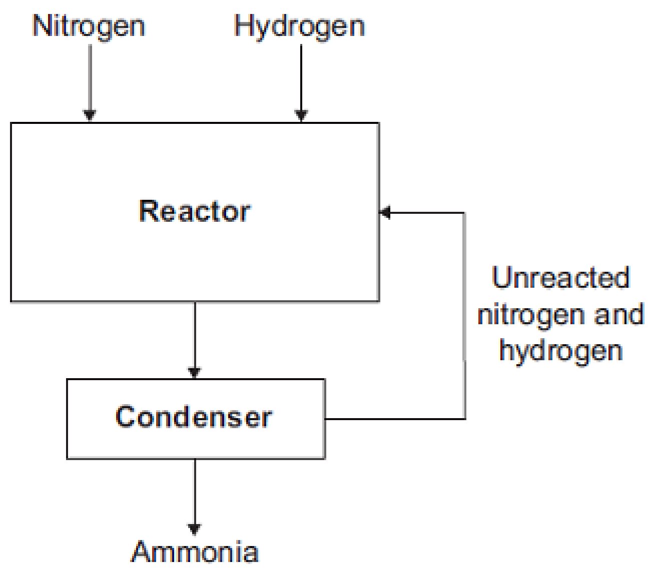
1 The flow diagram shows the Haber process. In the Haber process ammonia is produced from nitrogen and hydrogen.



(a) The word equation for the production of ammonia is:

nitrogen + hydrogen $\rightleftharpoons$ ammonia

Draw a ring around the correct answer to complete the sentence.

The symbol $\rightleftharpoons$ in the word equation shows the reaction is

exothermic.
reversible.
slow.

(1)

(b) The reactor contains iron.

Complete the sentence.

The iron speeds up the reaction because it is a ....

(1)

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

....

....

(1)

(d) The sentences describe how ammonia is produced in the Haber process.

The sentences are in the wrong order.

P Ammonia is separated as a liquid.

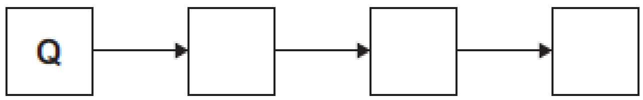
Q Nitrogen and hydrogen are mixed together.

R A mixture of gases enters the condenser.

S Nitrogen and hydrogen react to produce ammonia.

Complete the boxes below to show the correct order of the sentences.

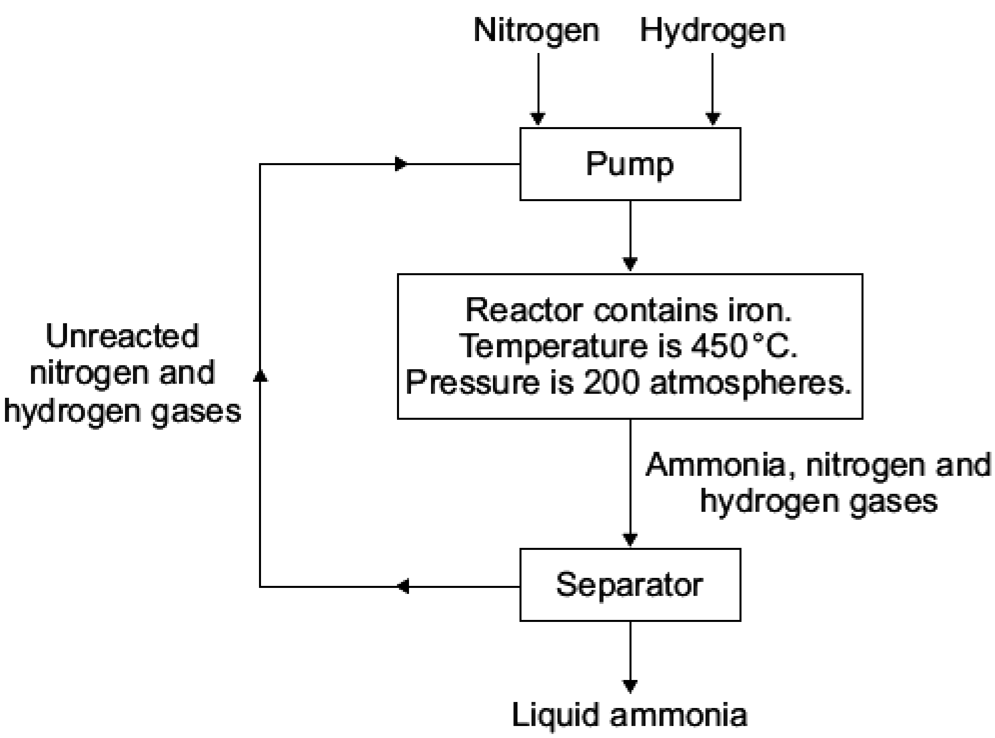
The first box has been done for you.



(2)

(Total 5 marks)

2 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:

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

(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.

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

(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.

....

....

....

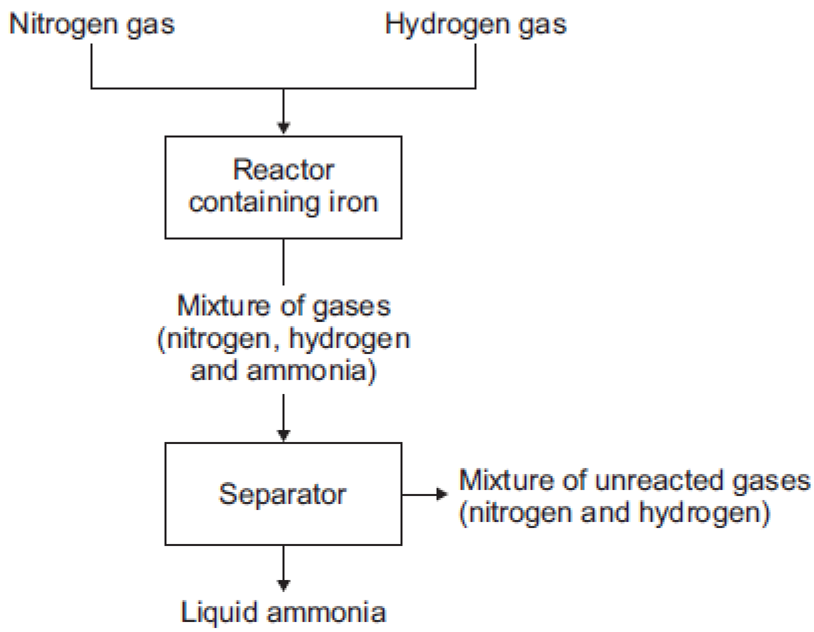
....

(2)

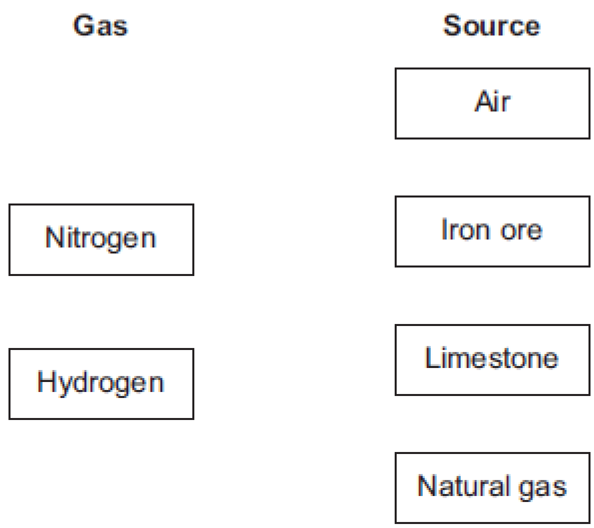
(Total 14 marks)

3 This question is about the Haber process.

The diagram below shows a flow diagram for the Haber process.



(a) (i) Nitrogen gas and hydrogen gas are obtained from different sources.
Draw **one** line from each gas to its source.



(2)

(ii) Explain why iron is used in the reactor for the Haber process.

....

....

....

(2)

(iii) Describe how the ammonia is separated from the other gases.

....

....

....

(2)

(iv) What happens to the mixture of unreacted gases (nitrogen and hydrogen)?

....

....

....

(1)

(b) The reaction to produce ammonia is reversible.

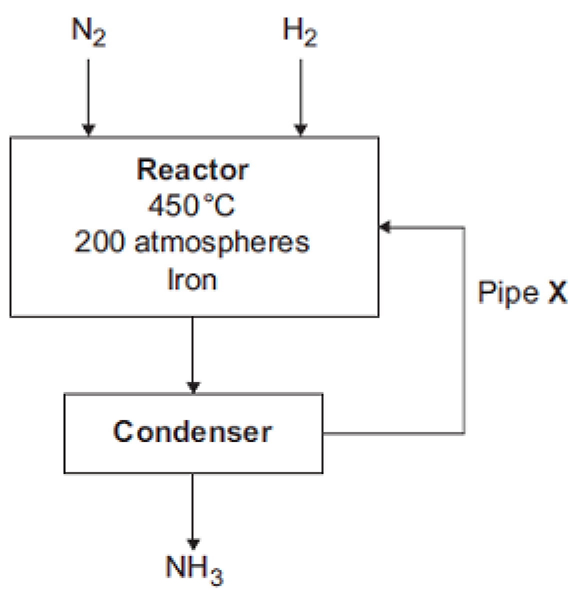
Complete the word equation for this reaction.

nitrogen + ...

(2)

(Total 9 marks)

4 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.

....

....

....

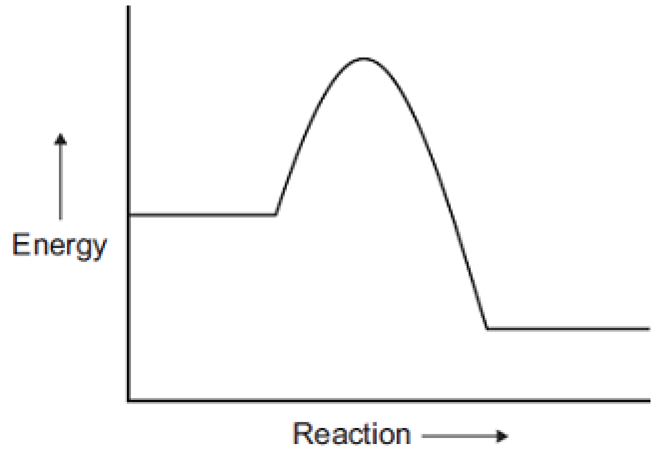
....

....

....

(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.

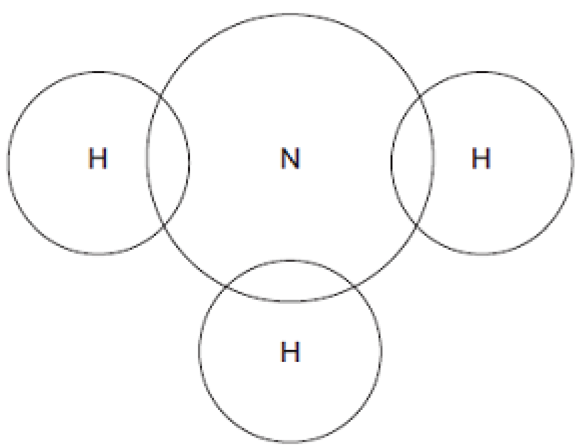
Draw a line on the energy level diagram to show the effect of adding a catalyst.

