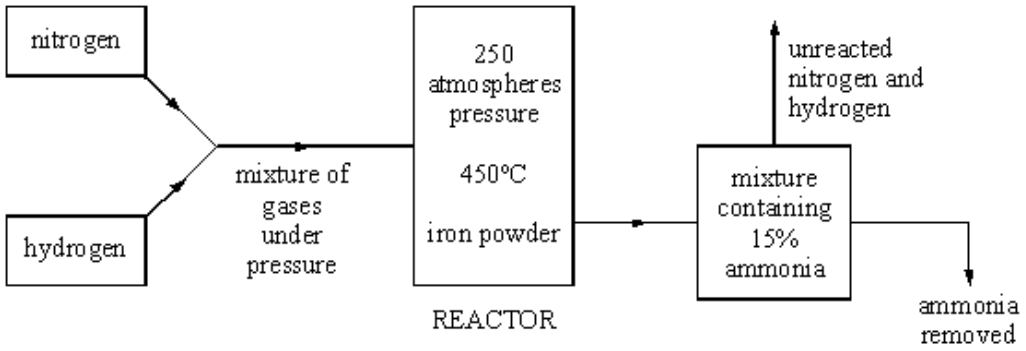
Q1. Ammonia is manufactured from nitrogen and hydrogen in the Haber Process. The diagram shows some details of the manufacturing process.



(a) Nitrogen is obtained from the air.
From where is the hydrogen obtained?

.....

(1)

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

.....

.....

(1)

(c) Ammonium nitrate is made from ammonia.

Farmers spread nitrates on to soil to make crops grow better.

The nitrates may get into people's bodies even if they do not eat the crops.

Explain how this can happen.

.....

.....

.....

(2)

(d) The equation for the Haber Process is this:

$$N_2 + 3H_2 \underset{\text{exothermic}}{\rightleftharpoons} 2NH_3$$

At equilibrium, nitrogen, hydrogen and ammonia are present in the reactor.

(i) What is meant by 'equilibrium'?

.....

.....

.....

(1)

(ii) Explain, as fully as you can, why:

- the yield of ammonia decreases with increase in temperature,
- despite this fact, a comparatively high temperature of 4500C is used for the industrial process,
- iron powder is added to the reactor.

.....

.....

.....

.....

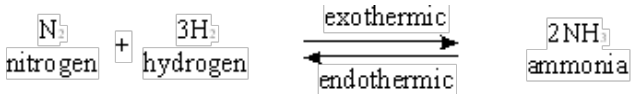
.....

.....

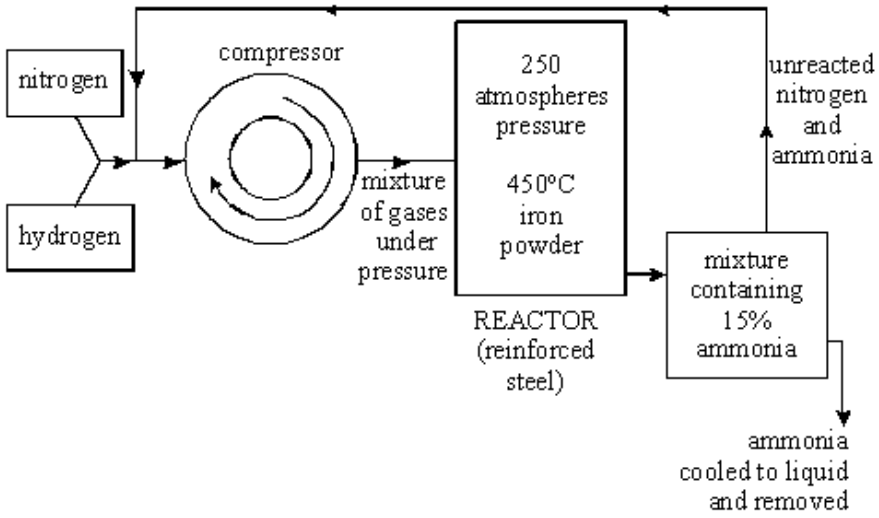
.....

(4)
(Total 9 marks)

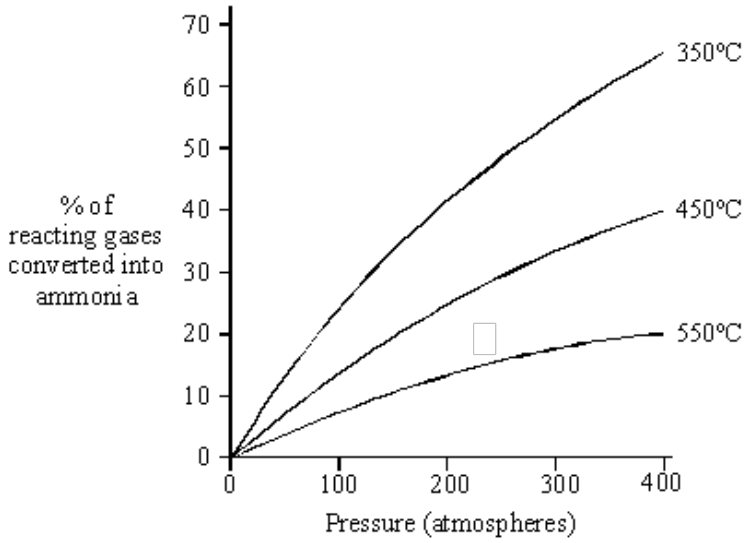
Q2. Ammonia is manufactured from nitrogen and hydrogen. The reaction is shown in the equation below.



The diagram shows some details of the manufacturing process.



The graph shows the percentage of reacting gases converted into ammonia at different temperatures and pressures.



At room temperature and pressure, the reaction is very slow and only a small percentage of the reacting gases is converted to ammonia.

Use the information on the diagram and graph to:

(a) describe the conditions used in the manufacture of ammonia **to increase the rate of reaction**.

.....

.....

.....

.....

.....

.....

(4)

(b) describe and explain the conditions used in the manufacture of ammonia **to increase the yield.**

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(7)

(Total 11 marks)

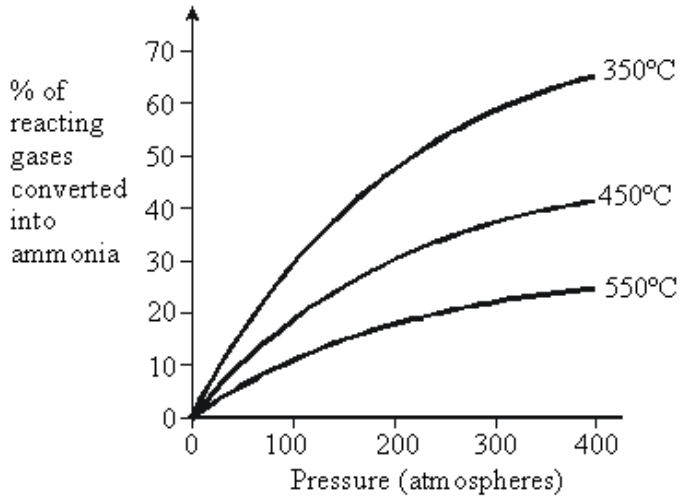
Q3. Ammonia is manufactured in the Haber Process, from nitrogen and hydrogen.

(a) Balance this symbol equation for the process.

$$N_2 + \quad H_2 \rightleftharpoons \quad NH_3$$

(2)

(b) The graph below shows the percentage of reacting gases converted into ammonia, at different temperatures and pressures.



