperature.

Write your answers in the table.

(2)

	Effect on percentage of ammonia at equilibrium
increase in temperature	
increase in pressure	

(ii) Explain why these changes have the effects you have given in (b)(i).

(2)

Increase in temperature.....

.....

Increase in pressure.....

.....

(c) The reaction between nitrogen and hydrogen is used to manufacture ammonia in the Haber process. This process operates at a pressure of 200 atmospheres and a temperature of 450 °C, with an iron catalyst.

If the reaction mixture reached a position of equilibrium, the expected yield of ammonia would be about 30%.

The actual yield of ammonia obtained in the Haber process is about 15%.

(i) Suggest why the actual yield of ammonia is lower than the expected yield.

(1)

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(ii) How is the ammonia separated from the unreacted nitrogen and hydrogen?

(2)

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(iii) What happens to the unreacted nitrogen and hydrogen?

(1)

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(d) The reaction would be faster if a higher temperature were used.

Suggest why a higher temperature is not used in the Haber process.

(1)

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(e) The equation for the formation of ammonia is

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

(i) Calculate the amount, in moles, of ammonia, that could be formed in the Haber process from 112 kilograms of nitrogen, assuming all the nitrogen is converted into ammonia.

(3)

Amount of ammonia = ... mol

(ii) Only 15% of the nitrogen is converted into ammonia.

Calculate the actual amount, in moles, of ammonia that is formed from 112 kilograms of nitrogen.

(1)

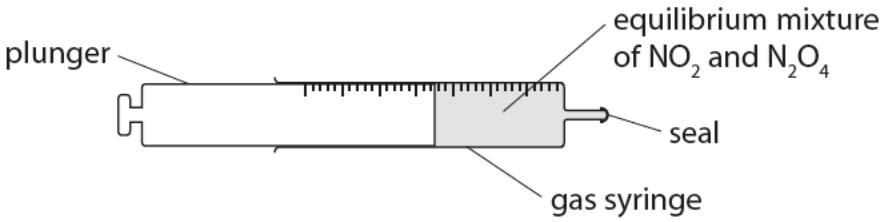
Amount of ammonia = ... mol

(Total for Question 2 = 15 marks)

3 Nitrogen dioxide (NO_2) and dinitrogen tetraoxide (N_2O_4) exist together in equilibrium.

$$\underset{\text{brown}}{2NO_2(g)} \rightleftharpoons \underset{\text{colourless}}{N_2O_4(g)}$$

(a) The gas syringe contains a sample of an equilibrium mixture of the two gases.
The mixture is brown in colour.



The plunger is pulled out to reduce the pressure of the gaseous mixture.
When the equilibrium is reached the mixture is darker in colour.

Explain this observation.

(3)

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(b) (i) A sealed tube containing an equilibrium mixture of NO_2 and N_2O_4 at room temperature is plunged into water at 0 °C. The colour of the mixture changes from brown to pale yellow.

Explain whether the forward reaction is exothermic or endothermic.

(2)

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(ii) In the forward reaction, a bond is formed between the two nitrogen dioxide molecules.

$$NO_2 + NO_2 \rightarrow O_2N{-}NO_2$$

Explain whether this information supports your answer in (b)(i).

(1)

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(Total for Question 3 = 6 marks)

4 Carbon monoxide and hydrogen are used in the manufacture of methanol (CH_3OH).

The reaction is reversible and can reach a position of dynamic equilibrium.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -91 \text{ kJ/mol}$$

The reaction is carried out at a pressure of about 100 atmospheres and a temperature of 250 °C.

(a) State two features of a reaction that is in dynamic equilibrium.

(2)

1 .....

.....

2 .....

.....

(b) (i) How would a decrease in temperature at constant pressure affect the amount of methanol in the equilibrium mixture?

Explain your answer.

(2)

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(ii) How would an increase in pressure at constant temperature affect the amount of methanol in the equilibrium mixture?

Explain your answer.

(2)

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(c) Methanol (CH_3OH) can be converted into methanal (H_2CO).

