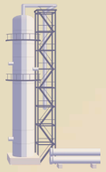
10 Ammonia



1 The Haber Process

1.1 Making ammonia

- Ammonia is made industrially by the **Haber process**. About 80% of it is used to make _____. It is also used to make plastics, explosives, dyes and cleaning products.

Raw material	Obtained from
nitrogen, N_2	the _____
hydrogen, H_2	the _____ of crude oil fractions

$$N_2(g) + 3H_2(g) ____ 2NH_3(g)$$

Forward reaction
$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

Backward reaction
$2NH_3(g) \rightarrow N_2(g) + 3H_2(g)$

- The reaction is **reversible**, so some of the ammonia made breaks down again into nitrogen and hydrogen.

NOTE At room temperature nitrogen is very unreactive. Recall from Chemical Bonding that a nitrogen molecule has a strong **triple bond**, N≡N. So the forward reaction needs a high pressure, a relatively high temperature and a catalyst.

1.2 Choosing the conditions

Condition	Effect	Used
pressure	A higher pressure gives a _____ and a faster reaction. But keeping a high pressure is costly: it needs expensive equipment and a large amount of electricity.	200 to 250 atm (a compromise)
temperature	A lower temperature gives a _____, because less ammonia decomposes. But the reaction would be too slow.	450 °C (a compromise)
catalyst	The reaction is still slow under these conditions, so a catalyst speeds it up. It does not change the yield.	finely divided _____

EXAM TIP When asked why a condition is a compromise, give both sides: what a change would do to the **yield**, and what it would do to the **rate** or the **cost**.

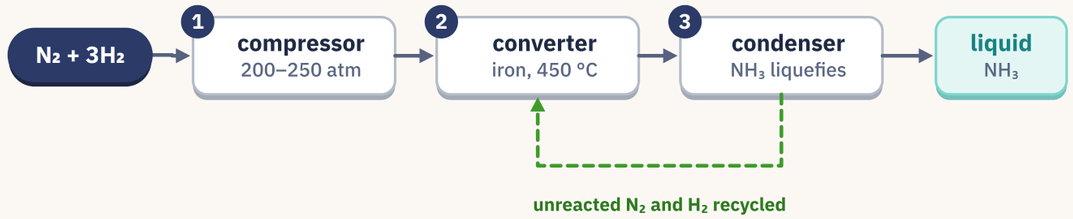
WORKED EXAMPLE Some plants run the Haber process at 300 atm instead of 200 atm. Suggest one advantage and one disadvantage of the higher pressure.

Advantage: a higher yield of ammonia *or* a faster reaction.

Disadvantage: keeping the higher pressure costs more, because more energy is needed.

1 The Haber Process (continued)

1.3 Inside the plant



1. Nitrogen and hydrogen are mixed in the ratio **1 : 3** by volume.
2. The mixture is compressed to 200 to 250 atm.
3. The gases flow over the iron catalyst at 450 °C. Only about _____ of the mixture leaving the converter is ammonia.
4. The mixture is cooled. Ammonia _____ into a liquid and is pumped into tanks.
5. The unreacted nitrogen and hydrogen are _____ back to the converter, so none is wasted.

1.4 Reading yield data

- The yield _____ as the pressure increases.
- The yield _____ as the temperature increases.
- The conditions used are a compromise between a good yield, a fast enough rate and a reasonable cost.

WORKED EXAMPLE In the Haber process, a temperature of 450 °C is used instead of 150 °C or 650 °C. Explain why.

1. At 150 °C the yield would be higher, but the reaction would be too **slow**.
2. At 650 °C the reaction is faster, but more ammonia decomposes, so the **yield is lower**.
3. 450 °C is a **compromise**: a reasonable yield at a fast enough rate.

2 Reversible Reactions

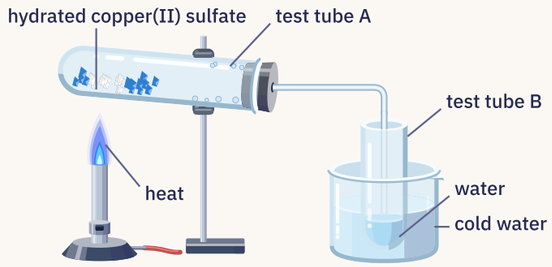
2.1 Reversible and irreversible reactions

DEFINITION A **reversible reaction** can go both _____. Its equation uses the sign ⇌.