(1)

(Total 8 marks)

5 (a) Complete the dot and cross diagram to show the electrons in the outer energy levels of ammonia (NH_3).

You may use the periodic table to help you.



(2)

(b) Ammonia can be used to make ammonium nitrate (NH_4NO_3).

(i) Draw a ring around the correct answer to complete the sentence.

Ammonium nitrate can be made by reacting ammonia with [ethanoic / hydrochloric / nitric] acid.

(1)

(ii) State **one** use of ammonium nitrate.

....

(1)

(iii) Calculate the relative formula mass (M_r) of ammonium nitrate (NH_4NO_3).

Relative atomic masses: H = 1; N = 14; O = 16.

....

....

Relative formula mass (M_r) = ...

(2)

(iv) Calculate the percentage by mass of nitrogen in ammonium nitrate.

....

....

....

....

Percentage by mass of nitrogen = ... %

(2)

(c) *In this question you will be assessed on using good English, organising information clearly and using specialist terms where appropriate.*

Ammonia is manufactured from nitrogen and hydrogen by the Haber process:

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

The forward reaction is exothermic.

The conditions used in the Haber process are:

- 200 atmospheres pressure
- 450 °C
- iron catalyst.

Use the equation and your knowledge of reversible reactions to explain why these conditions are used in the Haber process.

To get full marks you must consider **both** yield **and** rate of reaction in your answer.

....

....

....

....

....

....

....

....

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....

....

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....

....

....

....

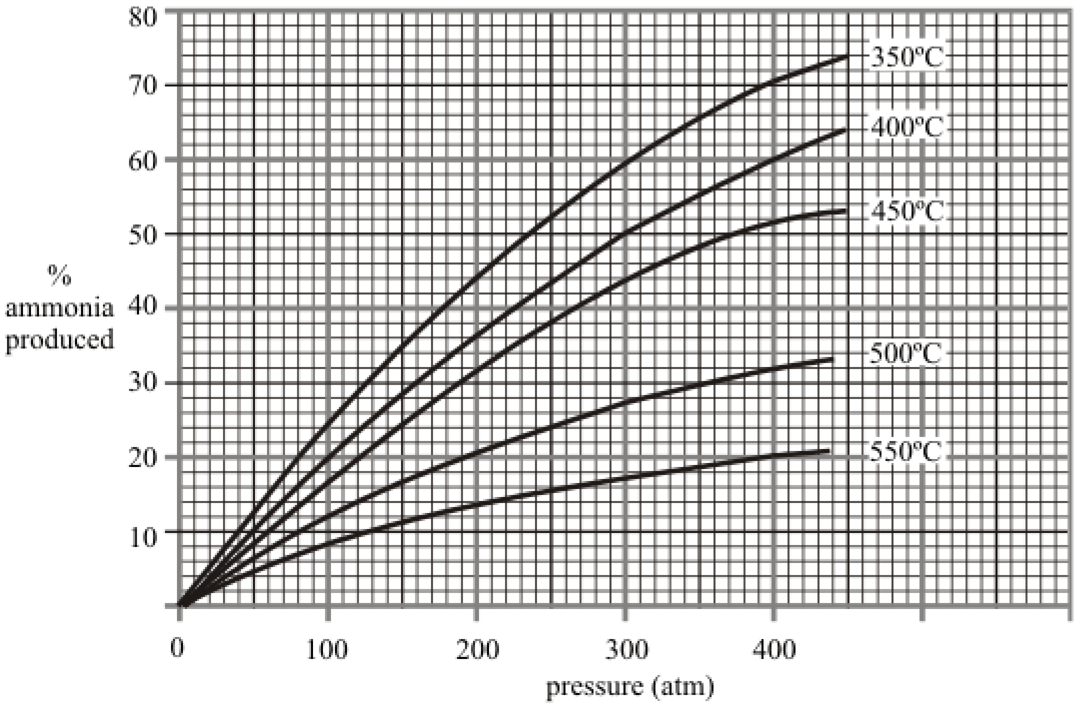
(6)

(Total 14 marks)

6 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:

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

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)

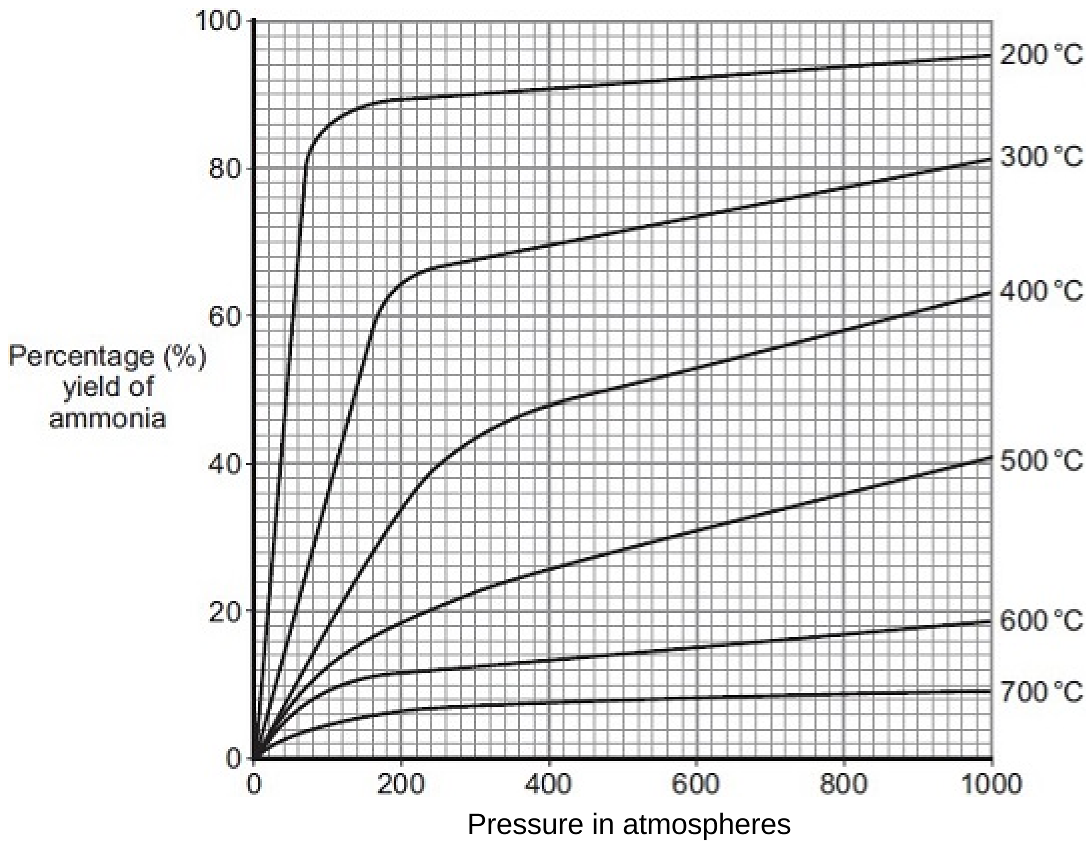
7 In 1909 Fritz Haber invented a process to produce ammonia from nitrogen and hydrogen.

(a) Complete and balance the chemical equation for the production of ammonia from nitrogen and hydrogen.

$$N_2 \quad + \quad 3\,H_2 \quad \rightleftharpoons \quad \ldots\ldots\ldots\ldots\ldots\ldots$$

(2)

(b) The figure below shows how the equilibrium yield of ammonia changes with pressure at different temperatures.



(i) Use the information in given in the figure to complete the sentence.

The temperature on the graph that gives the highest yield of ammonia is .... °C.

(1)

(ii) The temperature used in the Haber process for the production of ammonia is 450 °C.

Why is a temperature much lower than 450 °C **not** used for the Haber process?

....

....

(1)

(iii) Use the information in the figure to answer this question.

Draw a ring around the pressure that gives the highest yield of ammonia.

100 **200** **300** **400**

(1)

(iv) The pressure used in the Haber process for the production of ammonia is 200 atmospheres.

Why is a pressure lower than 200 atmospheres **not** used for the Haber process?

....

....

(1)

(c) Explain how ammonia is separated from unreacted nitrogen and hydrogen in the Haber process.

....

....

....

....

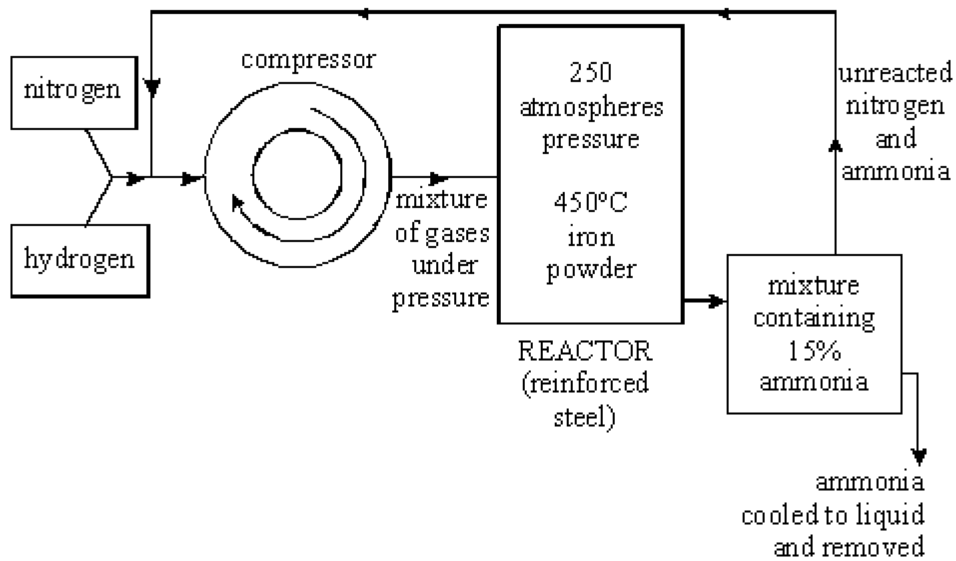
(2)

(Total 8 marks)

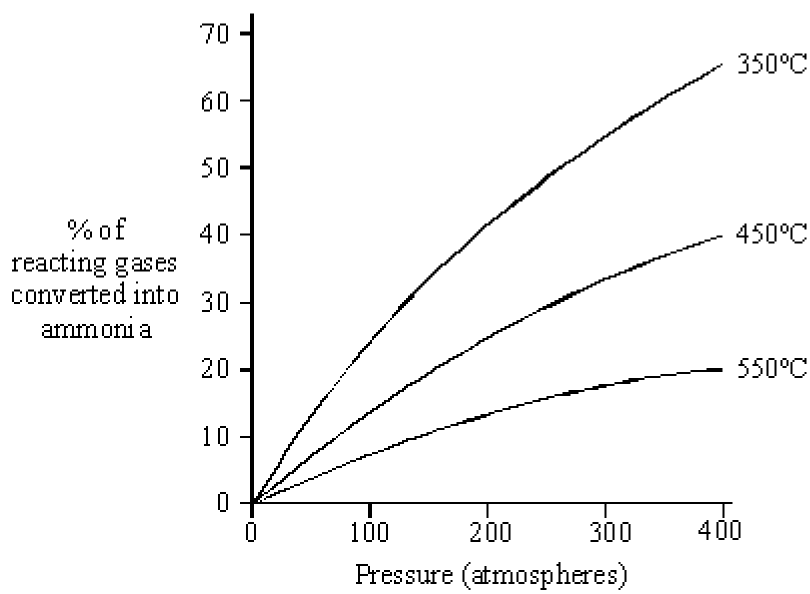
8 Ammonia is manufactured from nitrogen and hydrogen. The reaction is shown in the equation below.