A mixture of methanol and oxygen is passed over an iron oxide catalyst at 250 °C.

Methanal and water are the only two products.

(i) Write a chemical equation for the conversion of methanol into methanal.

(2)

(ii) What is meant by the term **catalyst**?

(2)

(iii) Explain how a catalyst works.

(2)

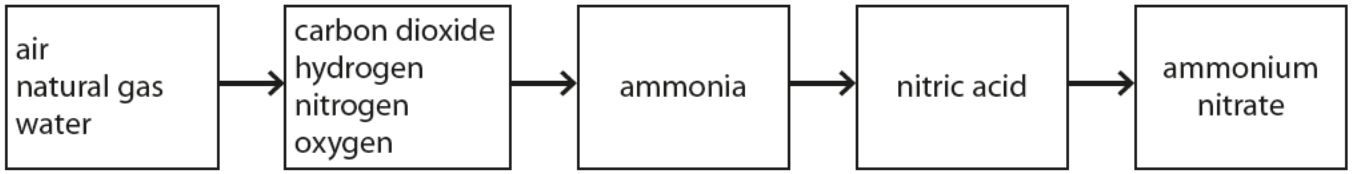
(d) Methanol can be used in racing cars as an alternative fuel to petrol.

Write the chemical equation for the complete combustion of methanol.

(2)

(Total for Question 4 = 14 marks)

5 The flow diagram shows how a fertiliser is manufactured from raw materials.



The hydrogen needed is formed in two reactions.

(a) Reaction 1 occurs between steam and methane in natural gas.

Balance the equation for this reaction.

(1)

..... CH_4 + ... H_2O → ..... CO + ... H_2

(b) The equation for reaction 2 is

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H = -41 \text{ kJ/mol}$$

(i) Assuming that this reaction reaches equilibrium, explain what happens to the yield of hydrogen if the reaction is carried out at a higher pressure but at the same temperature.

(2)

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(ii) Assuming that this reaction reaches equilibrium, explain what happens to the yield of hydrogen if the reaction is carried out at a higher temperature but at the same pressure.

(2)

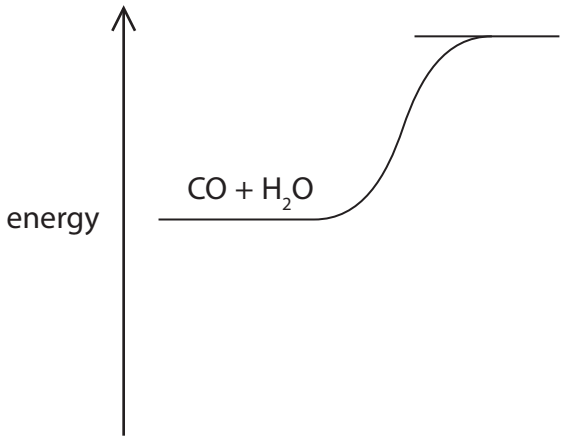
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(c) Reaction 2 can be represented on an energy profile.



(i) Complete the profile by showing the products of the reaction and the enthalpy change for the reaction.

(2)

(ii) Reaction 2 is carried out using an iron oxide catalyst.

State the effect, if any, of using a catalyst on the enthalpy change for the reaction.

(1)

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.....

(iii) Explain how a catalyst increases the rate of a reaction.

(2)

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(d) The equations for some other reactions used in the manufacture of ammonium nitrate are

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

reaction 4 $4NH_3 + 5O_2 \rightleftharpoons 4NO + 6H_2O$

reaction 5 $2NO_2 \rightleftharpoons N_2O_4$

reaction 6 $NH_3 + HNO_3 \rightarrow NH_4NO_3$

Explain which two of these are redox reactions.

(2)

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(e) The manufacturer produces a batch of 34 kg of ammonia.

Calculate the maximum mass of ammonium nitrate that can be made from this mass of ammonia, using reaction 6 in part (d).

Give a unit for your answer.