(i) What does the graph suggest about the temperature and pressure needed to convert the maximum percentage of reacting gases into ammonia?

.....

.....

.....

(2)

(ii) Suggest reasons why the manufacture of ammonia in the Haber Process is usually carried out at about 400°C and 200 atmospheres pressure.

.....

.....

.....

(2)

(Total 6 marks)

Q4. (a) Ammonia is manufactured from nitrogen and hydrogen. The equation for the reaction between them is:

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

(i) What is the source of the nitrogen?

.....

(1)

(ii) Why does increasing the pressure increase the chance of molecules of hydrogen reacting with molecules of nitrogen?

.....

.....

(1)

(iii) The percentage yield of ammonia is the percentage, by mass, of the nitrogen and hydrogen which has been converted to ammonia. Calculate the mass, in tonnes, of ammonia which can be produced from 90 tonnes of hydrogen when the percentage yield is 50%. The relative atomic masses are: H 1; N 14.

Show clearly how you get to your answer.

.....

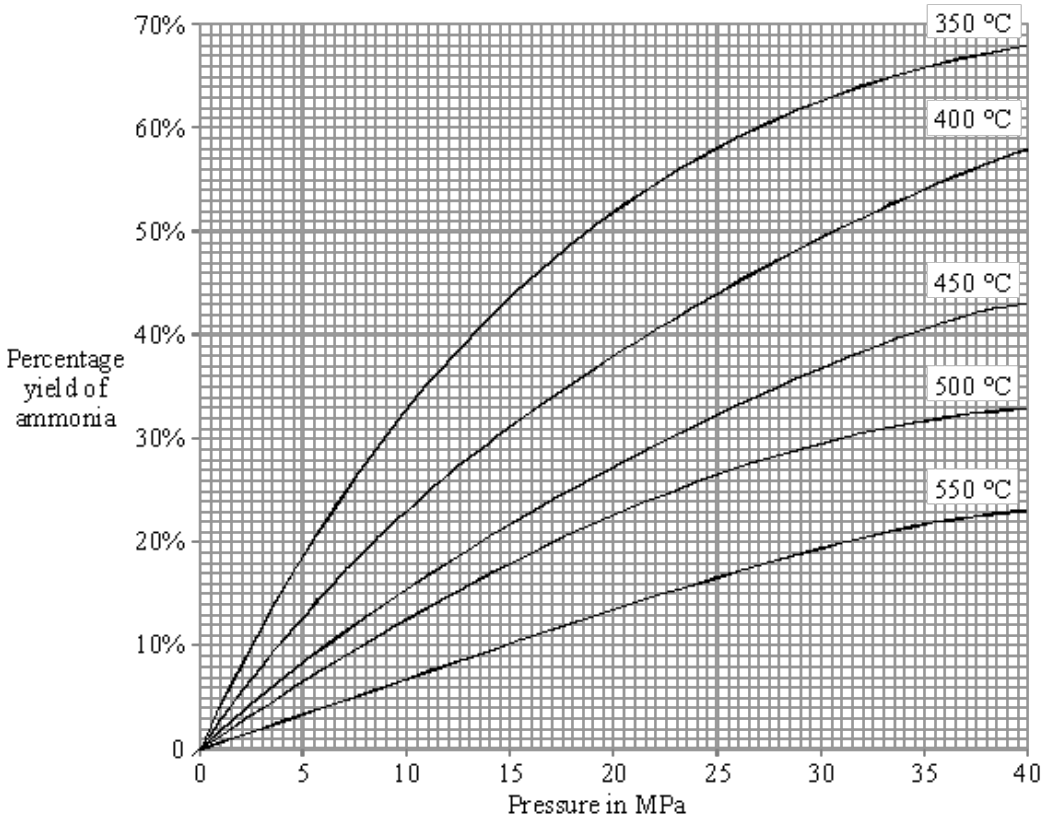
.....

.....

Mass = ... tonnes

(2)

(b) The percentage yield of ammonia depends on the temperature and pressure inside the reaction vessel. The set of graphs show this.



(i) MPa is the symbol for which unit?

.....

(1)

(ii) What is the percentage yield of ammonia produced at a temperature of 450 °C and a pressure of 20 MPa?

.....

(1)

(iii) Suggest what changes the chemical engineers should make to both the temperature and the pressure to **increase** the percentage yield of ammonia.

Temperature .....

Pressure .....

(1)

(iv) How can the rate of ammonia production be increased without changing the temperature or pressure or the mass of hydrogen and nitrogen?

.....

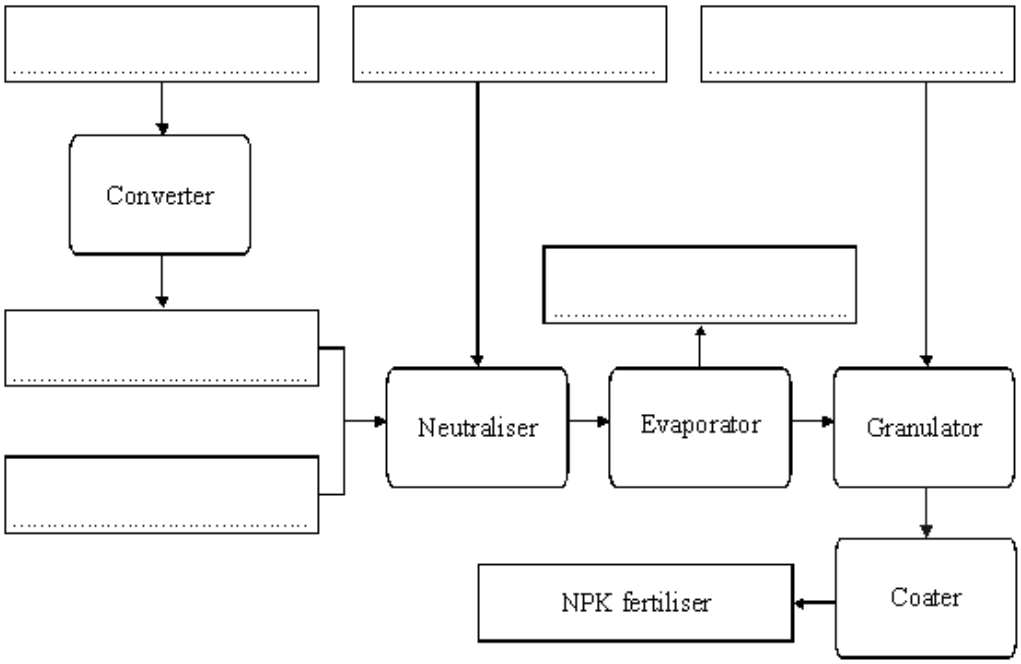
.....

(1)

(c) About four-fifths of ammonia production is used to produce fertilisers. One of them is known as NPK. It is made in the following way.

- Some ammonia is converted to nitric acid which is then mixed with phosphoric acid.
- The mixture is neutralised with more ammonia and the solution is partly evaporated.
- Potassium chloride is added to form granules.
- The granules are coated to make the fertiliser free-flowing.

Complete the flow-chart for the production of NPK by writing in the names of the correct chemicals in the **six** boxes.



(2)

(Total 10 marks)

Q5. (a) In industry ammonia is produced from nitrogen and hydrogen. The equation for the reaction is:

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

(i) What does the symbol (g) represent?

.....

(1)

(ii) What does the symbol $\rightleftharpoons$ represent?

.....