$$\underset{\text{nitrogen}}{N_2} + \underset{\text{hydrogen}}{3H_2} \underset{\text{endothermic}}{\overset{\text{exothermic}}{\rightleftharpoons}} \underset{\text{ammonia}}{2NH_3}$$

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)

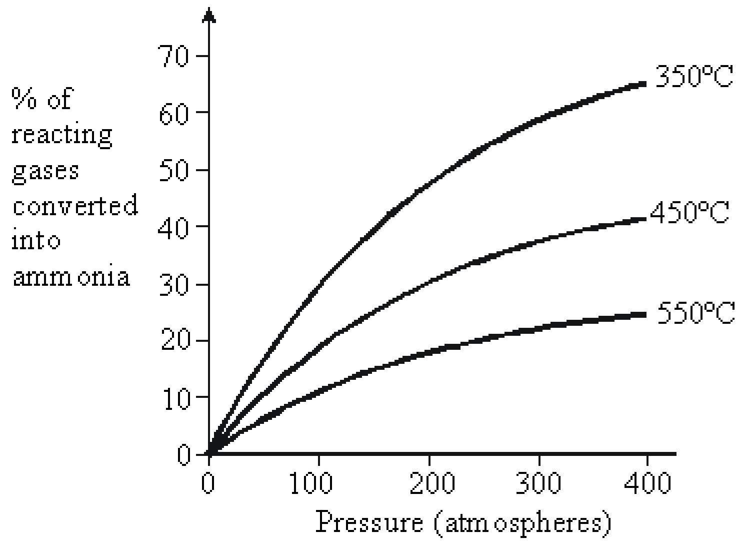
9 Ammonia is manufactured in the Haber Process, from nitrogen and hydrogen.

(a) Balance this symbol equation for the process.

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

(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)

10 (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)

11

(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.

....

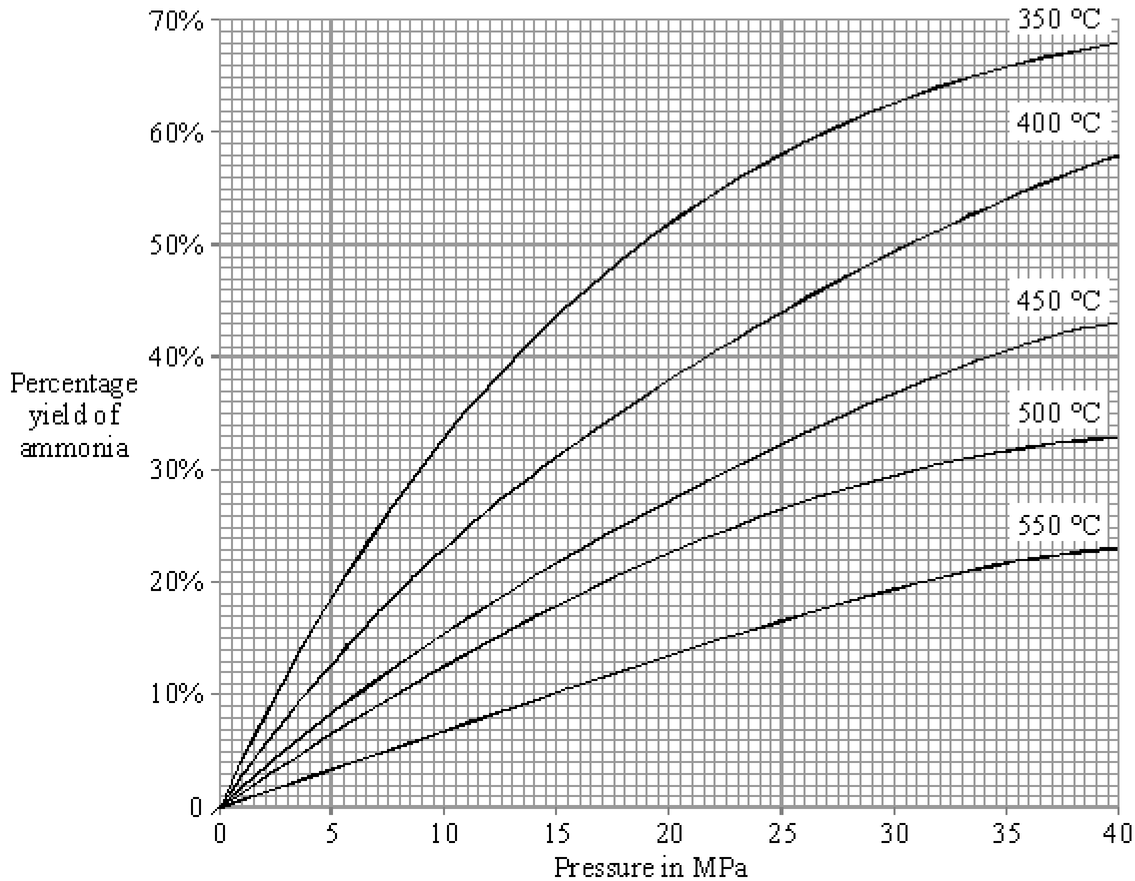
....

....

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?

....

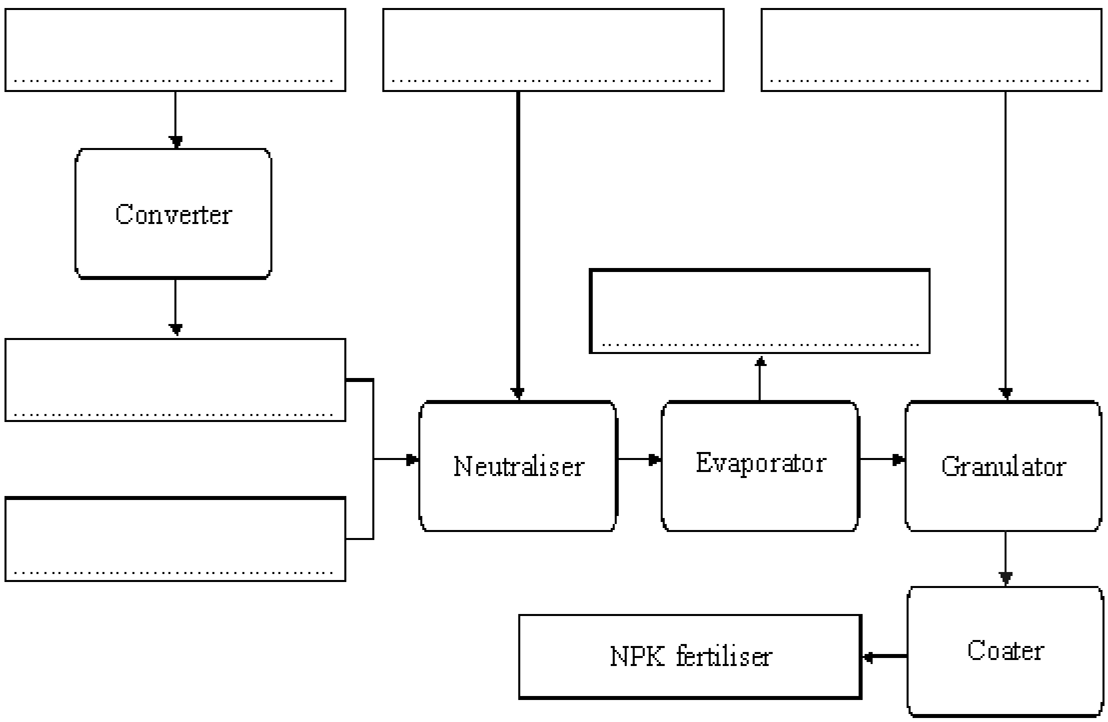
....

(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)

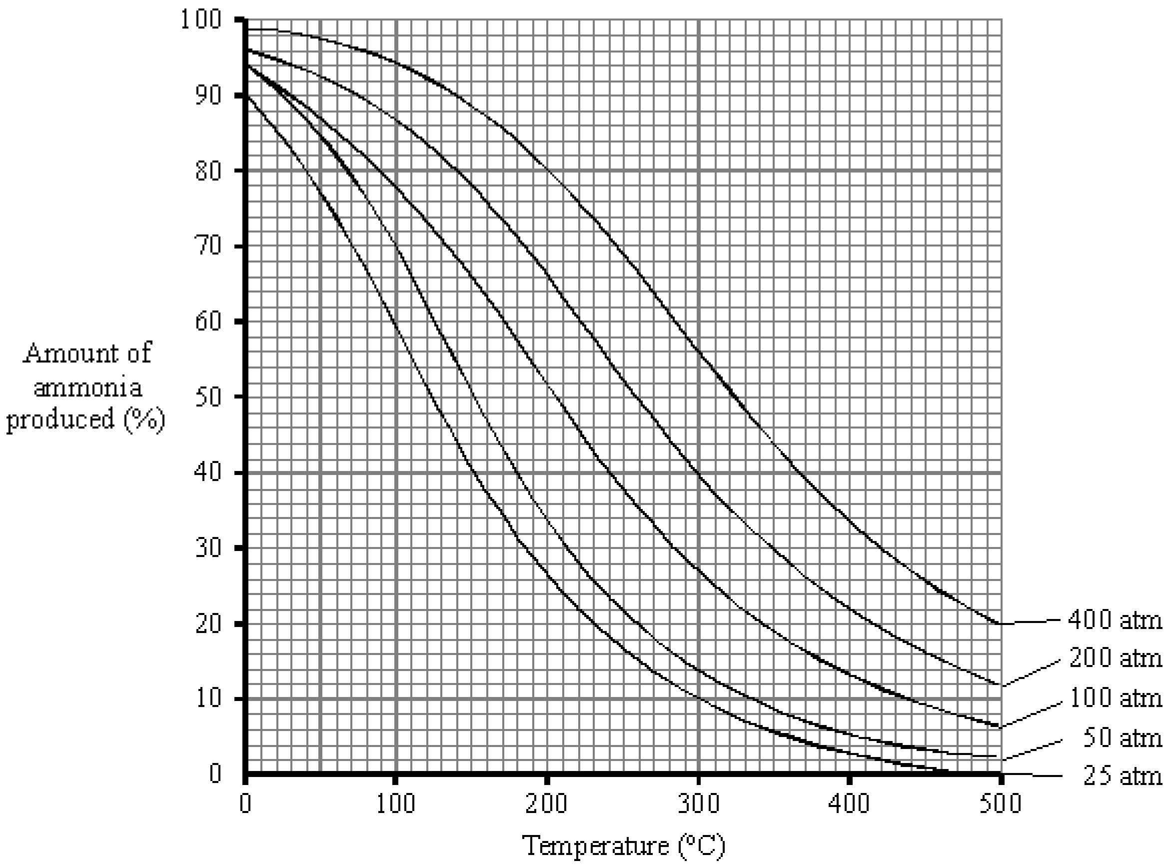
(Total 10 marks)