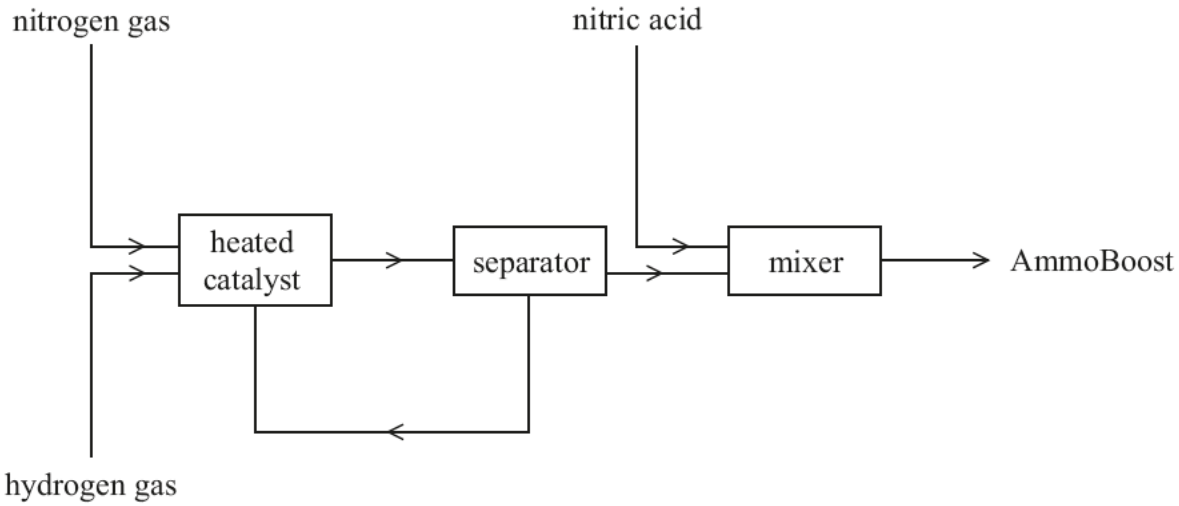
(3)

maximum mass of ammonium nitrate = ... unit .....

(Total for Question 5 = 15 marks)

6 AmmoFert Chemicals is a company that manufactures fertilisers.

The flow chart shows how the company manufactures a fertiliser called AmmoBoost.



(a) The first step in the process is the conversion of nitrogen gas and hydrogen gas into ammonia.

(i) State a raw material used as the source of each gas.

(2)

nitrogen .....

hydrogen .....

(ii) Identify the catalyst used in this conversion.

(1)

.....

(iii) State **one** other condition used in this conversion.

(1)

.....

(iv) Only a small percentage of the nitrogen gas and hydrogen gas is converted into ammonia.
Explain how the unreacted gases are separated from the ammonia.

(2)

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(b) The equation for the production of ammonia is

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H \quad 92 \text{ kJ/mol}$$

Calculate the maximum mass of ammonia that can be obtained from 56 tonnes of nitrogen.
(1 tonne 1 000 000 grams)

(3)

(c) EnAitchThree is another company that manufactures ammonia using the same reaction as AmmoFert but using different conditions.
EnAitchThree uses a higher temperature and a higher pressure than AmmoFert.

(i) Predict the effect on the rate of reaction and on the equilibrium position by changing to the temperature used by EnAitchThree.

(2)

Effect of higher temperature on rate of reaction

.....

.....

Effect of higher temperature on equilibrium position

.....

.....

(ii) Predict the effect on the equilibrium position by changing to the pressure used by EnAitchThree. Justify your prediction.

(2)

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(d) The main compound in AmmoBoost contains 35% nitrogen and 5% hydrogen by mass. The remainder is oxygen.

(i) Calculate the percentage by mass of oxygen in the compound.

(1)

(ii) Determine the empirical formula of the compound.

(3)

(iii) What is the **name** of the main compound in AmmoBoost?

(1)

.....

(Total for Question 6 18 marks)