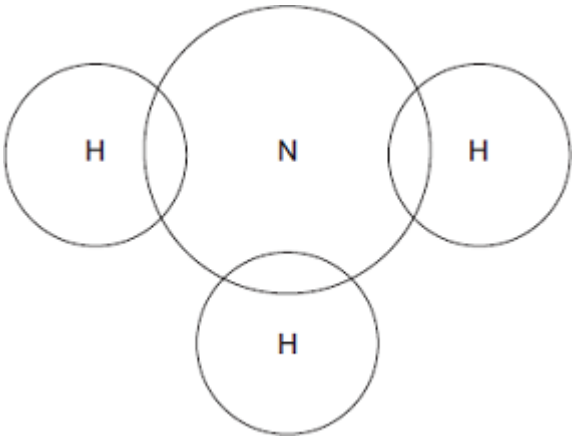
C3 Revision – Haber Process

21.(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:

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

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.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

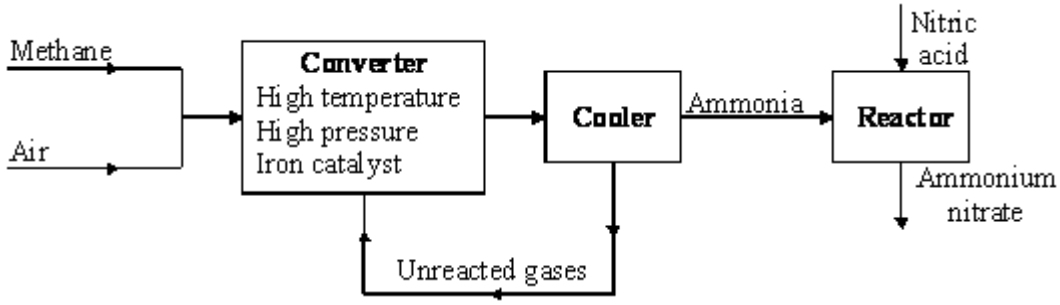
.....

.....

..... **(6)**

(Total 14 marks)

Q2. The flow diagram shows some stages in the manufacture of ammonium nitrate, NH_4NO_3.



(a) Which elements are obtained from the raw materials to make ammonia in the converter?

.....

.....**(2)**

(b) Suggest the purpose of the iron catalyst.

..... **(1)**

(c) Farmers add ammonium nitrate to the soil. Explain why.

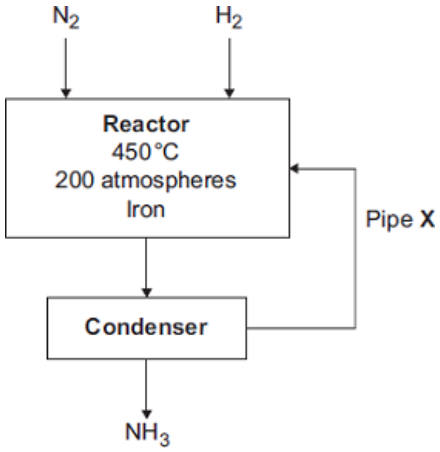
.....

.....

.....

.....**(2)(Total 5 marks)**

Q3. 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.

.....

.....

.....

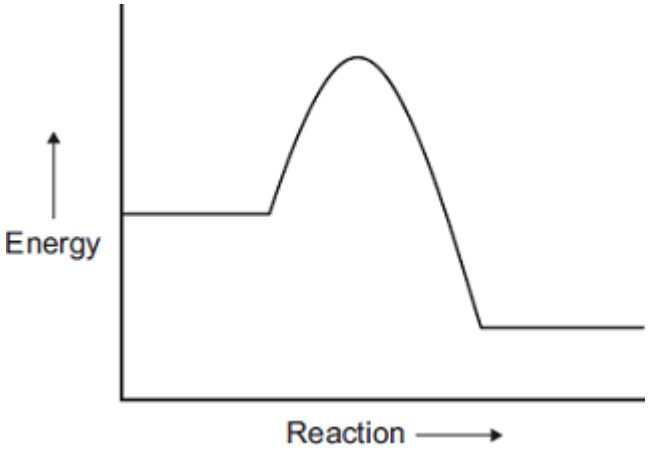
.....

.....

.....