(1)

(iii) Nitrogen is used for the industrial production of ammonia. From what raw material does this nitrogen come?

.....

(1)

(iv) Hydrogen is used for the industrial production of ammonia. It is obtained from the reaction between methane and steam. The equation for this reaction is:

$CH_4 + H_2O \rightarrow 3H_2 + CO$

Explain how you can tell that this equation is balanced.

.....

.....

.....

.....

(2)

(b) Ammonia is used to make ammonium salts which can be used as fertilisers.

(i) Complete the names in the following sentence.

One example is ammonium ..... which is made by reacting ammonia with ..... acid.

(2)

(ii) All ammonium salts are soluble in water. Why is this a useful property of a fertiliser?

.....

.....

(1)

(c) Ammonia is a covalent, chemical compound.

(i) Complete the following sentence to describe a chemical compound.

In a chemical compound, two or more .....

.....

.....

(1)

(ii) What is a covalent bond?

.....

.....

(1)

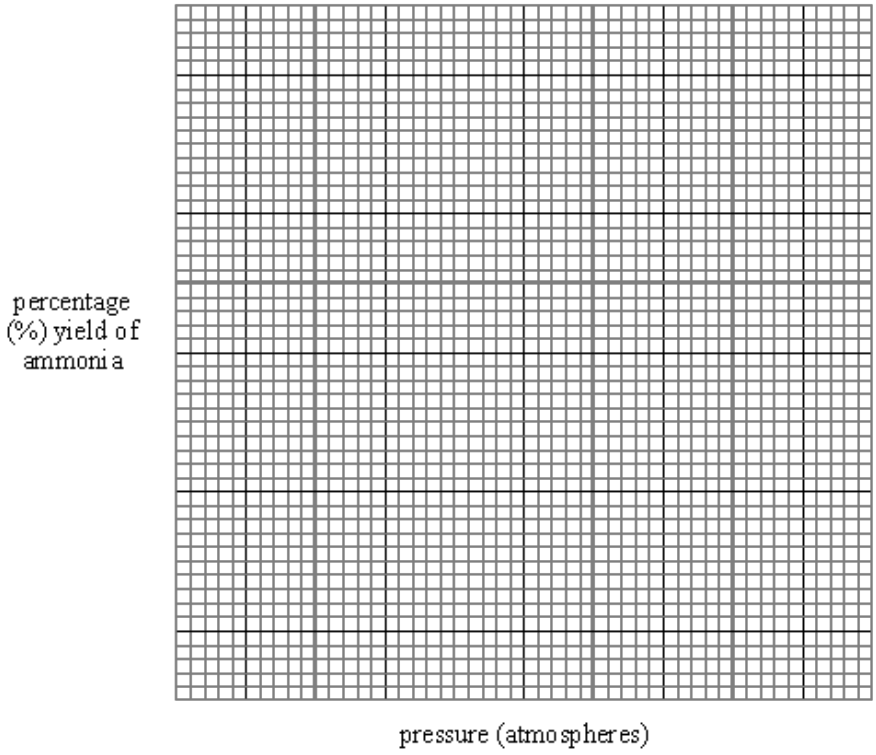
(Total 10 marks)

Q6. The Haber process is used to make ammonia NH_3.

The table shows the percentage yield of ammonia at different temperatures and pressures.

PRESSURE (ATMOSPHERES)	PERCENTAGE (%) YIELD OF AMMONIA AT 350°C	PERCENTAGE (%) YIELD OF AMMONIA AT 500°C
50	25	5
100	37	9
200	52	15
300	63	20
400	70	23
500	74	25

(a) (i) Use the data in the table to draw two graphs on the grid below. Draw one graph for a temperature of 350°C and the second graph for a temperature of 500°C.
Label each graph with its temperature.



(4)

(ii) Use your graphs to find the conditions needed to give a yield of 30% ammonia.

..... °C and ..... atmospheres

(1)

(iii) On the grid sketch the graph you would expect for a temperature of 450°C.

(1)

(b) (i) This equation represents the reaction in which ammonia is formed.

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)} + \text{heat}$$

What does the symbol $\rightleftharpoons$ in this equation tell you about the reaction?

.....

(1)

(ii) Use your graphs and your knowledge of the Haber process to explain why a temperature of 450°C and a pressure of 200 atmospheres are used in industry.

.....

.....

.....

.....

.....

.....

(5)

(c) (i) Ammonium nitrate is one type of artificial fertiliser.
Calculate the relative formula mass of ammonium nitrate NH_4NO_3.
(Relative atomic masses: H = 1, N = 14, O = 16.)

.....

.....

(1)

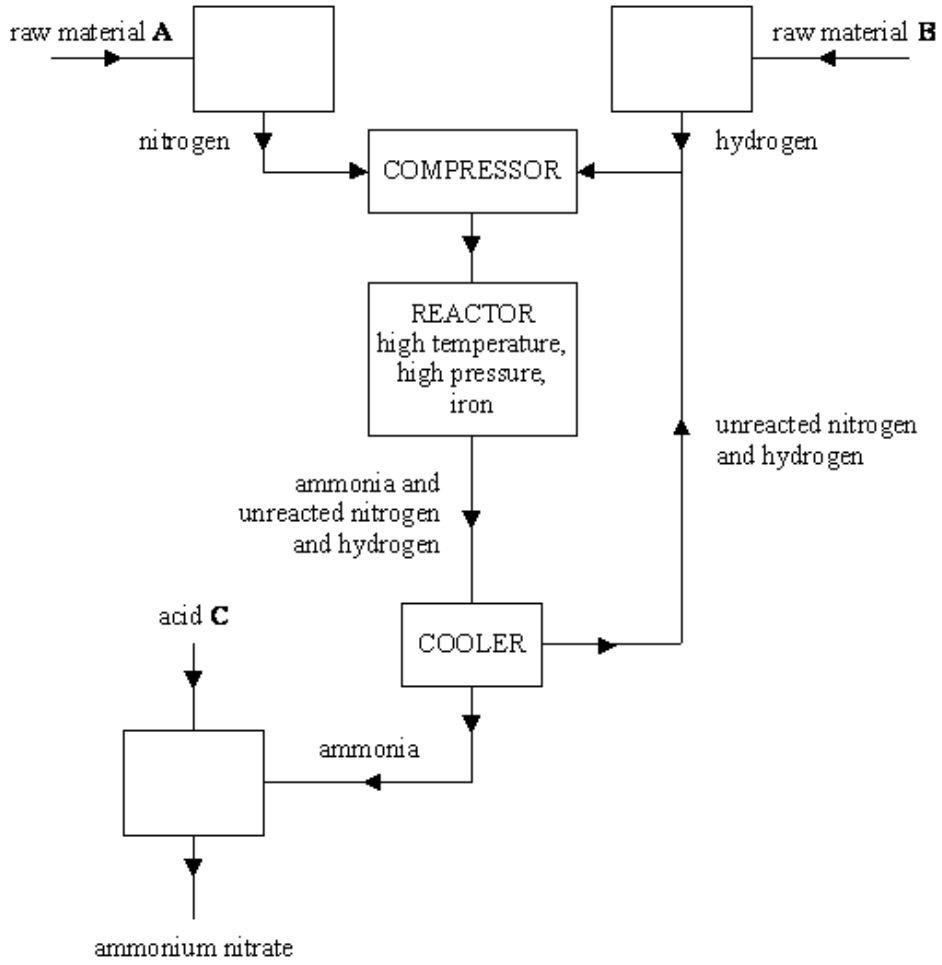
(ii) Use your answer to part (c)(i) to help you calculate the percentage by mass of nitrogen present in ammonium nitrate NH_4NO_3.

