The Haber process

4.10.4.1 · Using resources · revision notes

How ammonia is manufactured from nitrogen and hydrogen, the conditions used, and (Higher tier) why those conditions are a compromise between rate, equilibrium yield and cost. This is in GCSE Chemistry only, not in Combined Science. Expect recall of the conditions and 4 to 6 mark 'explain why' questions on Paper 2, often with a graph or table of yield against temperature and pressure.

Key facts

- $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (forward reaction exothermic)
- Conditions: iron catalyst, about 450 °C, about 200 atmospheres
- Grade 7+ only Higher pressure → equilibrium shifts to fewer gas molecules (right) → higher yield and faster rate, but more expensive and dangerous
- Catalyst: faster rate, no change to the yield
- Nitrogen from the air; hydrogen from natural gas
- Cool → ammonia liquefies and is removed; unreacted N_2 and H_2 are recycled
- Grade 7+ only Lower temperature → higher yield (forward reaction exothermic) but slower rate
- Ammonia is used to make nitrogen-based fertilisers

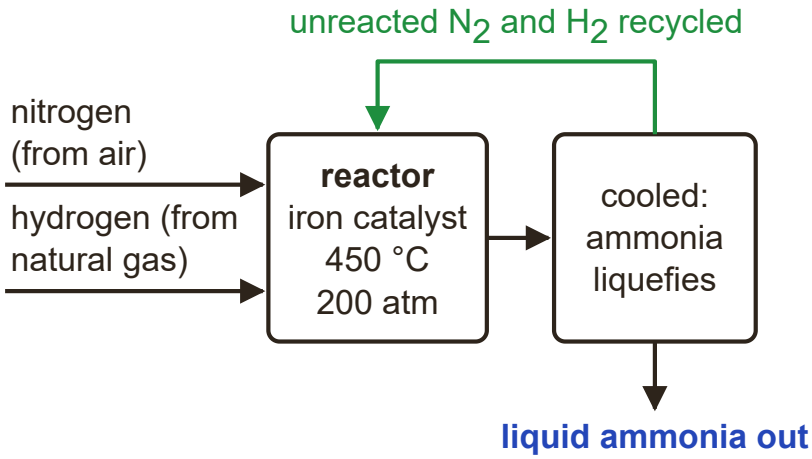
Notes

Making ammonia

- The **Haber process** manufactures **ammonia**, NH_3, which can be used to produce nitrogen-based fertilisers.
- The raw materials are **nitrogen**, from the **air**, and **hydrogen**, from **natural gas** (methane).
- nitrogen + hydrogen ⇌ ammonia, or $N_2 + 3H_2 \rightleftharpoons 2NH_3$
- The reaction is **reversible**, and the forward reaction is **exothermic**.

The process

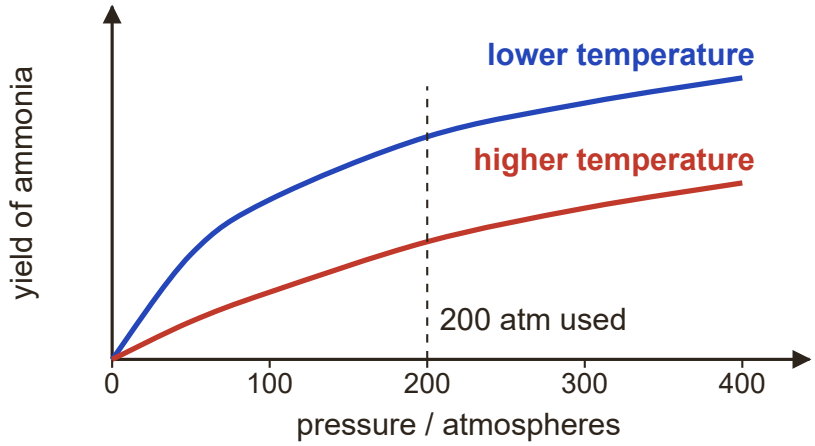
- The purified gases are passed over an **iron catalyst** at a high temperature (about **450 °C**) and a high pressure (about **200 atmospheres**).
- Some of the nitrogen and hydrogen react to form ammonia. Because the reaction is reversible, some of the ammonia breaks down again into nitrogen and hydrogen.
- The gas mixture is **cooled**: the ammonia **liquefies** and is removed. Nitrogen and hydrogen have much lower boiling points, so they stay as gases.
- The unreacted nitrogen and hydrogen are **recycled** back over the catalyst, so little is wasted.