(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)

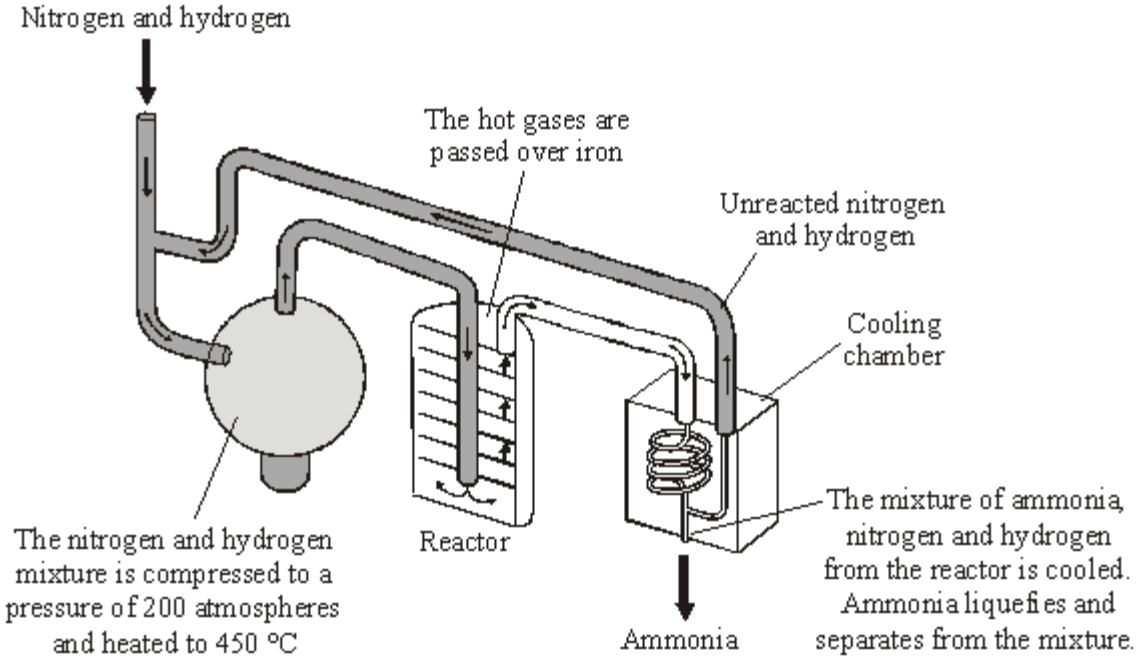
(ii) In the Haber process iron is used as a catalyst.

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

(1)
(Total 8 marks)

Q4. 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.

.....

.....

.....

.....

.....