.....

.....

(2)
(Total 15 marks)

Q7. The flow chart below shows the main stages in the production of ammonium nitrate.



(a) (i) Name the two raw materials shown in the flow chart as **A** and **B**.

Raw material **A** .....

Raw material **B** .....

(2)

(ii) What is the purpose of the iron in the reactor?

.....

.....

(1)

(b) (i) Balance the equation which represents the reaction which produces ammonia in the Haber process.

N_2 + ... H_2 $\rightleftharpoons$ ..... NH_3 and heat

(1)

(ii) The table shows how temperature and pressure affect the amount of ammonia produced in this reaction.

TEMPERATURE (°C)	PRESSURE (ATM)	PERCENTAGE OF NITROGEN AND HYDROGEN CONVERTED TO AMMONIA (%)
250	200	75
250	1000	96
1000	1	0.01
1000	1000	1

Explain, as fully as you can, why a temperature of about 450°C and a pressure of about 200 atmospheres are normally used in the industrial process.

.....

.....

.....

.....

.....

.....

.....

.....

.....

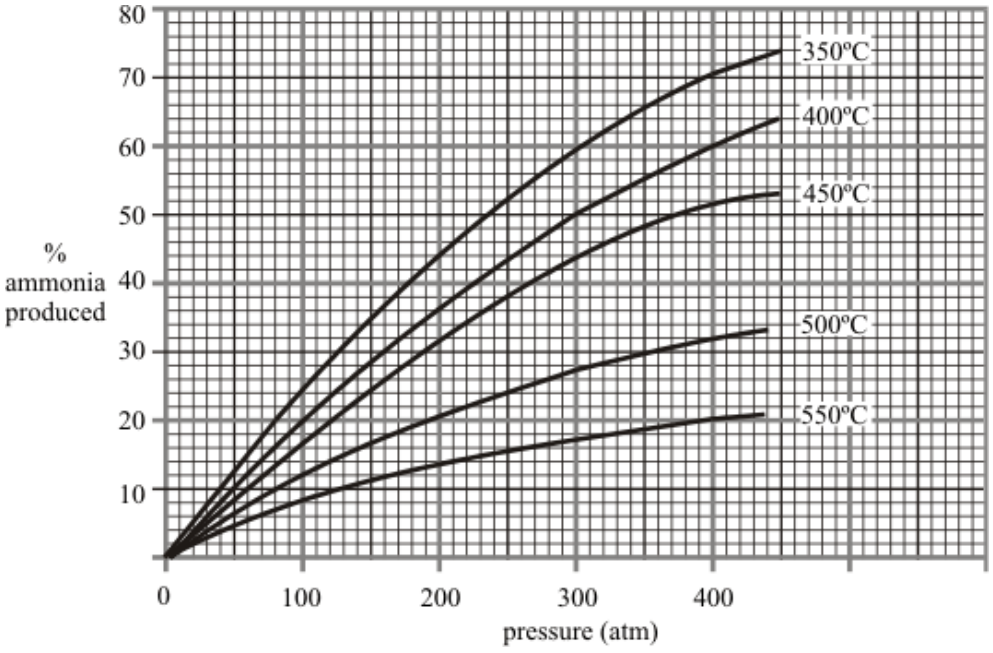
(6)

(Total 10 marks)

Q8. Ammonia is produced by the Haber process. In the process nitrogen and hydrogen are mixed. The pressure is increased to about 200 atmospheres. The gases are passed over an iron catalyst at about 450°C. The equation for the reaction is:

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

The reaction between nitrogen and hydrogen is reversible. This affects the amount of ammonia that it is possible to obtain from the process. The graph below shows how the pressure and temperature affect the percentage of ammonia that can be produced.



Use this information, together with your knowledge of the process, to explain why many industrial ammonia plants operate at 200 atmospheres and 450°C.

.....

.....

.....

.....

.....

.....

.....

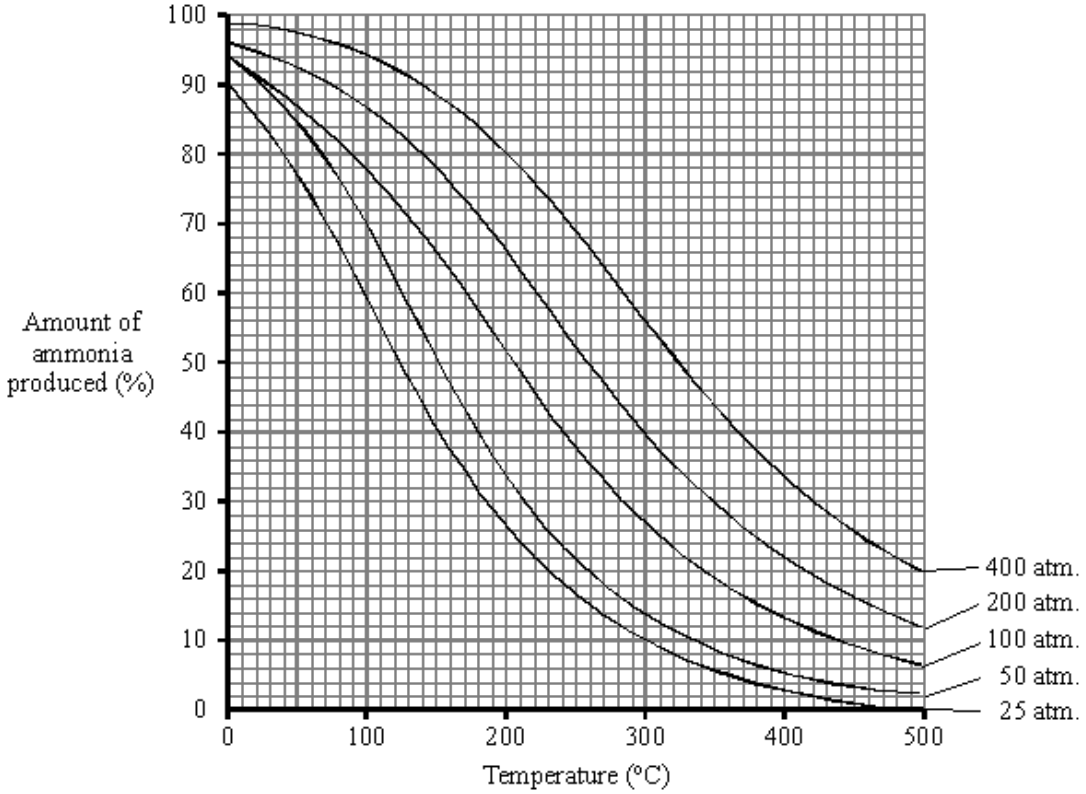
(Total 5 marks)

Q9. The Haber process is used to make ammonia (NH_3) which is an important substance.

The equation below shows the reaction in which ammonia is formed.

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)} + \text{Heat}$$

The graph below shows how temperature and pressure affect how much ammonia is produced in the reaction.



In the industrial process a mixture of nitrogen and hydrogen is passed over iron at a temperature of about 450 °C and 200 atmospheres pressure.

(a) Use the graph to find the percentage of ammonia present when the temperature and pressure are 450 °C and 200 atmospheres.

..... %

(2)

(b) Explain why the nitrogen and hydrogen mixture is passed over iron.

.....

.....