$N_2 + 3H_2 \rightleftharpoons 2NH_3$: ammonia is removed as a liquid; unreacted gases go round again.

Why these conditions? Grade 7+ only

- **Pressure**: there are 4 molecules of gas on the left and 2 on the right. A higher pressure shifts the equilibrium to the right (fewer gas molecules), increasing the yield. It also increases the rate, because the gas particles are closer together and collide more often.
- But very high pressures need strong, expensive equipment and a lot of energy to compress the gases, and are more dangerous. About 200 atmospheres is a **compromise**.
- **Temperature**: the forward reaction is exothermic, so a **lower** temperature shifts the equilibrium to the right and gives a **higher yield**. But at a low temperature the rate is too slow.
- About 450 °C is a **compromise**: the yield is lower, but ammonia is produced quickly enough, so more is made each hour.



Higher pressure and lower temperature give a higher yield, but the conditions used are a compromise.

- **Catalyst**: iron increases the rate of the forward and reverse reactions equally. Equilibrium is reached faster, but the position of equilibrium (the yield) does not change.
- The conditions also depend on the availability and cost of raw materials and energy: recycling the unreacted gases saves raw materials, and energy costs limit how high the pressure can be.

How to answer each type of question

Recall the raw materials and conditions

1 to 4 marks | Grade 4

1. Nitrogen from the air; hydrogen from natural gas.
2. Give the conditions with units: about 450 °C and about 200 atmospheres.
3. The catalyst is iron.

Example. (a) Give the source of the hydrogen used in the Haber process. (1 mark)
(b) State the temperature and pressure used in the Haber process. (2 marks)
(c) Name the catalyst. (1 mark)

Model answer.

(a) Natural gas / methane (1)
(b) About 450 °C (1); about 200 atmospheres (1)
(c) Iron (1)

Describe what happens to the gases after the reactor

2 to 3 marks | Grade 5

1. Say that the mixture is cooled.
2. Say that the ammonia liquefies and is removed.
3. Say that the unreacted nitrogen and hydrogen are recycled.

Example. The gas mixture leaving the reactor contains ammonia, nitrogen and hydrogen. Describe how the ammonia is separated from the mixture and what happens to the other gases. (3 marks)

Model answer. The mixture is cooled (1). The ammonia liquefies (condenses) and is removed (1). The unreacted nitrogen and hydrogen are recycled back over the catalyst (1).

Interpret yield data

2 to 4 marks | **Grade 7**

1. Describe the trend, quoting values from the data.
2. Explain it using the equation: the forward reaction is exothermic, or there are fewer gas molecules on the right.
3. Remember that the equilibrium yield is not the same as the amount made per hour: the rate matters too.

Example. The table shows the percentage yield of ammonia at equilibrium at 200 atmospheres.

Temperature (°C)	300	400	500
Yield of ammonia (%)	63	36	18

(a) Describe the trend shown by these data. (1 mark)
(b) Explain this trend. (2 marks)
(c) Suggest why a temperature of 300 °C is not used, even though the yield is highest. (1 mark)

Model answer.

(a) As the temperature increases, the yield of ammonia decreases (1).

(b) The forward reaction is exothermic (1), so increasing the temperature shifts the position of equilibrium to the left, in the endothermic direction (1).

(c) The rate of reaction would be too slow, so less ammonia would be produced per hour (1).

Calculate the mass of ammonia produced

2 to 3 marks | **Grade 7**

1. Use the balanced equation: 1 N_2 gives 2 NH_3.
2. Convert mass to moles (or use a mass ratio): moles = mass ÷ M_r.
3. Multiply by the mole ratio, then by the M_r of ammonia. Keep the same mass unit throughout.