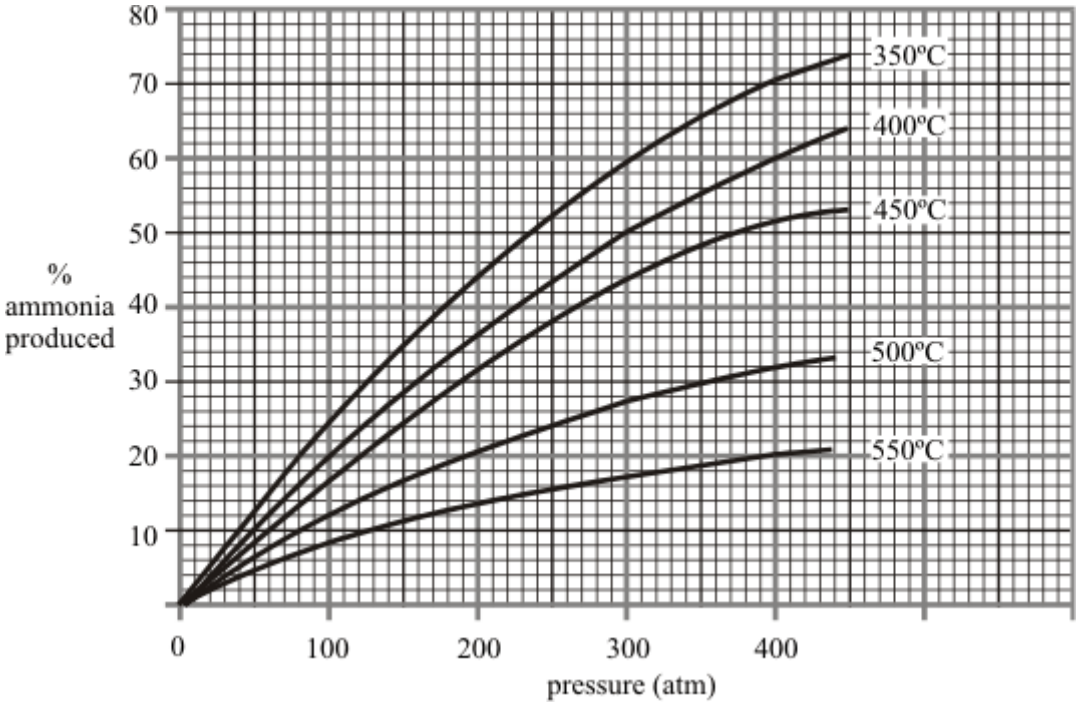
..... **(3)**

(Total 12 marks)

Q5. 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)

M1.(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]

M2. (a) nitrogen

consider answers as a list

1

hydrogen

1

(b) speed up the reaction

accept increase rate of reaction

1

(c) fertiliser

*accept to replace **or** add nitrogen **or** nutrients*

*do **not** accept minerals or nitrates*

1

growth

*accept for protein **or** increased yield*

1

[5]

M3.(a) air

1

(b) recycle

allow re-use

1

(unreacted) nitrogen and hydrogen

allow N_2 and H_2

1

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

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]

M4. (a) 1213.8 to 1214.3

*gains **3** marks without working*

correct answer not given then check working

1) moles of N_2 = $\frac{1000}{28}$ = 35.7 mol

***1** mark for each correct step*

*do **not** penalise rounding errors in this part*

2) moles of NH_3 = 2 × (answer from (1)) = 71.4 mol

3) mass of NH_3 = (answer from 2) × 17 = 71.4 × 17 = 1214 g

3

or

- 28g of N_2 → 34g of NH_3

***1** mark for each correct step*

- 1g of N_2 → $\frac{34}{28}$ = 1.214g NH_3

*do **not** penalise rounding errors in this part*

- 1000 g of N_2 → 1000 × 1.214
  = 1214g

allow error carried forward eg

or

- 1000 × $\frac{34}{28}$

*gains **2** marks if correct answer not given*

*1000 × $\frac{28}{34}$ gains **1** mark, **2** marks if correctly calculated*

*(823.5g) 1000 × $\frac{28}{17}$ gains **1** mark if calculated correctly*
(1647.05g)

or

other correct methods
look for the key ideas in the methods above

(b) 25 **/** 25.035 **or** ecf from (a)
*gains **2** marks even when there is no working*
*incorrect answer then 304/(their answer from (a)) × 100 gains **1** mark*

or using figures from part (b)

27.6 / 28
*gains **2** marks even when there is no working*
*accept 27 for **1** mark*
*if answers incorrect then304/1100 × 100 gains **1** mark*

2

(c) (i) increase yield

1

reaction is exothermic

or

allow decreased yield because rate of reaction is slower / fewer collisions for **2** marks
***must** get both points for **2** marks*

1

(ii) increase yield

1

plus **one** from:

- more (gaseous) reactant molecules than (gaseous) product molecules (owtte)

accept greater volume on the left than the right owtte

- increased rate of reaction / more collisions

1

(d) any **one** from:

economic

- large town provides workforce
- workers do not have to travel far to the factory. (owtte)
- transport infrastructure already in place for large town. (owtte)
- factory brings prosperity to town (owtte)
- factory provides employment
- reduced tourism
- reduction in local house prices
- any other sensible economic factor linked to town

1

any **one** from:

safety

- <u>escape</u> of dangerous / harmful chemicals / gases (owtte)
  *do **not** allow polluting gases unqualified*
- <u>danger</u> of increased traffic
- risk of explosion.(owtte) /danger of high pressure
- consequences of an accident could be severe if the town is close
- any other sensible safety idea

1

any **one** from:

environmental

- factory might be unsightly (owtte)
- screening of factory (owtte)
- loss of habitats (owtte)

- plant trees/ hedges etc on and around plant site

- pollution of water / air / soil could harm plants / animals **or** noise pollution
must be explained

- CO_2 is produced by burning fuels / heating

- CO_2 causes global warming / any effect of global warming

- eye sore

- any other sensible environmental factor

1

[12]

-

M5. 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]