(2)

(c) Explain, as fully as you can, using the graph and your knowledge of the Haber process why 450 °C and 200 atmospheres were chosen as conditions for this process.

.....

.....

.....

.....

.....

(8)

(Total 12 marks)

Q10. Early atmospheres on Earth contained ammonia (NH_3).

(a) (i) Complete the sentence.

Our atmosphere today is made up of about ..... % nitrogen.

(1)

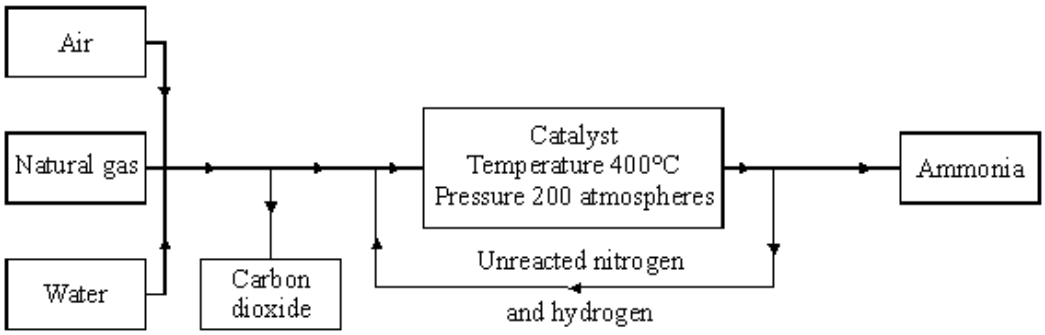
(ii) Today we convert nitrogen back to ammonia mainly for the production of fertilisers. What do plants convert the nitrogen in these fertilisers into?

.....

.....

(1)

(b) The conversion of nitrogen to ammonia is shown.



(i) When making ammonia, what is **one** source of hydrogen?

.....

(1)

(ii) Apart from ammonia, name **one** other product formed during this conversion.

.....

(1)

(c) The main reaction is the formation of ammonia from nitrogen and hydrogen.

(i) Complete and balance the equation for this reaction.

.....(g) + ...(g) → .....NH_3(g)

(2)

(ii) Name the metal catalyst used in this reaction.

.....

(1)

(iii) This reaction does not work successfully at room temperature (20 °C) and needs a much higher temperature of 400 °C. Explain why.

.....

.....

.....

(2)

(d) Draw a diagram to show the arrangement of the electrons in a molecule of ammonia. The electron arrangement of each atom is hydrogen 1 and nitrogen 2.5.

(2)
(Total 11 marks)

Q11. Transition metals are useful as catalysts. Iron is used as a catalyst in the manufacture of ammonia.

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

(i) What is meant by $\rightleftharpoons$ in the chemical equation?

.....

.....

(1)

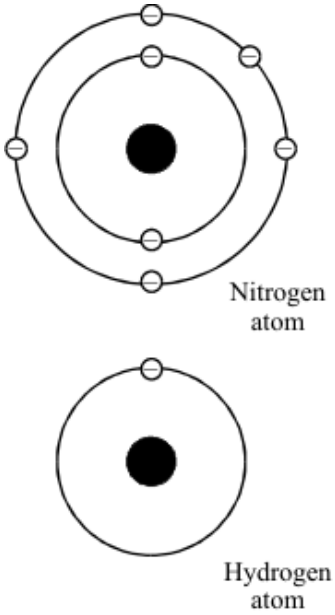
(ii) What would be the effect on the yield of ammonia if the pressure was increased?

.....

.....

(1)

(iii) Draw a diagram to show the arrangement of the electrons in a molecule of ammonia. The electron arrangement of each atom is shown.



(1)
(Total 3 marks)

Q12. The monomer chloroethene is made from ethene in a two-stage process,

(a) The first stage is to convert ethene to 1,2-dichloroethane.

$$2C_2H_4(g) + 4HC1(g) + O_2(g) \rightleftharpoons 2C_2H_4Cl_2(g) + 2H_2O(g)$$

ethene 1,2-dichloroethane

State and explain the effect of increasing the pressure on:

(i) the yield of 1,2-dichloroethane;

.....

.....

(2)

(ii) the rate of reaction.

.....

.....

(2)

(b) In the second stage 1,2-dichloroethane is converted into chloroethene.

$C_2H_4C1_2 \rightarrow C_2H_3C1 + HCl$

This reaction is a thermal decomposition.

Suggest what would need to be done to decompose 1,2-dichloroethane.

.....

.....

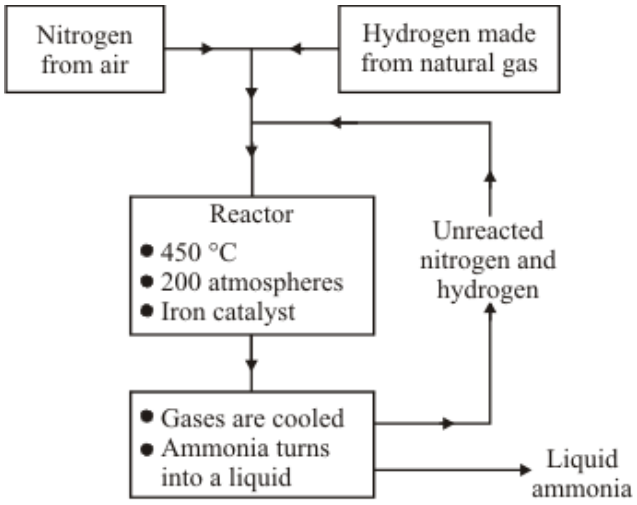
(1)

(Total 5 marks)

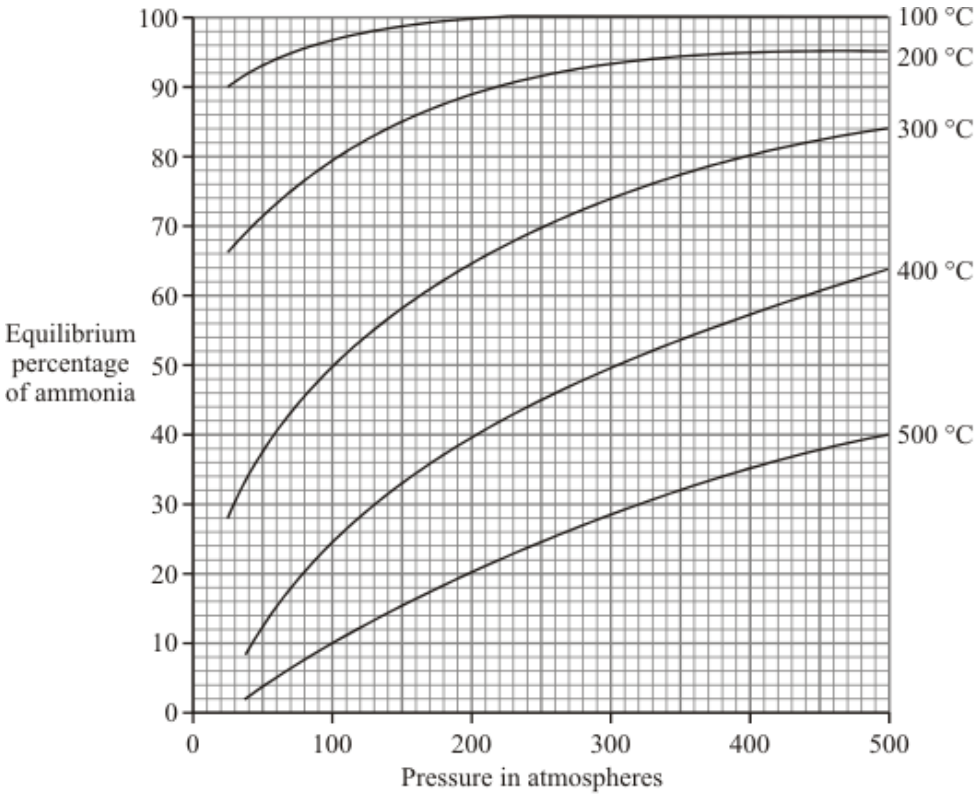
Q13. Ammonia is made from nitrogen and hydrogen in the Haber process.