12 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)

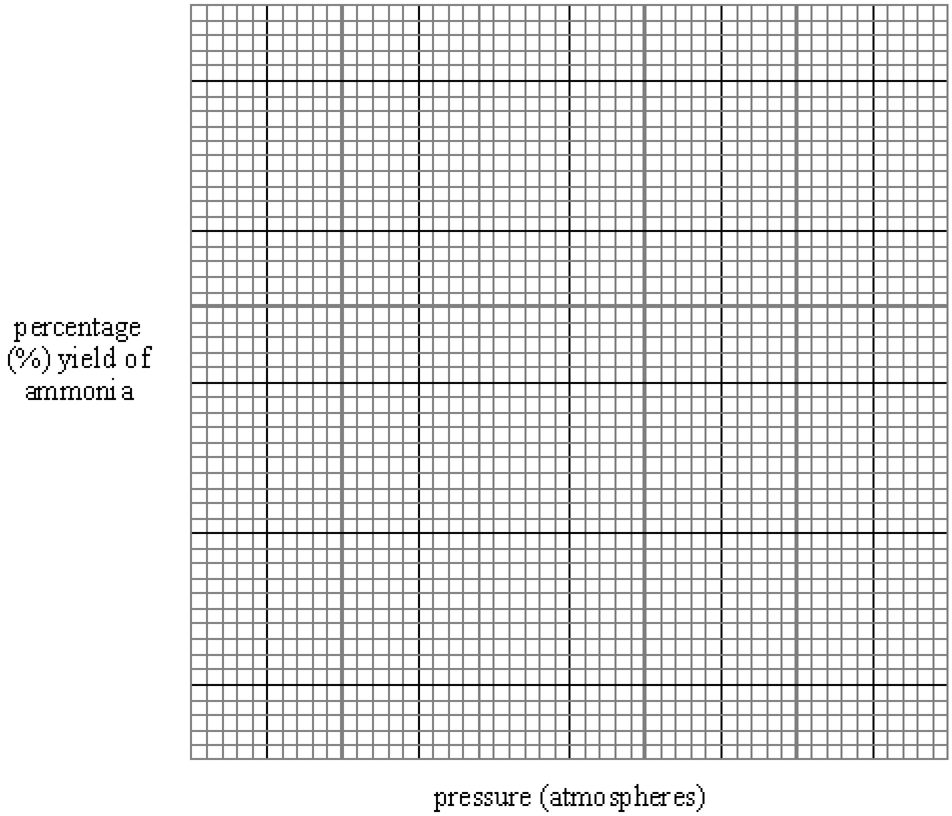
(Total 12 marks)

13 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)

14 Early atmospheres on Earth contained ammonia (NH_3).

(a) (i) Complete the sentence.

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

(1)

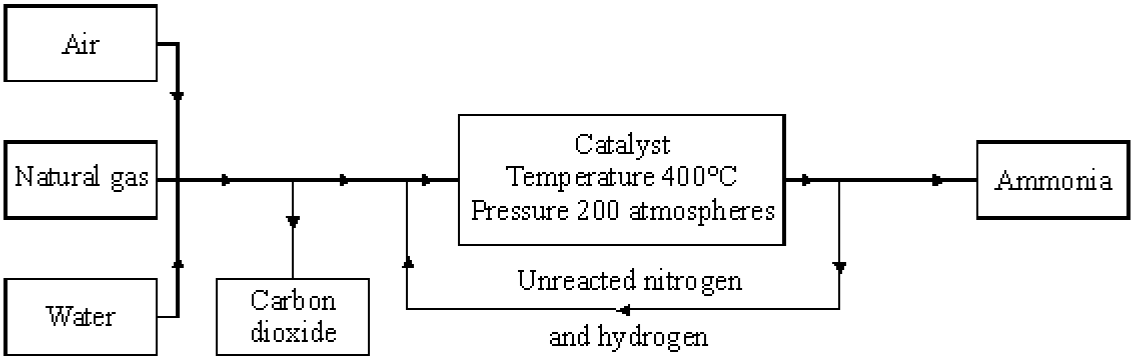
(ii) Today we convert nitrogen back to ammonia mainly for the production of fertilisers.
What do plants convert the nitrogen in these fertilisers into?

....

....

(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.

....

....

....

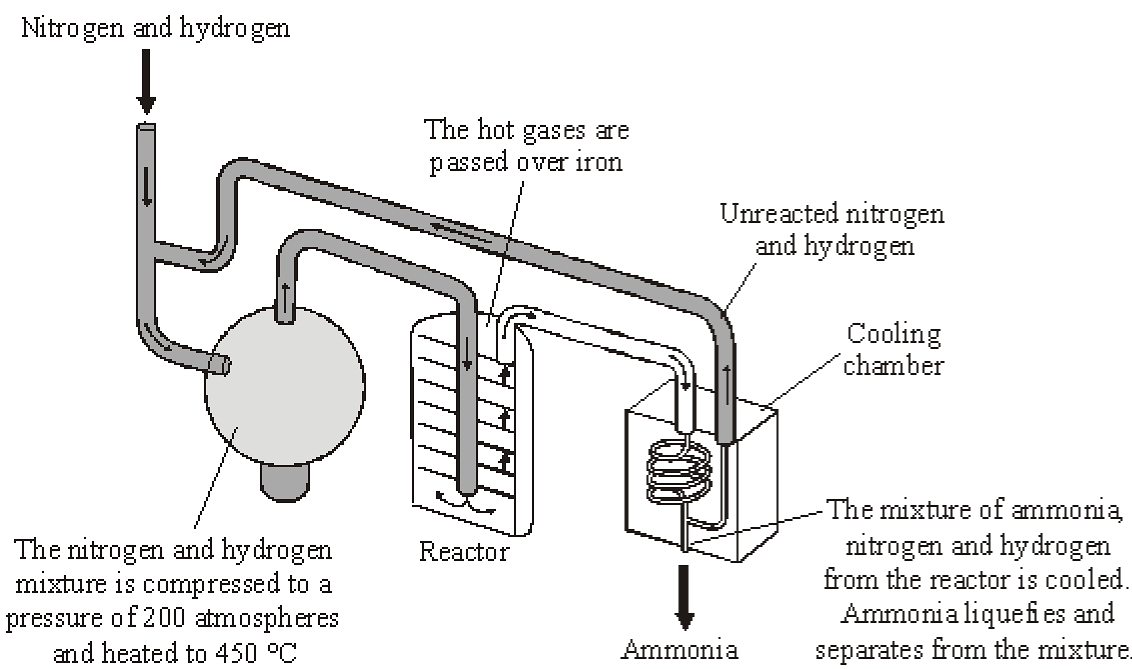
(2)

(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)

15 The Haber process is named after the German chemist, Fritz Haber.
The diagram shows the main stages in the Haber process.



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(a) Use the diagram to help you to answer these questions.

(i) Complete the word equation for the reaction that takes place in the reactor.

nitrogen + ... $\rightleftharpoons$ ....

(1)

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

....

(1)

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

....

(1)

(iv) Ammonia is separated from unreacted nitrogen and hydrogen.

Draw a ring around the physical property that allows this separation to take place.

....

(1)

(v) What is done with the unreacted nitrogen and hydrogen?

....

(1)

(b) Some of the products that can be made from ammonia are:

- fertilisers
- dyes
- explosives
- medicines
- plastics

(i) The Haber process was invented a few years before the start of the First World War. It is thought that the First World War would have finished earlier if the Germans had **not** invented the Haber process.

Suggest why.

....

....

(1)

(ii) The Haber process has helped to increase food production.

Explain why.

....

....

(1)

(c) Factories that make ammonia are very large and operate night and day.

(i) Ammonia factories are often near towns.

Suggest why.

....

(1)

(ii) Suggest and explain **one** reason why local people might not want an ammonia factory near their town.

....

....

....

....

(2)

(Total 10 marks)

16 In 1909 Fritz Haber invented a process to produce ammonia from nitrogen and hydrogen.

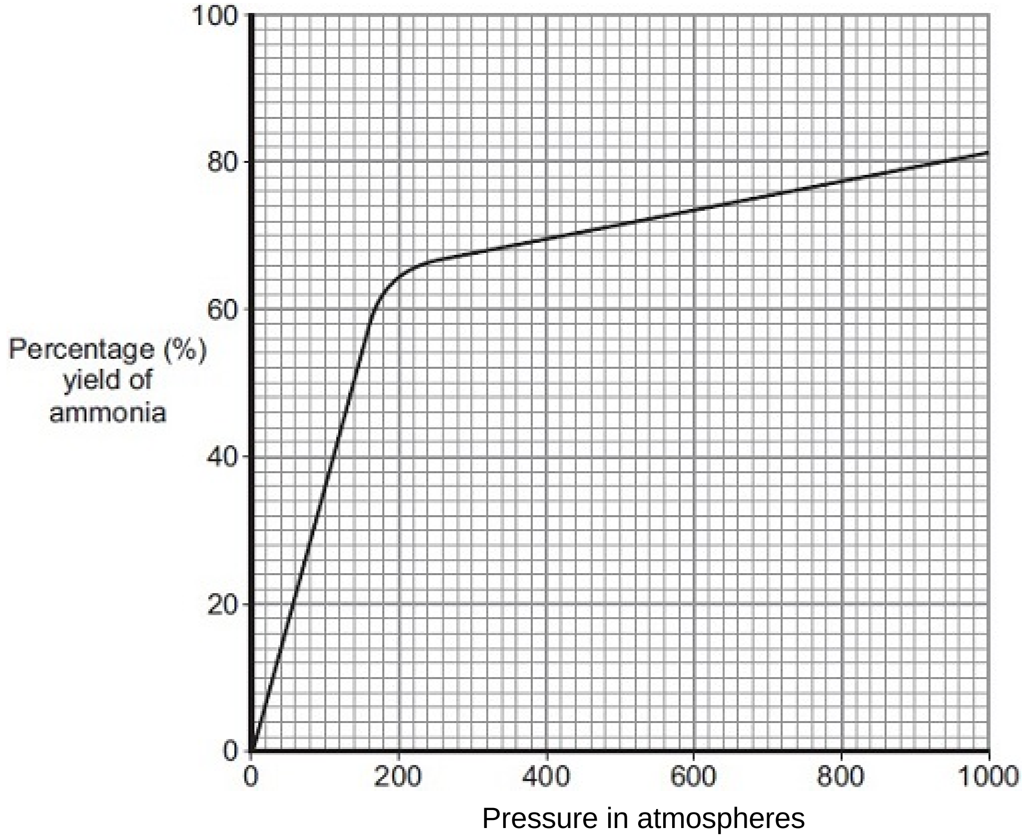
(a) Complete the word equation, showing that the reaction is reversible.

nitrogen + hydrogen ....