	Reversible reaction	Irreversible reaction
What happens	The reactants change into the products, and the products can change _____ into the reactants.	The reactants change into the products, but the products cannot change back.
Examples	the Haber process, heating hydrated copper(II) sulfate, heating ammonium chloride	burning charcoal: the ash cannot be turned back into charcoal

NOTE A reversible reaction does not go to **completion**. Even under the best conditions, the forward and backward reactions keep taking place at the same rate, so the yield is always less than 100%.

2.2 Heating hydrated copper(II) sulfate

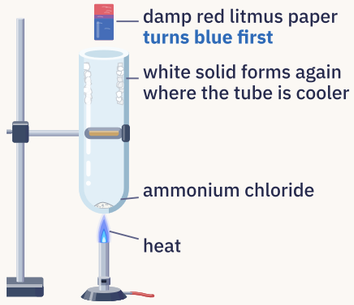


- When heated, blue **hydrated** copper(II) sulfate gives off water and turns into white **anhydrous** copper(II) sulfate. The water is collected in test tube B.
- When the water is added back, the white powder turns _____ again.



$CuSO_4 \cdot 5H_2O(s) \rightleftharpoons CuSO_4(s) + 5H_2O(l)$

2.3 Heating ammonium chloride



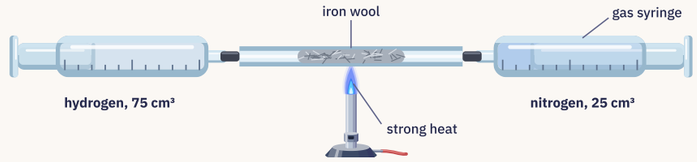
- When heated, solid ammonium chloride breaks down into **ammonia** and **hydrogen chloride**.
- Where the tube is cooler, the two gases combine to form ammonium chloride _____.
- Ammonia is lighter, so it diffuses faster and turns damp red litmus paper blue before the hydrogen chloride arrives.

$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$

WORKED EXAMPLE When solid ammonium chloride is heated, it forms ammonia and a gas X. On cooling, X combines with ammonia to form ammonium chloride again. (a) Identify X. (b) Write the equation with state symbols. (c) Ammonia reaches the end of the test tube first. What can you deduce? (d) What is the effect of X on damp blue litmus paper?

(a) X is **hydrogen chloride**, HCl.
(b) **$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$**
(c) Ammonia has a lower relative molecular mass (17) than hydrogen chloride (36.5), so it diffuses **faster**.
(d) Hydrogen chloride turns damp blue litmus paper **red**.

2.4 Yield from a reversible reaction



WORKED EXAMPLE 25 cm^3 of nitrogen and 75 cm^3 of hydrogen are passed forward and backward over heated iron wool until no further reaction is observed. Suggest the volume of ammonia produced. Explain your answer.

1. $N_2 + 3H_2 \rightleftharpoons 2NH_3$, so from the mole ratio, 25 cm^3 of nitrogen and 75 cm^3 of hydrogen could give at most **50 cm^3** of ammonia.
2. The reaction is **reversible**, so it does not go to completion.
3. The volume of ammonia is **less than 50 cm^3**.

NOTE At the same temperature and pressure, volumes of gases react in the same ratio as their moles. The iron wool is a **catalyst**.

2.5 Other industrial processes

WORKED EXAMPLE The first stage of making nitric acid is a reversible reaction in which ammonia reacts with oxygen to form nitrogen monoxide, NO, and water. (a) Write the balanced equation. (b) The yield of NO is higher at lower temperatures, yet 600 °C is used. What would happen below 600 °C?

(a) **$4NH_3 + 5O_2 \rightleftharpoons 4NO + 6H_2O$**
(b) The yield of NO would be higher, but the reaction would be too **slow**.

EXAM TIP For data on another industrial process, such as the Contact process, first describe the trend: how the yield changes as the pressure or the temperature increases, quoting values. Then weigh the yield against the rate and the cost, as for the Haber process.