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

Flow Chart for the Haber Process



Effect of temperature and pressure on the amount of ammonia at equilibrium



(a) Use the information given above and your knowledge of the Haber process and reversible reactions to help you to answer this question.

State which conditions of temperature and pressure would give the highest percentage of ammonia at equilibrium. Explain why.

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(b) The Haber process uses a temperature of 450 °C and a pressure of 200 atmospheres.

Explain why these conditions are chosen.

.....

.....

.....

.....

.....

.....

(3)

(Total 7 marks)

Q14. The reaction of methane with steam is used in industry to make hydrogen.

(a) One of the reactions in this process is represented by this equation.

$CH_4(g) + H_2O \rightleftharpoons CO(g) + 3H_2(g)$

The forward reaction is endothermic.

State the conditions of temperature and pressure that would give the maximum yield of hydrogen.

Explain your answers.

(i) Temperature

.....

.....

.....

.....

(2)

(ii) Pressure

.....

.....

.....

.....

(2)

(iii) Which one of the following metals is most likely to be a catalyst for this process? Draw a ring around your answer.

aluminium **lead** **magnesium** **nickel** **sodium**

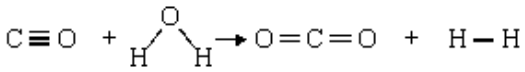
Give a reason for your choice.

.....

.....

(1)

(b) A second stage in this process is represented by this equation.



(i) Use the bond energies given in the table to help you to calculate the nett energy transfer (energy change) for this reaction.

Bond	Bond energy in kJ/mol
C ≡ O	1077
C = O	805
H – H	436
O – H	464

.....

.....

.....

.....

.....

.....

Nett energy transfer = ... kJ/mol

(3)

(ii) State whether this reaction is exothermic or endothermic. .....

Explain, by reference to your calculation, how you know.

.....

.....

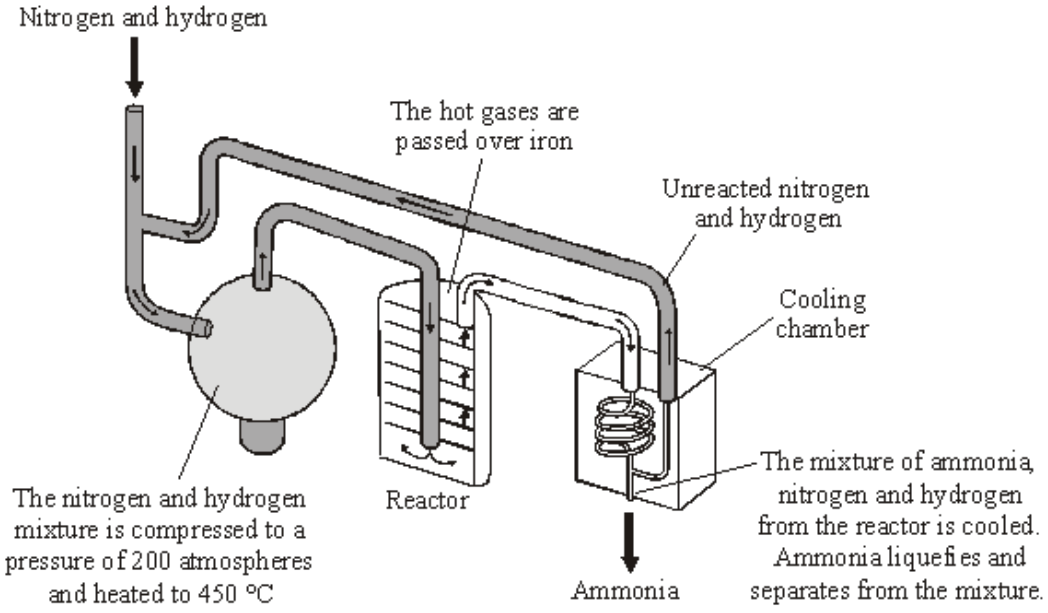
.....

.....

(2)
(Total 10 marks)

Q15. The Haber process is named after the German chemist, Fritz Haber.

The diagram shows the main stages in the Haber process.



An exothermic reaction takes place when nitrogen reacts with hydrogen to make ammonia.

The reaction can be represented by this equation.

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

(a) Calculate the maximum mass of ammonia that could be made from 1000 g of nitrogen.

Relative atomic masses: H = 1; N = 14

.....

.....

.....

.....

Mass .....g

(3)

(b) At a temperature of 450 °C and 200 atmospheres the actual mass of ammonia produced when 1000 g of nitrogen is passed through the reactor is 304 g.

Calculate the percentage yield of ammonia produced in the reactor.

(If you did not answer part (a), then assume that the maximum mass of ammonia that can be made from 1000 g of nitrogen is 1100 g. This is **not** the correct answer to part (a).)

.....

.....

.....

.....

.....

Percentage yield of ammonia = ... %

(2)

(c) State **and** explain:

(i) how a **decrease** in temperature would affect the yield of ammonia

.....

.....

.....

.....

(2)

(ii) how an **increase** in pressure would affect the yield of ammonia.

.....

.....

.....

.....

(2)

(d) Factories that make ammonia are often near to large towns.

Discuss the economic, safety and environmental factors to be considered when there is an ammonia factory near a town.

.....

.....

.....

.....

.....

.....

.....

(3)

(Total 12 marks)

Q16. Methanol is a fuel that is used in some racing cars instead of petrol.

Methanol can be made from carbon monoxide and hydrogen. The equation for this reaction is shown below.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

The forward reaction is exothermic.

(a) A high pressure (between 50 and 100 atmospheres) is used in this process.

Explain why the highest equilibrium yield of methanol is obtained at high pressure.

.....

.....

(1)

(b) The temperature used in this process is about 250 °C.

It has been stated that, 'the use of this temperature is a compromise between the equilibrium yield of product and the rate of reaction'.

Explain this statement.

.....

.....

.....

.....

.....

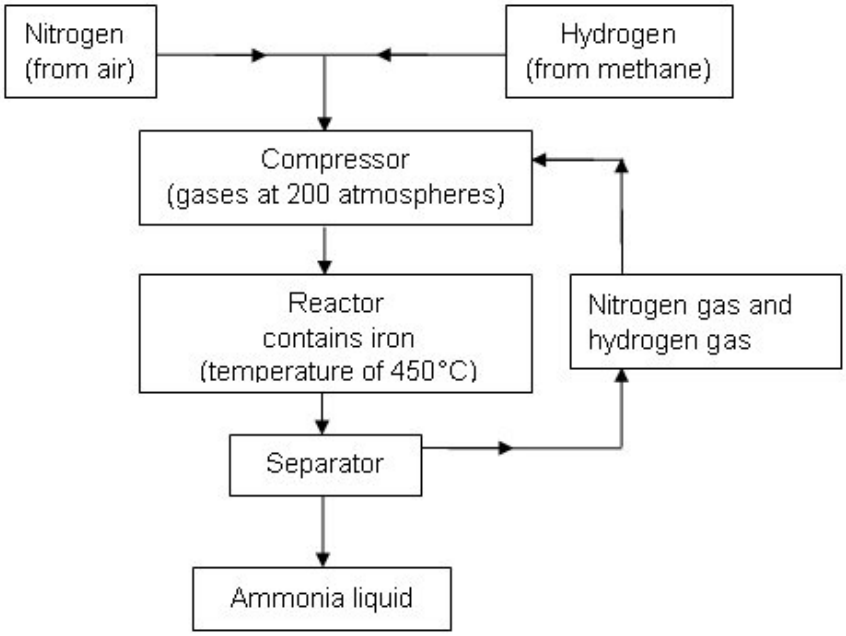
.....