(2)

(b) **Figure 1** shows how the yield of ammonia at 300 °C changes with pressure.

Figure 1



Describe how the yield of ammonia changes as the pressure increases.

....

....

....

....

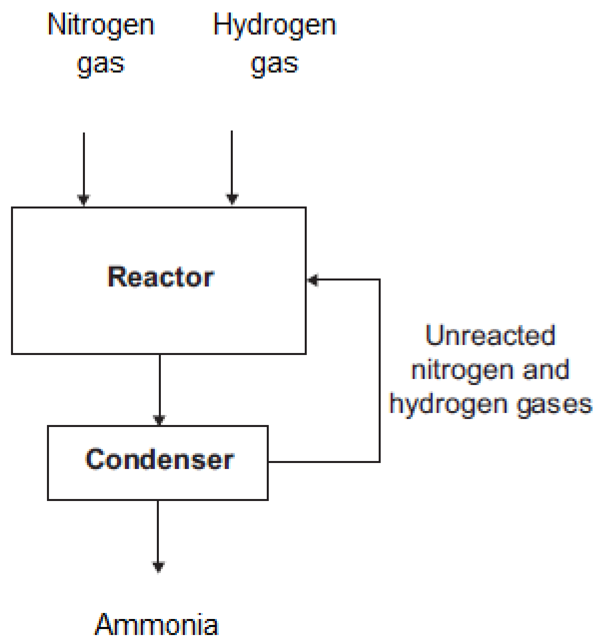
....

....

(3)

(c) **Figure 2** represents the Haber process.

Figure 2



How does the Haber process avoid wasting nitrogen and hydrogen?

....

....

(1)

(d) Before the Haber process, nitrates had been mined in South America. Nitrates are used for making fertilisers.

The Haber process allowed nitrates to be produced on a large scale, anywhere in the world.

(i) Suggest what effect the Haber process had on the miners in South America.

....

....

(1)

(ii) Suggest **one** advantage of producing nitrates on a large scale.

....

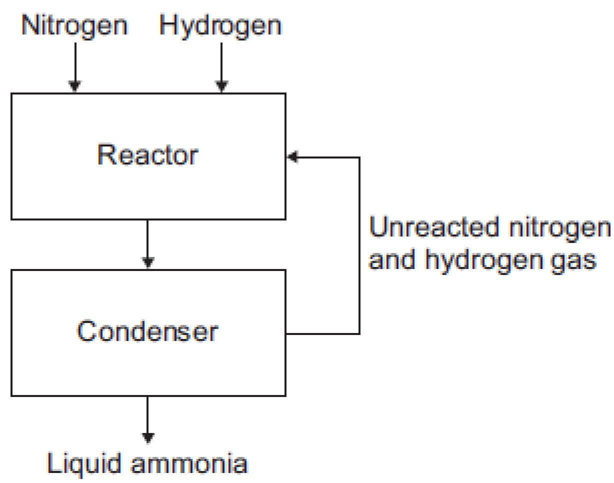
....

(1)

(Total 8 marks)

17 A flow diagram of the Haber process is shown below.

The Haber process produces ammonia from nitrogen and hydrogen.



(a) Use the correct answer from the box to complete the sentence.

air	**limestone**	**natural gas**

Hydrogen is obtained from ....

(1)

(b) In the reactor, nitrogen and hydrogen at a high pressure are heated and passed over a catalyst.

(i) Use the correct answer from the box to complete the sentence.

25	**100**	**450**

The temperature in the reactor is .... °C

(1)

(ii) Use the correct answer from the box to complete the sentence.

copper	**iron**	**nickel**

The catalyst used in the reactor is ....

(1)

(iii) How does a catalyst speed up a reaction?

Tick (✓) **one** box.

The catalyst lowers the activation energy.	☐
The catalyst gives the reactants extra energy.	☐
The catalyst increases the pressure in the reactor.	☐

(1)

(c) A mixture of gases leaves the reactor.

The mixture contains ammonia, nitrogen and hydrogen.

Describe what happens to this mixture of gases in the condenser.

Use the flow diagram to help you.

....

....

....

....

....

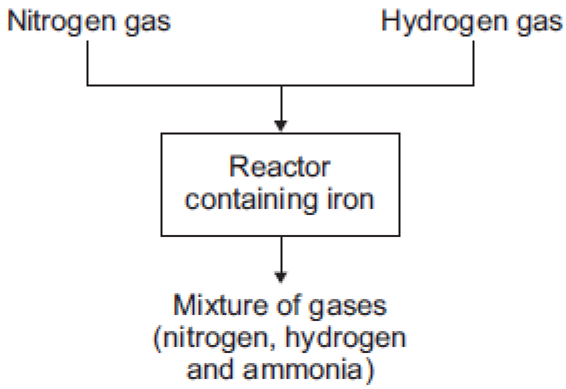
....

(3)

(Total 7 marks)

18 The graph in **Figure 1** shows a flow diagram for the Haber process.

Figure 1



(a) (i) Hydrogen gas is obtained from methane.
Name **one** source of methane.

....

(1)

(ii) Air is the source used to produce nitrogen for the Haber process.
Suggest why air must **not** get into the reactor.

....

....

....

(2)

(iii) Describe what happens to the mixture of gases from the reactor.

....

....

....

....

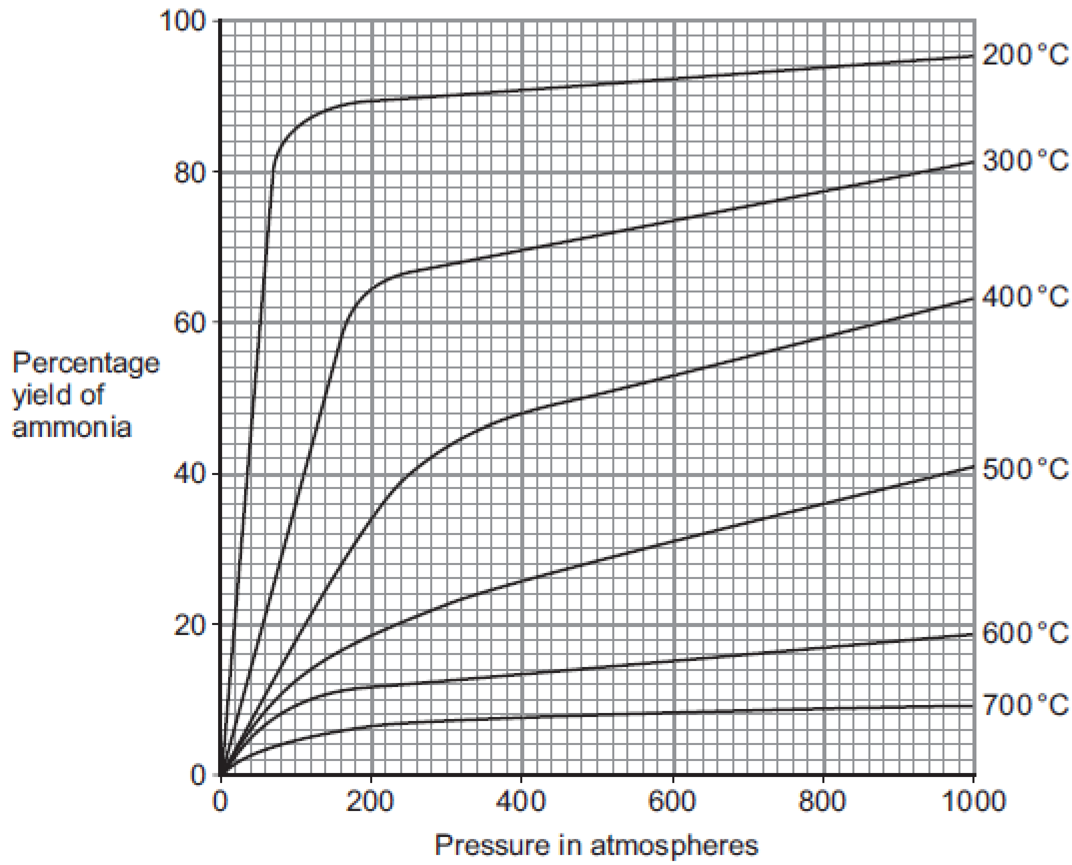
....

....

(3)

(b) The graph in **Figure 2** shows the percentage yield of ammonia using different conditions.

Figure 2



(i) Use **Figure 2** to suggest the conditions that produce the greatest yield of ammonia.

....

....

(1)

(ii) Use **Figure 2** to suggest and explain why the conditions used to produce ammonia in the Haber process are a temperature of 450 °C and a pressure of 200 atmospheres.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

(5)

(Total 12 marks)

Mark schemes

1 (a) reversible

1

(b) catalyst

1

(c) recycled

allow re-used

1

(d) (Q) S R P

*allow **1**mark if one letter in correct place.*

2

[5]

2 (a) mixture is cooled / cooling

1

so ammonia / it condenses

or

so ammonia <u>turns into</u> a liquid (but nitrogen and hydrogen remain as gases)

1

(b) (i) exothermic reaction

accept reverse reaction is endothermic

or

equilibrium / reaction moves in the direction which raises the temperature

ignore answers based on rate or collisions

1

(ii) they / particles / molecules move faster **or** have more (kinetic) energy

allow atoms instead of particles

ignore particles move more / vibrate

*do **not** accept electrons (max1)*

1

any **one** from:

- particles / molecules collide more often / more frequently / more likely to collide

  ignore collide faster

  ignore more collisions

- more of the collisions are successful **or** particles collide with more energy / harder **or** more of the particles have the activation energy

  accept more successful collisions

1

(iii) more molecules / particles / moles / volumes on LHS (of equation than RHS)

accept 4 molecules / particles / moles / volumes on LHS and 2 molecules / particles / moles / volumes on RHS

or

greater volume on LHS (than RHS)

or

equilibrium / reaction moves in the direction which reduces the pressure / volume

accept converse

1

(iv) cost

or

difficulty in containing such a high pressure

allow risk of explosion

ignore dangerous

1

(c) (i) 60

1

(ii) 2.4(2857….)

*correct answer gains **3** marks with or without working*

accept any answer that rounds to 2.4

ignore units

*if answer is incorrect look for evidence of correct working to a maximum of **2** marks.*

moles of N_2 = 2/28 = (0.0714)

moles of ammonia = 2 × 0.0714 = (0.1428)

mass of ammonia = 0.1428 × 17 = (2.4276)

or

28 → 34

1g →34/28

2g →2.4… ….