Example. Calculate the maximum mass of ammonia that can be produced from 14 tonnes of nitrogen.
$N_2 + 3H_2 \rightleftharpoons 2NH_3$
Relative formula masses (M_r): N_2 = 28, NH_3 = 17 (3 marks)

Model answer. 28 tonnes of N_2 produce 2 × 17 = 34 tonnes of NH_3 (1); 14 × 34 ÷ 28 (1) = 17 tonnes (1)

6-mark: explain the conditions used

4 to 6 marks | **Grade 8**

1. For each condition, give its effect on the equilibrium yield AND on the rate.
2. Explain the equilibrium effect from the equation: fewer gas molecules on the right (pressure); forward reaction exothermic (temperature).
3. Give the cost or safety problem that stops a more extreme condition being used.
4. Use the word compromise, and say that the catalyst increases the rate without changing the yield.

Example. $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$. The forward reaction is exothermic.
Explain why the Haber process uses a temperature of about 450 °C and a pressure of about 200 atmospheres. (6 marks)

Model answer.

Temperature: the forward reaction is exothermic, so a lower temperature would shift the equilibrium to the right and give a higher yield (1). But at a lower temperature the rate would be too slow (1). About 450 °C is a compromise that gives a reasonable yield at a fast enough rate (1).
Pressure: there are fewer gas molecules on the right (2 molecules) than on the left (4 molecules), so a higher pressure shifts the equilibrium to the right and increases the yield; it also increases the rate (1). But higher pressures need stronger, more expensive equipment and more energy to compress the gases, and are more dangerous (1). About 200 atmospheres is a compromise between yield, rate and cost or safety (1).

Don’t lose marks

- Saying the catalyst increases the yield. It only increases the rate; the position of equilibrium is unchanged.
- Saying a high temperature is used to increase the yield. A higher temperature decreases the yield because the forward reaction is exothermic.
- Leaving out the effect of temperature on rate, which is the reason 450 °C is used instead of a lower temperature.
- Swapping the sources: nitrogen comes from the air and hydrogen from natural gas.
- Writing that high pressure is 'too expensive' without saying why: strong equipment, energy to compress the gases, safety risk.

More tips

Memory tricks

- The Haber numbers: iron, 450 °C, 200 atmospheres.
- Pressure: count the gas molecules. 1 + 3 = 4 on the left, 2 on the right. High pressure favours the side with fewer.
- Temperature: exothermic forward reaction, so cooler favours ammonia, but cooler is slower.
- A catalyst changes how fast, never how much.
- Every Haber 'why' answer needs the word compromise.

Exam technique

- In 6-mark questions, cover temperature and pressure (and the catalyst if there is space), each with its effect on yield AND rate.
- Explain equilibrium shifts from the equation: 'there are fewer molecules of gas on the right-hand side' or 'the forward reaction is exothermic'.
- When a graph or table is given, quote values from it with units to support your answer.
- Give the conditions with 'about': about 450 °C and about 200 atmospheres.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3

State what the Haber process makes

Ammonia, which is used to make nitrogen-based fertilisers.

Grade 4

Give the sources of nitrogen and hydrogen

Nitrogen comes from the air; hydrogen comes from natural gas (methane).

Grade 4

Recall the conditions used

An iron catalyst, about 450 °C and about 200 atmospheres.

Grade 5

Describe how ammonia is separated and gases recycled

On cooling, ammonia liquefies and is removed; unreacted nitrogen and hydrogen are recycled.

Grade 6

Write the balanced equation

$N_2 + 3H_2 \rightleftharpoons 2NH_3$; the reaction is reversible and the forward reaction is exothermic.

Grade 7

Explain the choice of pressure

Higher pressure favours the side with fewer gas molecules and increases the rate, but costs more and is more dangerous.

Grade 8

Explain the temperature compromise

A lower temperature gives a higher yield but is too slow; about 450 °C gives a fast enough rate with a reasonable yield.

Grade 8

Interpret graphs of yield against conditions

Describe the trends with data and use them to justify the conditions chosen.

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