(3)

(Total 4 marks)

Q17. Ammonia is used in the production of fertilisers. The flow diagram shows the main stages in the manufacture of ammonia.

Study the flow diagram and then answer the questions.



(a) What is the purpose of the iron in the reactor?

.....

.....

(1)

(b) In the reactor the equation to produce ammonia is:

$$N_2(g) + 3H_2(g) \underset{\text{endothermic}}{\overset{\text{exothermic}}{\rightleftharpoons}} 2NH_3(g)$$

(i) The equation shows that the reaction is reversible.

Explain how the reaction reaches an equilibrium.

.....

.....

(1)

(ii) The best yield of ammonia at equilibrium is produced at a low temperature.

Explain why.

.....

.....

.....

.....

(2)

(iii) The best yield of ammonia at equilibrium is produced at a high pressure.

Explain why.

.....

.....

(1)
(Total 5 marks)

Q18. The equation for a reaction to produce hydrogen is:

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

(a) Explain why changing the pressure does **not** affect the yield of hydrogen at equilibrium.

.....

.....

(1)

(b) Suggest why the best yield of hydrogen at equilibrium is obtained at **low** temperatures.

.....

.....

(1)

(c) The temperature used in industry needs to be high enough for the reaction to take place quickly. Explain, in terms of particles, why the rate of reaction increases when the temperature is increased.

.....

.....

.....

.....

.....

.....

(3)

(d) Scientists have developed catalysts which allow the reaction to take place quickly at lower temperatures. How could this be good for the manufacturer and for the environment?

.....

.....

.....

.....

(2)
(Total 7 marks)

Q19. Humberstone was a town in the desert of Northern Chile in South America. It was built for the people who worked in the nearby sodium nitrate mines.

The sodium nitrate was used as a fertiliser.

The sodium nitrate was exported by ship to countries all around the world.

Today the mines have closed and nobody lives in Humberstone.

One of the reasons for the mines closing was the invention of the Haber process.

By Sznegra (Own work) [CC-BY-SA-3.0], via Wikimedia Commons

(a) The Haber process is used to make ammonia (NH_3).

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

The forward reaction is exothermic.

(i) Name the raw materials that are used to supply the nitrogen and hydrogen.

Nitrogen .....

Hydrogen .....

(2)

(ii) The Haber process uses a temperature of 450 °C.

Explain, as fully as you can, why a temperature of 450 °C is used rather than a much higher temperature or a much lower temperature.

.....

.....

.....

.....

.....

.....

.....

.....

(3)

(iii) Ammonia can be converted to ammonium nitrate by adding an acid.

Name this acid.

.....

(1)

(b) Suggest and explain why the invention of the Haber process caused the closure of the Humberstone mines in Chile.

.....

.....

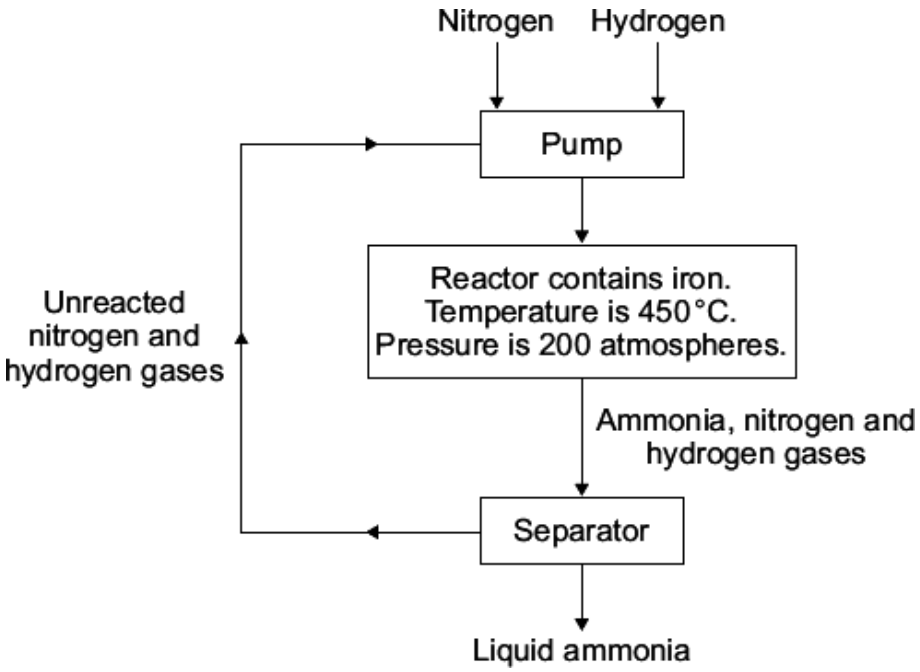
.....

.....

.....

(2)
(Total 8 marks)

Q20. Ammonia is made using the Haber process.



(a) How is ammonia separated from unreacted nitrogen and hydrogen in the separator?

.....

.....

.....

.....

(2)

(b) The equation shows the reaction which takes place in the reactor:

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

(i) Why does the yield of ammonia at equilibrium increase as the temperature is decreased?

.....

.....

(1)

(ii) A temperature of 450 °C is used in the reactor to make the reaction take place quickly.

Explain, in terms of particles, why increasing the temperature makes a reaction go faster.

.....

.....

.....

.....

(2)

(iii) Why does the yield of ammonia at equilibrium increase as the pressure is increased?

.....

.....

(1)

(iv) The pressure used in the reactor is 200 atmospheres.
Suggest why a much higher pressure is **not** used.

.....

.....

(1)

(c) Use the equation for the reaction in the reactor to help you to answer these questions.

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

(i) It is important to mix the correct amounts of hydrogen and nitrogen in the reactor.

20 m^3 of nitrogen is reacted with hydrogen.

What volume of hydrogen (measured at the same temperature and pressure as the nitrogen) is needed to have the correct number of molecules to react with the nitrogen?

Volume of hydrogen needed = ... m^3

(1)

(ii) Calculate the maximum mass of ammonia that can be made from 2 g of nitrogen.

Relative atomic masses: H = 1; N = 14.

.....

.....

.....

.....

.....

.....

Maximum mass of ammonia = ... g

(3)

(d) The expected maximum mass of ammonia produced by the Haber process can be calculated.

(i) In one process, the maximum mass of ammonia should be 80 kg.

The actual mass of ammonia obtained was 12 kg.

Calculate the percentage yield of ammonia in this process.

.....

.....

Percentage yield of ammonia = ... %

(1)

(ii) Give **two** reasons why it does **not** matter that the percentage yield of ammonia is low.
Use the flow diagram at the start of this question to help you.

.....