3

(d) (i) 15

1

(ii) unreacted gases are recycled

allow unreacted gases are reused

1

rate (of production) is fast

accept production is continuous

ignore compromise between rate and yield

1

[14]

3 (a) (i) nitrogen: air

1

hydrogen: natural gas

1

(ii) as a catalyst

1

so the reaction speeds up

allow lowers activation energy or so a lower temperature can be used

1

(iii) cooled

1

ammonia condenses / liquefies

*allow nitrogen **and** hydrogen remain in the gaseous state*

1

(iv) recycled

allow reused or returned to the reactor

1

(b) reversible arrows

1

hydrogen **and** ammonia

1

[9]

4 (a) air

1

(b) recycle

allow re-use

1

(unreacted) nitrogen and hydrogen

allow N_2 and H_2

1

(c) $N_2 + \mathbf{3}H_2 \rightarrow \mathbf{2}NH_3$

allow correct multiples

1

(d) *allow converse arguments*
ignore references to compromise

because a higher temperature would reduce (equilibrium) yield
allow higher temperature favours backward reaction
1

because a lower temperature would reduce rate
1

(e) (i) (energy of) reactants greater than (energy of) products
allow converse
allow (overall) energy decreases
allow energy required to break bonds is less than the energy released making bonds
1

(ii) line starting and finishing at same levels but with lower peak
1

[8]

5

(a) three bonding pairs
*do **not** allow non-bonding electrons in hydrogen*
ignore any inner shells on nitrogen
1

two non-bonding electrons
allow either dots and crosses or combination of both
1

(b) (i) nitric
1

(ii) fertilisers / explosives
ignore other uses
1

(iii) 80
*correct answer with or without working gains **2** marks*
*if answer incorrect, allow 14 + (1 × 4) + 14 + (16 × 3) for **1** mark*
2

(iv) 35
*allow ecf from **(b)(iii)***
*allow ecf for **1** mark for correct working but incorrect answer.*
*if answer incorrect, allow 28 / 80 × 100 for **1** mark*
*if answer is 17.5 % allow **1** mark*
2

(c) Marks awarded for this answer will be determined by the Quality of Communication (QoC) as well as the standard of the scientific response. Examiners should also refer to the information on page 5, and apply a 'best−fit' approach to the marking.

0 marks
No relevant content

Level 1 (1 − 2 marks)
There are statements about the conditions used. There is no correct explanation of the link between rate or yield and the conditions.

Level 2 (3 − 4 marks)
There is a correct explanation of the conditions used that links the conditions to rate **or** yield

Level 3 (5 − 6 marks)
There is an explanation covering at least temperature and pressure, which shows understanding of the compromise between rate **and** yield

examples of chemistry points made in the response:

200 atmospheres pressure

- high pressure gives a high yield of ammonia
- too high a pressure causes risk of explosion
- high pressure costly to maintain
- a high pressure will cause the rate to be higher
- 4 moles of gas become 2 (or fewer moles of gas in products)

450 °C

- high temperature increases the rate of reaction
- optimum temperature
- (forward reaction is exothermic so) a high yield of ammonia requires a low temperature
- but too low a temperature causes the rate of reaction to be too slow

iron catalyst

- a catalyst speeds up the reaction
- an iron catalyst allows a lower temperature to be used (saving energy and causing a higher yield)
- iron catalyst increases the rate of reaction equally in both reactions

others

- compromise conditions
- unreacted nitrogen and hydrogen is recycled

6

[14]

6 Effect of pressure

- high pressure increases yield

  for 1 mark

- either because less product molecules (Le Chatelier)
  or but high pressure increases cost/safety

  for 1 mark

Effect of temperature

- low temperature increases yield

  for 1 mark

- either because exothermic reaction (Le Chatelier)

  for 1 mark

- or but at low temperature rate is slow/catalyst does not work

Compromise

- optimum conditions to balance rate and % yield

  for 1 mark

- or rate is slow (at higher temperature) so need a catalyst
  or low percentage conversion so recycle untreated gases

[5]

7 (a) $2NH_3$

*allow NH_3 with incorrect or missing balancing for **1** mark*

allow multiples

2

(b) (i) 200

1

(ii) rate of reaction (too) slow

allow converse

ignore references to yield / cost

1

(iii) 400

1

(iv) lower yield

allow converse

accept shifts equilibrium to left

allow favours the backward reaction

allow favours side with more (gaseous) molecules

allow lower rate

1

(c) (gases) cooled

it = ammonia

1

ammonia liquefied

accept ammonia condensed

*accept ammonia cooled below boiling point for **2** marks*

1

[8]

8 (a) rate of reaction is increased

iron/powder

acts as catalyst

at higher temperatures

at higher pressures

any 4 answers for 1 mark each

4

(b) yield of ammonia is increased at higher pressure
since equilibrium is moved to the right (idea)
but there is high cost in manufacturing the plant to withstand very high pressures
so optimum* pressure of about 250 atmospheres is used
(– just quoting the figures not enough)*
very high pressure increases safety risk
yield of ammonia is increased at lower temperatures
since equilibrium is moved to the right
but the rate of reaction is reduced at lower temperatures
so process becomes uneconomic
optimum temperature of about 450°C is used
yield of ammonia is increased if the ammonia is removed from the reaction mixture

since equilibrium is moved to the right (idea)
so ammonia is removed as a liquid after cooling and condensing
unreacted nitrogen and hydrogen recycled

(credit nitrogen and ammonia because of misprint on the diagram)

NB Answers in (b) must clearly relate to yield not to rate
(except for the qualification w.r.t. temperature)

any 7 points for 1 mark each

7

[11]

9 (a) $N_2 + \mathbf{3}\ H_2 \leftrightarrow \mathbf{2}\ NH_3$

2

(b) (i) lower temperature gives higher % conversion
higher pressure gives higher % conversion

each for 1 mark

2

(for T = 350 °C and P = 400 At. award 2 marks)

the most economical combination
reaction too slow at lower temperatures
plant too expensive at higher pressures

any 2 for 1 mark each

2

[6]

10 (a) (i) gas

accept they are all gases

1

(ii) reversible (reaction)

accept can go either way
accept ammonia can be decomposed (to nitrogen and hydrogen)
accept could be (an) equilibrium
do not credit just 'equilibrium'

1

(iii) (liquid) air **or** atmosphere

1

(iv) same number **or** amount **or** weight (of atoms) on each side (of the equation)

accept "sums" for each side

accept same amounts of elements on each side
do not credit molecules ***or*** *compounds*
do not credit both sides are the same unless explained

1

of the same type

or *gives a correct example 'e.g. six hydrogen atoms' (on each side)*

1

(b) (i) nitrate **or** sulphate **or** phosphate

if first left blank, second may be awarded

do not credit chloride

nitric **or** sulphuric **or** phosphoric

1

(only if correct above, exception is for ammonium chloride followed by hydrochloric acid (1 mark))

as appropriate if only the formula is given this should be credited only if it is correct in every detail i.e. NH_4NO_3 HNO_3 $(NH_4)_2SO_4$ H_2SO_4

accept correct name with an incorrect version of the formula

do not credit a correct formula with an incorrect version of the name e.g. 'nitrate/sulphite' etc

1

any **one** of

* (solution) can be sprayed (on the fields **or** crops)

accept more even distribution

* dissolves in <u>soil</u> water **or** rain (water)

accept soaks into soil (because soaks implies water)

* can be taken up by (plant) roots

do not credit can be added to water to “feed” the plants

1

(c) (i) elements **or** <u>different</u> atoms are bonded or joined **or** combined **or** reacted

do not credit just ‘atoms’

do not credit added ***or*** *mixed*

1

(ii) (pairs of) electrons are shared

do not credit <u>an</u> electron is shared

1

[10]

11 (a) (i) atmosphere

or (fractional distillation of liquid) air

1

(ii) **either**

more (chance) of them colliding/

not just ‘faster’

coming into contact

or

the volume of the product / the ammonia is less than / only half the volume of the reactants / the nitrogen and hydrogen

1

(iii) 3 × (1 ×2) of hydrogen

→ 2 × (14 +1 ×3) of ammonia

accept 6 parts of hydrogen →34 parts of ammonia ***or*** *similar*

i.e. candidate uses the atomic masses and works correctly from the equation

1

= 225 (tonnes/t)

unit not required

1

(b) (i) megapascal(s)

accept million pascal(s)

1

(ii) 28 (%)

accept any answer in the range 28.0 to 28.5 inclusive

1

(iii) reduce the temperature and increase the pressure

both required

1

(iv) **either**

use a catalyst

accept use iron as a catalyst

accept use iron which has been more finely divided

accept use iron / catalyst with a bigger (surface) area

accept use a better catalyst

1

or

remove the ammonia (as it is produced)

accept react the ammonia with ***or*** *dissolve the ammonia in water (as it is produced)*

1

(c) ammonia
nitric acid
phosphoric acid

all three on the left correct

ammonia potassium chloride

all three on the right correct

water **or** water vapour

accept 'steam'

1

[10]

12 (a) 16%

for 2 marks

(attempt by drawing lines etc gains 1 mark)

2

(b) iron is a catalyst;
which speeds up the reaction

for 1 mark each

2

(c) (from the graph) the best **yield** is obtained at high pressure;
and low temperature;
it is a reversible reaction;
in which formation of ammonia is favoured at low temperature
(because) the reaction is exothermic;
and the formation of ammonia is favoured at high pressure
because greater number of gaseous reactant molecules than
gaseous product molecules/because greater vol of reactant
than volume of product molecules;
pressure used is limited by cost/materials;
rate of reaction slow at low temperatures;
actual temperature and pressure used is a good compromise
(between a good yield and reasonable rate);
removal of ammonia makes rate more important than yield;

any 8 for 1 mark each

8

[12]

13

(a) (i) both scales (must be sensible) (use at least half the paper)
plots for 350°C (to accuracy of +/- 1/2 square)
plots for 500°C (to accuracy of +/- 1/2 square)
lines of best fit (sensible smooth curves) (ignore below 50 atm.)
(must not join the dots and each curve must be a single line)

for 1 mark each

4

(ii) read accurately from their graph (must be 350 °C and pressure read
to +/– half square from their graph)

for one mark

1

(iii) smooth curve drawn between 350ºC and 500 °C - must be of similar
shape to the other curves - a dashed line would be accepted here but
would not be accepted for part (i)

for one mark

1

(b) (i) reversible reaction (owtte) / equilibrium / equilibria / reaction goes in both directions etc.

for one mark

1

(ii) maximum of 2 marks from each section up to a maximum total of 5

effect of temperature (max. 2 marks)
best yield at low temperature / poor yield at high temperature
reaction too slow at low temperature / fast at high temperature

effect of pressure (max. 2 marks)
high yield at high pressure (owtte) / low yield at low pressure
ideas to do with cost / safety factor of using higher pressures

evaluation (max. 2 marks)
formation of ammonia favoured at low temperature **because** reaction is exothermic formation of ammonia favoured at high pressure **because** more reactant molecules than product molecules actual temperature and / or pressure used are a compromise between good yield and reasonable rate ammonia removed / unreacted nitrogen and hydrogen recycled so rate more important than yield catalyst used (not a wrongly named catalyst)

for 1 mark each

5

(c) (i) NH_4NO_3 = 14 + (4 × 1) + 14 + (3 × 16) = 80 (ignore units)

for one mark

1

(ii) ecf (error carried forward from part (i))
look for (28/80) for first mark

gains 1 mark

but 35% (% sign not needed)

special case of (14/80 × 100 = 17.5%) gains one mark

gains 2 marks

2

[15]