.....

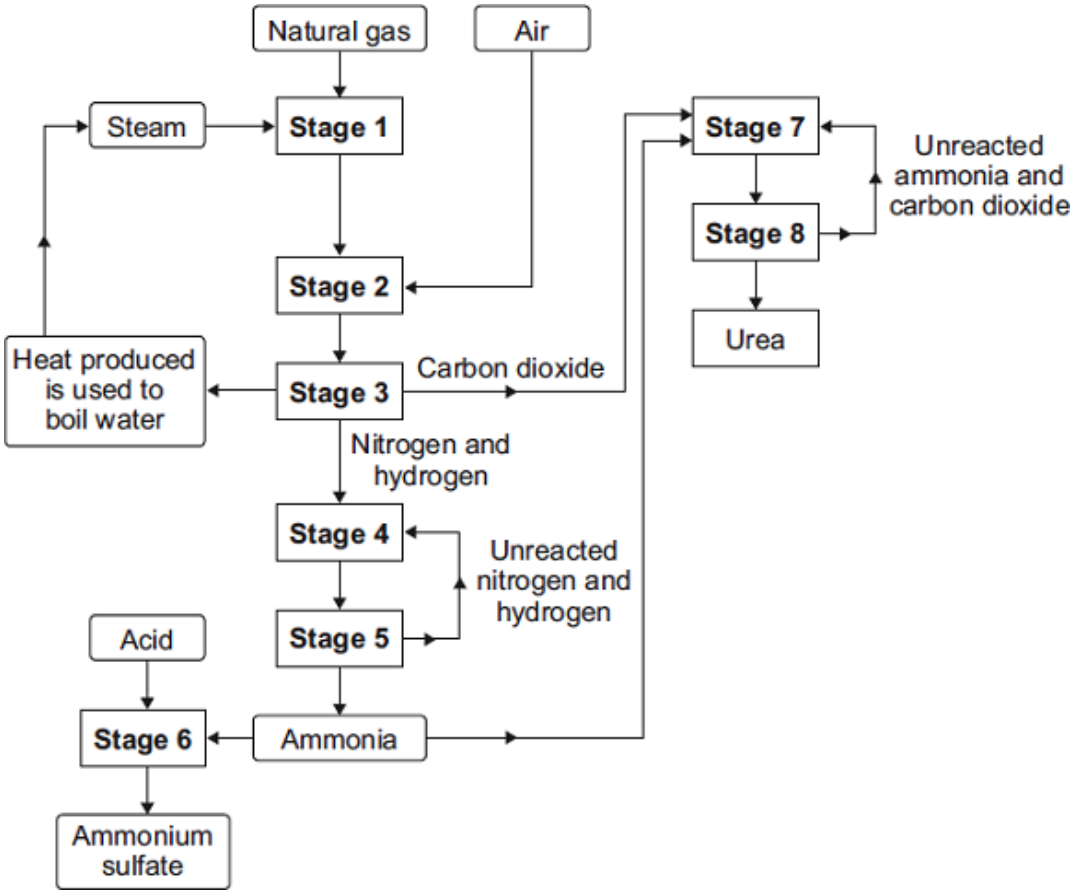
.....

.....

(2)
(Total 14 marks)

Q21. Ammonium sulfate and urea are made from ammonia. These compounds are used by farmers.

The flow diagram shows the stages to make ammonium sulfate and urea.



(a) Give **two** examples from the flow diagram of the efficient use of energy and raw materials.

.....

.....

.....

.....

.....

.....

(2)

(b) The equation for the reaction in Stage **4** is shown below.

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

The forward reaction is exothermic.

State **and** explain:

(i) how a **decrease** in temperature would affect the yield of ammonia at equilibrium

.....

.....

.....

.....

.....

(2)

(ii) how an **increase** in pressure would affect the yield of ammonia at equilibrium.

.....

.....

.....

.....

.....

(2)

(c) The equation for the reaction in Stage **7** is shown below.

$$\underset{\text{ammonia}}{2\,NH_3} + CO_2 \rightleftharpoons \underset{\text{urea}}{NH_2CONH_2} + H_2O$$

The table gives the relative formula masses (M_r) of the reactants and the products for this reaction.

Formula of reactant or product	**Relative formula masses (M_r)**
NH_3	17
CO_2	44
NH_2CONH_2	60
H_2O	18

Percentage atom economy can be calculated using:

$$\text{Percentage atom economy} = \frac{M_r \text{ of useful product}}{\text{total } M_r \text{ of all reactants added together}} \times 100\%$$

Calculate the percentage atom economy for the reaction in Stage **7**.

.....

.....

.....

.....

.....

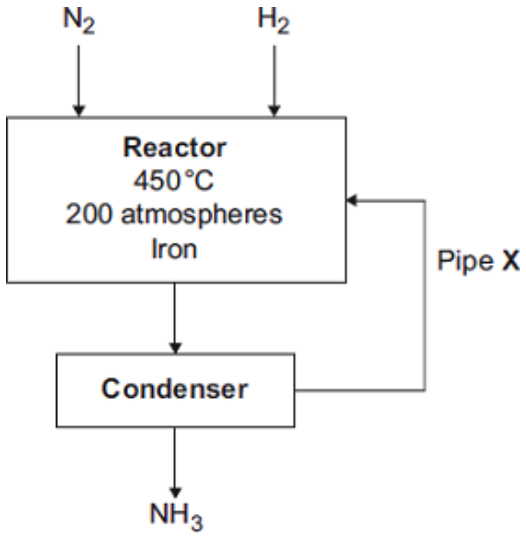
.....

Percentage atom economy = ... %

(2)

(Total 8 marks)

Q22. The flow diagram shows the Haber process. In the Haber process, ammonia (NH_3) is produced from nitrogen (N_2) and hydrogen (H_2).



(a) Which raw material is nitrogen obtained from?

.....

(1)

(b) What is the purpose of Pipe **X**?

.....

.....

.....

.....

(2)

(c) Balance the chemical equation below for the production of ammonia.

N_2 + ...H_2 $\rightleftharpoons$ .....NH_3

(1)

(d) A temperature of 450°C is used in the reactor.
The reaction of nitrogen with hydrogen is reversible.
The forward reaction is exothermic.

Explain why a temperature of 450°C is the optimum temperature for the Haber process.

.....

.....

.....

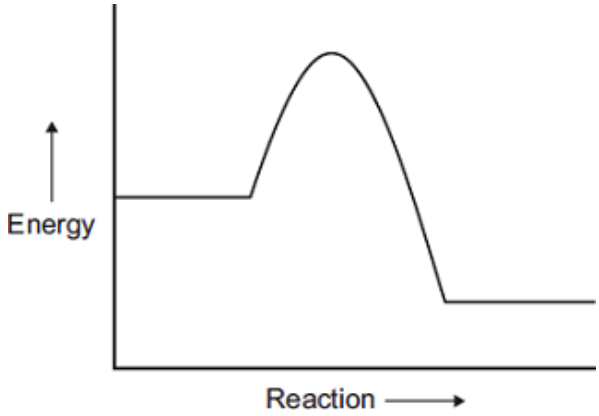
.....

.....

.....

(2)

(e) An energy level diagram for the reaction between nitrogen and hydrogen is shown below.



(i) How does the energy level diagram show this reaction is exothermic?

.....

.....

(1)

(ii) In the Haber process iron is used as a catalyst.

Draw a line on the energy level diagram to show the effect of adding a catalyst.

(1)

(Total 8 marks)