14 (a) (i) 78-80%

1

(ii) proteins

accept amino acids

1

(b) (i) natural gas

accept methane (CH_4)

accept water (H_2O)

1

(ii) carbon dioxide

1

(c) (i) $N_2 + H_2$

1

correct balancing 1 + 3 → 2

award only if reactants are correct

1

(ii) iron

accept Fe

1

(iii) at low temperatures rate of reaction is too slow

accept very few collisions at low temperatures

accept converse

particles need enough (activation) energy to react

accept particles need enough energy for bonds to break

accept converse

1

(d) all three covalent bonds displayed correctly as electron pairs

1

two lone electrons displayed not necessarily as a pair

1

[11]

15 (a) (i) nitrogen + hydrogen → ammonia

accept full correct balanced equation

1

(ii) reversible (reaction) (owtte)

*do **not** allow just 'backwards' (unqualified)*

1

(iii) catalyst / speed up reaction

accept to lower activation energy

1

(iv) boiling point

1

(v) recycled (owtte)

1

(b) (i) used to make explosives (owtte) used to make medicines (owtte)

1

(ii) used to make fertilisers (owtte)

1

(c) (i) sensible answers such as

provides workers (owtte)

good transport links

ignore reference to raw materials

1

(ii) sensible idea

1

linked reason

idea
linked reason

eg escape of chemicals /fumes /waste gases / pollution
harmful to health / environmental damage owtte
*do **not** allow harmful / damage / smell (unqualified)*

risk of explosion
because of high pressures / may endanger local people / dangerous

risk of fire
because of high temperatures / may endanger local people

noise
*any detrimental effect on quality of life **or** night and day*

lorries / traffic
danger / noise / pollution etc

unsightly
detrimental effect on quality of life / house prices / reduced tourism

uses a lot of land
loss of habitats

1

[10]

16 (a) $\rightleftharpoons$

1

ammonia

allow NH_3

1

(b) increases

1

quickly at first *then slows*

ignore levels off

allow rate of increase slows for first two marking points

1

at any number in range from 160 – 220 (atmospheres)

allow any number in range 60 – 66 (%)

1

(c) (nitrogen and hydrogen) recycled

allow (nitrogen and hydrogen) reused

1

(d) (i) *jobs lost*

accept mines closed ***or*** *local economy damaged*

1

(ii) any **one** from:

- *nitrates* / fertilisers cost less
- more crops / food can be grown
- food costs less
- *nitrates / fertilisers more widely available*

1

[8]

17 (a) natural gas

allow correct answer shown in box if answer line blank

1

(b) (i) 450

allow correct answer shown in box if answer line blank

1

(ii) iron

allow correct answer shown in box if answer line blank

1

(iii) The catalyst lowers the activation energy.

1

(c) (the gases are) cooled

1

ammonia condenses

allow ammonia liquefies

1

nitrogen and hydrogen are recycled

*if no other mark awarded allow ammonia is separated for **1** mark*

1

[7]

18 (a) (i) natural gas

allow fossil fuels / biogas generator

1

(ii) air contains oxygen

1

this would react with / oxidise the hydrogen

allow this would react with / oxidise the iron

ignore nitrogen

1

(iii) cooled

1

ammonia condenses / liquefies (so can be separated)

1

nitrogen and hydrogen (remain as gases and) are returned to the reactor

allow recycled

1

(b) (i) 200 °C **and** 1000 atmospheres

1

(ii) the reaction is reversible

allow stated as equilibrium or forward / backward reaction anywhere in answer

1

forward reaction is exothermic so increased temperature lowers the yield of ammonia

allow converse

1

a lower temperature would decrease rate of reaction

allow converse

1

a higher pressure would increase the yield of ammonia because the forward reaction produces the least number of (gaseous) molecules / moles

allow converse

1

higher pressures would involve high cost / energy 1

ignore risk / explosion

[12]

Examiner reports

1

(a) The great majority of students knew the meaning of the reversible reaction symbol.

(b) About three quarters of students answered correctly.

(c) The majority of the students scored a mark here. However, there were some who stated that nitrogen and hydrogen were released into the air or condensed.

(d) Although most students managed to score one mark, disappointingly only about a third managed to sequence the statements entirely correctly for two marks.

2 (a) Many students gained a mark for indicating that ammonia is turned into a liquid in the separator but fewer gained a mark for stating that this is achieved by cooling the mixture. Common misconceptions were that the mixture is filtered or that the ammonia is heavier than the nitrogen and hydrogen. Some students stated that the mixture is heated so that the nitrogen and hydrogen evaporate off, leaving the liquid ammonia. This did not gain credit.

(b) (i) Despite the reversible nature of the Haber process being quite frequently referred to, only a minority of students were able to link the fact that the forward reaction is exothermic to the effect of a decrease in temperature on the position of equilibrium. Some students confused exothermic and endothermic; other non-scoring answers attempted an explanation based on Le Chatelier's principle but only restated the information given in the question. Some weaker students attempted an explanation based on rate of reaction.

(ii) Many excellent, comprehensive answers to this rate of reaction question were seen. Despite the fact that there were some references to particles vibrating which were ignored, most students gained a mark for stating that the particles have more energy or move faster when the temperature is increased. Fewer students, but still the majority, gained a mark for referring to the increased frequency of collisions or the increased proportion of collisions that result in a reaction. A small number of students appear to have the misconception that the activation energy increases when more energy is put into a system.

(iii) Students found this question very difficult. Many students gave an explanation in terms of rate of reaction and did not make the link between the increased yield of ammonia and the numbers of reactant and product molecules in the chemical equation. A few students gave detailed answers in terms of Le Chatelier's principle which were, of course, accepted. The idea of the particles being squashed closer together was often given but did not gain credit.

(iv) Approximately half of the students gained this mark with the most common response being a reference to the cost implications of using a much higher pressure. References to the risk of explosion were sufficient to convey the idea of such a high pressure being difficult to contain but responses such as “it would be too dangerous” were considered to be too vague to gain credit.

(c) (i) Approximately half of the students were able to use the mole ratio in the chemical equation to correctly calculate the volume of hydrogen needed. The most common incorrect answer was 20.

(ii) Many of the students found this type of calculation very difficult but almost a fifth of students gained all three marks. The correct answer gained full credit even if there was no working but students should always be encouraged to show their working. It would be helpful to examiners if students would set out their working clearly since it is difficult to award marks to a jumble of numbers. The question revealed that a significant number of students do not fully understand the use of numbers and formulae in chemical equations; a common error was finding the mass of $2NH_3$ to be $(2 \times 14) + (3 \times 1) = 31$.

(d) (i) Most students correctly calculated the percentage yield of ammonia.

(ii) The majority of students gained a mark for the idea that the unreacted nitrogen and hydrogen are recycled and put through the process again. Few students gained a mark for stating that the process is fast or that it is continuous. Despite being asked to give two reasons, most students gave only one reason.

3

(a) (i) Just over half of students were able to select both sources correctly. The most common error was to assign air and natural gas the wrong way round, but a number thought that iron ore or limestone were the sources of one or both.

(ii) Under a third of students could both describe iron as a catalyst and explain what a catalyst does. A large number of students either wrote in terms of 'iron being a transition element' or it being 'magnetic'.

(iii) This was not well known. The vast majority of students missed out the 'cooled' mark but some recognised that ammonia is liquefied, from the information in the diagram.

(iv) This was much better answered. More than half knew that nitrogen and hydrogen are recycled. A common incorrect response was that they are 'released back into the air'.

(b) Many of the students knew the reversible sign, although some used a double headed single arrow. Although hydrogen was quite often seen, guesses were apparent for the product. All sorts of chemicals appeared, as long as 'nitrogen' and 'hydrogen' were in them e.g. nitrogen hydroxide, hydrogen nitrate, ammonium, nitrate hydroxide and sometimes even water.

4

(a) About two thirds of students knew that nitrogen is obtained from air. Popular incorrect answers included methane, the soil and ammonia.

(b) Most students gained both marks but a significant number, although mentioning recycling, failed to identify nitrogen and hydrogen as the substances being recycled. A number of students produced imaginative but incorrect answers ranging from systems for regenerating catalysts to methods of equalising pressure.

(c) This question presented no problem for most students, who were able to balance the equation successfully either from memory or by calculation.

(d) Many students gave good descriptions of the effect of temperature on equilibrium yield and rate for two marks although many also lost a mark by only considering one of the two. Some referred to the increased cost of higher temperatures; others addressed the effect of pressure. Many simply stated that it gave a good yield at a good rate without explaining why.

(e) (i) Approximately two thirds of students gained the mark. Some who chose to answer in terms of the energy difference between bond breaking and formation made the common mistake of describing both processes as requiring energy. Some explained what exothermic meant without relating it to the evidence in the diagram.

(ii) A little under half of students scored the mark. Many clearly did not know how to represent the effect of a catalyst on the diagram. Changes in the energies of the reactants and, particularly, products were very common, and a significant number of students tried to show that the reaction is speeded up by squeezing the diagram along the x-axis.

5

(a) Students were clearly familiar with this example from the specification. Most scored full marks by correctly adding three bonding pairs of electrons and two non-bonding electrons (not necessarily in a pair) to the outer energy levels of the atoms. The most common errors included extra electrons in the nitrogen and hydrogen atoms.

(b) (i) Students found this question easy and most correctly identified that ammonium nitrate is produced by reacting ammonia with nitric acid.

(ii) Students were familiar with the uses of ammonium nitrate that are given on the specification.

(iii) Virtually all students correctly calculated the *M*r of NH_4NO_3 as 80. Mathematical errors cost some students 1 mark.

(iv) Most students found this question straightforward. Some students calculated the percentage of nitrate instead of nitrogen and got the wrong answer. Some students scored 1 mark by calculating the percentage of nitrogen as 17.5% by failing to spot that there were two nitrogen atoms per molecule. Error carried forward from the previous part was used here in the case of a wrong answer.

(c) The question produced a wide range of responses. Some showed an excellent understanding of the conditions in the Haber process and how Le Chatelier's Principle is applied to the system and made excellent explanations of the compromise that exists between rate and yield. The most common sort of response explained the conditions relating to temperature, pressure and a catalyst but failed to fully explain the compromise that existed in the process. A lot of students confused the effect of temperature and pressure on the position of equilibrium and many were unclear as to the difference between rate and yield.

6

Some excellent answers were seen which went well beyond the requirements of the syllabus. Other candidates wrote at length and said very little. Some gave answers which confused rate and yield. A good answer was expected to state how temperature and pressure affects the yield of ammonia and to explain why the actual conditions used are a compromise between yield, rate, costs etc. A variety of responses were accepted.

7 (a) The majority of students knew the formula of ammonia and were also able to balance the equation. Only a few students scored just one mark. The most common incorrect answer, although there were many others, was N_2H_6.

(b) (i) The vast majority of students were able to interpret the graph correctly for this question.

(ii) A majority of candidate answered correctly but a very significant minority tried to answer, incorrectly, in terms of yield.

(iii) About two thirds of students answered correctly. Given that the question presented a restricted choice of answers it would seem that students found it significantly more difficult than question (i).

(vi) A majority of students answered correctly. The fact that answers in terms of either rate or yield were acceptable perhaps explains why students performed better in this question than in question (ii).

(c) About half of students gained at least one mark; only about a fifth gained both. The mark for the condensation of ammonia was much more common than the mark for explaining that this is achieved by cooling. Some confused the separation of the gases with their reaction, giving the conditions in the reactor. Many referred to nitrogen and hydrogen being recycled.

8 Part (a) was done reasonably well by most candidates but few candidates gained more than two or three marks in part (b). This part of the question was frequently answered in terms of rate rather than yield. Also constraints on increasing the yield - i.e. the increased cost of the plant and its decreased cost-effectiveness as the pressure increases and the slower rate of reaction if the temperature is too low - were seldom mentioned.

(The diagram incorrectly indicated that unreacted ammonia rather than unreacted hydrogen is recycled along with unreacted nitrogen. Candidates were, therefore, given full credit for quoting the re-cycling of the materials shown on the diagram as one aspect of increasing the yield.)

9 (a) Though a sizeable minority correctly balanced the equation, many – some of whom did not attempt the item – did not.

(b) Most candidates gained one mark for specifying the optimum temperature and pressure shown; many gained the second mark for identifying the trends.

10 **Foundation Tier**

Some candidates knew what the (g) meant and others used their imagination suggesting 'gen' in nitrogen, for example. Most candidates were able to explain the reversed arrows and the better ones gave air, or the atmosphere, as the source of the nitrogen. Only a minority of candidates were able to write a convincing explanation of how they could tell that the equation is balanced. The minority who could name an appropriate ammonium salt were usually able to name the required acid. Many candidates realised the value of solubility of ammonium fertilisers but a common erroneous belief was that plants feed on fertiliser. Few candidates were able to describe convincingly the nature of compounds with many references to chemicals and substances rather than to elements or different atoms. Only a small minority could say what a covalent bond is. Amongst those who made a start, a very common mistake was to write about one electron being shared.

Higher Tier

Both of the symbols were well known. Some gave grams instead of gas for (g). However, air was seldom given as the raw material for nitrogen. Most could give good explanations of why the equation was balanced. Surprisingly, many gave a wrong acid for a suitable ammonium salt. Candidates could apply their knowledge to suggest why the solubility of ammonia is a useful property of a fertiliser.

When specific explanations were required, weaker candidates did not give clear enough answers to gain marks. For example when completing the sentence defming a chemical compound, common mistakes were to fail to specify that the atoms were different or to refer only to mixing.

Similarly with the covalent bond, which was well answered by many, a number only referred to sharing one electron.

11 Parts (a)(i) and (ii) were generally well answered but only a minority appeared to have any idea about how to proceed with the calculation in part (iii).

Few candidates recognised the symbol for megapascals and some, without any regard for the context, identified it as a millipascal.

The remainder of the question was well answered except that, in (c), whilst all the other boxes were often correctly filled, the nature of whatever was leaving the evaporator was a mystery to many.

12 Parts (a) and (b) were usually well answered. In (c) candidates often found this question very difficult and some scored very few marks, despite giving quite long answers. It was hoped that the graph would give the candidates a starting point upon which they could build an answer, based on their knowledge of syllabus section 3.3.5. Two marks were available for simply interpreting the graph and stating that a high yield of ammonia would be obtained at low temperature and high pressure. A number of candidates clearly did not understand the graph and gave very confused answers. It was also hoped that the equation at the start of the question would jog their memories to the reversible nature of the reaction, but many candidates made no reference to this. A wide range of answers was accepted in the mark scheme. More able candidates often gave excellent answers which sometimes went far beyond the requirements of the syllabus.

13 The graph in part (a)(i) was usually well drawn with many candidates gaining all four marks. Some candidates found difficulty with the scales which were sometimes non-linear whilst others made the intervals complicated so that it was difficult for them to plot the points accurately. Best lines of fit were usually drawn well although some candidates join the dots with straight lines or draw multiple lines. The vast majority of candidates answered parts (a)(ii) and (a)(iii) correctly.

Most candidates were able to gain the mark for part (b)(i) and the quality of answers for (b)(ii) was significantly better than last year. Some candidates write about temperature and pressure at the same time so that the answer becomes confused and difficult to give credit. Others remembered that the conditions used are a compromise but fail to explain why. A minority of candidates seemed very confused about the reasons for the conditions used and gave answers such as ‘the yield is kept low so that they do not make too much ammonia’ or ‘the yield is kept low so that some of the nitrogen and hydrogen can be re-used’. It is pleasing to report that many candidates were able to explain the reason why a low temperature gives a high yield of ammonia in terms of the reaction being exothermic and similarly why pressure affects the yield in terms of the relative number of reactant and product molecules. Questions of this type are best answered when the candidate structures the answer with separate paragraphs on the effect of temperature, the effect of pressure and a concluding paragraph which explains the compromise or the fact that the yield is not too important because the unreacted gases can be recycled.

The calculations of part (c) were usually well answered. In part (c)(i) some candidates lost the mark because they did not understand the formula and interpreted NH_4 as $(NH)_4$ and NO_3 as $(NO)_3$. The percentage calculation was very well done. A number of candidates managed to complete this calculation even when they did not calculate the M_r correctly in part (c)(i). Some candidates calculated (28/100 x 80) rather than (28/80 x 100).

14 **Double Award only**

There were many good answers to this question. Part (a) caused problems to a few candidates who could not recall the amount of nitrogen in the atmosphere or thought that plants convert nitrogen into nitrates instead of proteins. Most candidates could identi1_ correctly one source of hydrogen and understand that another product was carbon dioxide. In (c), whilst the catalyst for the Haber process was known by most candidates, there were many incorrect chemical equations often using 2N or $2H_3$. In (ii) surprisingly few candidates scored both marks. Many appreciated that the reaction was too slow at the lower temperature, so they usually stated that the only reason for using a higher temperature was to increase the reaction rate. It was rare to find a description of, or the idea of. activation energy. There were many correct diagrams of the ammonia molecule, although several were quite carelessly drawn.

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15 Part (a)(i) was quite well answered. A common error was to reverse the positions of hydrogen and ammonia while some candidates invented names such as nitrogen hydroxide or inserted the conditions used in the process. A few candidates inserted incorrect formulae or mixed and matched names and formulae. Candidates would be well advised to give a word equation when asked rather than making the question more difficult by attempting a symbol equation.

Many candidates answered part (a)(ii) correctly either by stating reversible or by describing the meaning of reversible. A few candidates incorrectly thought that the symbol means equal or balanced.

A variety of responses were seen for part (a)(iii). Some candidates thought that the answer was linked to the reactivity of iron or heating effect of iron.

Part (a)(iv) was poorly answered with only about one third of the candidates giving the correct response.

Part (a)(v) was well answered. Credit was given for ideas such as the gases are reused or are sent back to the beginning. A few candidates mistakenly thought that the gases are released into the atmosphere, stored or sent to the cooling chamber.

In part (b)(i) good answers referred to explosives / bombs or medicines. The use of ammonia to gas people or in gas bombs was commonly seen. Some candidates gave vague answers such as weapons or equipment which did not gain credit.

In part (b)(ii) the majority of candidates made the link with fertilisers. Incorrect responses included dyes to colour the food and plastics to package food.

Very few candidates answered part (c)(i) correctly. A range of answers were accepted such as the availability of a workforce or the existence of a transport infrastructure. Incorrect responses included the idea that the atmosphere would contain a good supply of nitrogen and hydrogen.

Candidates found it difficult to suggest **and** explain in part (c)(ii). The majority of candidates gained one mark. This was often gained for some reference to pollution but candidates then failed to go on to discuss the effect of the pollution. Some good answers were seen which explained that the plant would produce a lot of noise which would affect the local neighbourhood day and night. Many vague answers were seen such as it will cause global warming.

16

(a) More than half the students gained both marks and the vast majority scored at least one. Most knew the reversible reaction sign although some did draw a double headed arrow. Guesses were apparent with the product. Suggestions mostly contained nitrogen and hydrogen e.g. nitrogen hydroxide, hydrogen nitrate, ammonium and nitrate hydroxide.

(b) More than half the students were awarded all three marks. The first and thirds marks proved reasonably easily achievable. Many students had difficulty in expressing themselves clearly. A number of students simply stated that ‘it levelled off’.

(c) The vast majority of students answered correctly There were some who stated that nitrogen and hydrogen were condensed or released into the air.

(d) (i) About two thirds of students were able to answer satisfactorily. Redundancy was the most common answer. Some stated that ‘it made their job much easier’ or ‘they had more jobs’, perhaps because they had not read the question correctly. Others made references to effects on health, such as breathing problems or poisonous gases.

(ii) Students found this question difficult. A large number of students effectively repeated the question in their own words.

17 (a) Just over half identified natural gas.

(b) (i) Three quarters recognised 450 °C correctly.

(ii) Around two thirds knew that iron is the Haber catalyst.

(iii) Just under half identified how a catalyst works correctly.

(c) Only a few students scored three marks. The vast majority of students missed out the 'cooled' mark. There was great confusion as to what was happening in the condenser. For some students, nitrogen and hydrogen were reacting in the condenser but they all seemed to know that the unreacted gases are recycled and ammonia is extracted in liquid form.

18 (a) (i) This was poorly answered. The most common reference by far was to livestock – usually cows – or livestock slurry. Other responses included marshes and swamps, rice plantations and landfill sites – none of which were creditworthy. The mark scheme did allow credit for biogas generators.

(ii) This was also poorly answered. Some students thought that the ratio of nitrogen to hydrogen would be disturbed, that equilibrium would be affected as it would not be a closed system or just gave a general comment that the reactions would not take place properly. Only relatively few recognised that oxygen would cause a reaction, and even then a proportion spoiled the first marking point by listing several gases in air rather than focussing on oxygen. For the second mark, 'air would react with hydrogen or iron' was creditworthy.

(iii) This Haber process question was poorly answered. Many students began with an irrelevant description of what had already taken place in the reactor. The idea that the mixture is cooled was the least well known available mark, whereas best known was that nitrogen and hydrogen are recycled. Condensation or liquefaction of ammonia lay between these extremes. Many students suggested that the mixture was indiscriminately condensed, or that it was separated by fractional distillation. There were also vague descriptions of ammonia going to storage and incorrect ones of nitrogen being released back into the air.

(b) (i) More than half of students were able to read correct values from the graphs. No credit was available for the vague 'high pressure and low temperature'.

(ii) This was an extended question about the Haber process equilibrium. The extended nature of it undoubtedly made the question challenging. Few students scored 3, 4 or 5 marks. The marks that were easiest to gain were for suggesting that high pressures are expensive, and that the reaction is slow at low temperatures. Few students explicitly mentioned that the reaction was reversible, but some gained this mark implicitly by talking about equilibrium, forward or backward as part of their answer. The two most difficult marks to obtain were those relating to the effect of temperature and pressure on yield, because these had to be linked with an understanding of the exothermic energy change and fewer moles or molecules in the forwards direction respectively. Some students got no further than saying that 450 °C and 200 atm are compromise conditions.